SCIENCE

FRIDAY, MAY 11, 1917

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THE MAKING OF SCIENTIFIC THEORIES[1]

THE ancient Hebrews conceived the earth to be a disk hemmed in on all sides by mountains and surmounted by the crystal dome or firmament of the "heavens." This covered disk floated upon "the waters under the earth" and from the "windows of heaven" waters were poured out upon the "thirsty earth" from another reservoir which was above the firmament. To the denizen of the humid temperature regions it is perhaps a little difficult to see how this theory could have come into existence. The rains with which he is so familiar are showers, and they suggest not so much windows in the sky as they do a ceiling with innumerable perforations or some other glorified sprinkling device. To the Children of Israel the phenomenon of showers was unknown, for the rains to which they had become accustomed both during their wanderings in the desert of Sinai and in Palestine, were of the local downpour or cloudburst type, the characteristic precipitation of the arid lands. So also their country was one in which earthquakes have been frequent, and they were not unaccustomed to seeing the earth open and water shoot upward from the fissures in much the same manner that it spurts into the hold of a ship from the opening of a seam. This oft-observed phenomenon is with little doubt responsible for the conception of the "waters under the earth" referred to in the twentieth chapter of Exodus. We see, therefore, that this crude theory of the

[1] Address of the president of the Michigan Academy of Science, delivered at the Annual Meeting in Ann Arbor, March 28, 1917.

world which was held by the early Hebrews and which appears to us so fantastic, was, after all, based upon facts, but like many theories which have followed it, upon too small a body of fact to supply a firm foundation.

It has often been said that the theories so tenaciously held by one generation are abandoned by the next. To a large extent this has been true of the past, and the explanation is in part that scientists are not less fallible than others, but are subject to like limitations in prejudice, in undue reverence for authority, in regard for the science vogue of their time, and in many other conditions. To an even greater degree the overturning of scientific doctrines has been due to the failure of both the scientists and their critics to distinguish clearly between legitimate theory within those fields where views may be rigidly tested, and audacious conjectures which have been offered under the verisimilitude of facts to explain problems whose complete solution belongs to the remote future, if they may not be regarded as insoluble by any methods which have yet been discovered.

The process of eruption within a volcanic vent as regards its physical and chemical aspects offers a problem which, though by no means simple, may yet be subjected to observation and experimentation and doubtless belongs to the realm of soluble scientific problems. The materials present at the earth's center and their peculiar state of aggregation, are by contrast very largely a subject of conjecture, and attempts to class these problems together lead to inexcusable confusion.

A theory has been defined as an explanation founded upon inferences drawn from principles which are established by evidence. By contrast the hypothesis is a supposition as yet untested. The working hypothesis of the scientist occupies an intermediate position and aims to explain, at least in part and better than any other, a set of related phenomena which are already known, and it is considered to be in a probationary stage until confirmed through rigid tests the nature of which is suggested by the hypothesis itself. When so examined it may be found wanting; but, if well founded, experimentation is likely to result in its improvement by pruning of error quite as much as through enlargement of the body of truth which it contains.

The inheritance of knowledge by the ancients was, compared to ours, small indeed; and with their limited resources in materials and in methods of investigation, even more than we, they saw "through a glass darkly." It was therefore but natural that the theories which they evolved should have been largely the product of introspective reasoning. In consequence it was in the field of mathematics that they achieved their greatest triumphs, and as an inheritance a mathematical language was common to other fields of science even late in the seventeenth century. Viewing the marvels of the universe with their limited outfit of exact knowledge, the ancient philosophers invoked the supernatural and the mysterious to explain whatever was baffling and otherwise incomprehensible. Without books the dissemination of knowledge was limited to the narrowest channels and was accomplished by the disciples of each leader of thought, who was thus under the temptation of finding an answer to all questions and founding an individual school of philosophy.

With the invasions of the barbarian Huns and the Germanic tribes in the fifth century of the Christian era, there ensued the eclipse of civilization which we are accustomed to refer to as the "Dark Ages." Out of the darkness of these centuries of intellectual stagnation we catch a glimpse which indicates that individual minds were still active in their search for the truth.

It is the twentieth day of June in the year 1320. The bells of Verona are ringing in the bright Sabbath morning and the crowd is saluting with respect a tall and serious figure—the great Dante—who with slightly bowed head is entering the chapel of Santa Helena. Dante has to-day invited the whole educated world of Verona to assemble in this chapel and listen to his discourse entitled "*De acqua et terra.*" He proposes to discuss the relative position of land and sea, and as he tells us himself, every one came at his bidding, "with the exception of a few, who feared by their presence to confirm the exceptional importance of others." . . .

With a gift for picture-writing never before equaled he has led his astounded contemporaries up to the abode of the saints and down into the depths of the lower world. Now to-day he is returning to the starting-point of his most powerful creation, to the critical examination of that which is greater than all the conceptions of poetry—the actual ordering of the universe.

Dante argued cogently for the spherical form of both the earth and the seas, and in accounting for the elevation of the land areas above the oceans, he even offered an early hint of the law of gravitation. The earth, he argued, can not elevate itself; nor can the cause be water, fire or air. He therefore suggested that the fixed stars might exercise this influence "*after the manner of magnets.*"

The new era which opened with the revival of learning after a thousand years of stagnation, was one dominated by new considerations within the realm of thought. The keynote of the period was the dominating influence of the Christian church, and for centuries all thinkers were required to make their expressions conform to the dogmas of the church of Rome. The emancipation supposed to have arrived with the Protestant Reformation was a partial one only, and complete freedom of thought was not secured until the modern period of science was ushered in in the latter half of the nineteenth century.

Living as we do when few obstacles are opposed to a full and free expression, it will be profitable to review by means of examples the position of science in the sixteenth and seventeenth centuries. In declaring his belief in the heliocentric theory of the planets which Copernicus had promulgated, Galileo in 1597 wrote cautiously to the Polish astronomer:

It explains to me the cause of many phenomena which according to the generally accepted view are entirely incomprehensible. I have assembled many arguments for combatting the latter, but I do not dare to bring them into the light of publication. I would certainly risk it if there were more men like you.

With the telescope which he invented Galileo nightly studied the heavens from his little tower in the outskirts of Florence, and to his friend he unburdened his soul in unbounded admiration for the works of his Creator. He writes:

The prohibition of science would be contrary to the Bible, which in hundreds of places teaches us how the greatness and the glory of God shine forth marvelously in all His works, and is to be read above all in the open book of the heavens. And let no one believe that the reading of the most exalted thoughts which are inscribed upon these pages is to be accomplished through merely staring up at the radiance of the stars. There are such profound secrets and such lofty conceptions that the night labors and the researches of hundreds and yet hundreds of the keenest minds, in investigations extending over thousands of years would not penetrate them, and the delight of the searching and finding endures forever.

From this revelation of intellectual exaltation in one of the greatest apostles of science of all time, it is necessary to turn to a far different scene staged in one of the dark chambers of the Inquisition, if we would correctly interpret the spirit of his age. Bowed with years and racked by the cruel torture, Galileo is seen kneeling before the crucifix and repeating in broken sentences the dictation of his persecutors:

I bow my knee before the Honorable General Inquisitors, and touching the holy gospels I do promise that I believe and in future always will believe whatever the church holds and teaches for the truth. I was commanded by the Holy Inquisition that I should neither believe nor teach the false doctrine of the motion of the earth and the stationary attitude of the sun, because they are contrary to the Holy Scriptures. In spite of it I have written and caused to be printed a book in which I teach this cursed doctrine and have brought forth arguments in its favor. I have on this account been declared a heretic and worthy of contempt.

In order now to redeem myself in the eyes of every true Christian who with justice must hold me in contempt, I forswear and curse the errors and heresies referred to, and above all every other error and every opinion which is contrary to the teaching of the Church. Also I swear in future never either in spoken word or in writing to express anything on account of which any one could have me in like contempt, but I will, if I anywhere find or suspect heresy, reveal it at once to the Holy Tribunal.

It is not pleasant to dwell on the extreme conditions which determined the making of theories at this period and which continued for fully a hundred years beyond the time of Galileo. For advocating the Copernican doctrine Giordano Bruno was burned at the stake. More prudent, de Maillet left his theories of nature to be published only after his death and then with his name disguised as Telliamed through printing the letters in reverse order; while Scheuchzer avoided persecution by describing as a human victim of the Noachian deluge a gigantic fossil salamander, and thus became the butt of succeeding generations. Steno, "the wise Dane," through enjoying the favor of a powerful Christian prince, was more fortunate than most of his contemporaries, and has left us in his "Prodromus," one of the great scientific legacies of his age, now accessible to all through the excellent translation from the Latin by Professor Winter.

Inductive methods of reasoning came to play a larger part in the construction of theories as the control by both branches of the Christian church began to be relaxed. The feeling of relief from restraint brought, however, a reaction in what was almost an epidemic of theories characterized by a carelessness of construction and an insecurity of foundation that were surpassed only by the ardor and the vindictiveness with which they were defended. The latter half of the eighteenth and the first part of the nineteenth centuries was thus a period characterized by notable controversies in science which affected the greater part of Europe. Theories were attacked or defended with almost fanatical bitterness, the aim of the advocates of each theory being apparently less to arrive at the truth than to win in the struggle. Geologists were divided into two hostile camps over the origin of basalt; the Neptunists led by the Freiberg school of Werner in Germany claiming that it was a chemical precipitate in the ocean, and the Vulcanists who followed James Hutton of Edinburgh, and believed the rock to be a product of the earth's internal heat. National boundaries were largely broken down and some of the most pertinacious and vindictive of the Wernerians were to be found in the British Isles.

On the other hand, the Neptunists had to meet in Germany a formidable champion of vulcanism in the poet Goethe, who, like Dante five centuries earlier, had a keen interest in science. For a time the bone of contention was found in a small hill near Eger in Bohemia, known as the Kammerbühl, a hill which Goethe stoutly maintained was "a pocket edition of a volcano." He suggested a simple method by which the question might be settled, and proposed that a tunnel should be driven into the hill to its center. If the mountain was a volcano, as he believed, a plug of basalt should be found occupying its axis. A wealthy friend, Count Casper von Sternberg, undertook extensive excavations, which when completed in 1837 abundantly proved the correctness of the poet's position.

Another great controversy was waged

over the theory of the German geologist von Buch, known as the "Elevation Crater Theory," which assumed that volcanoes were pushed up in much the same manner as is the cuticle in the formation of a blister upon the body. Like the theory of the Neptunists, this doctrine was overthrown as soon as inductive methods of examination were applied to it.

Two doctrines of geology which were destined to play a large rôle in the history of science were developed in France. The "pentagonal network" theory of Elie de Beaumont furnished the age of every range of mountains from the direction of its trend referred to the cardinal points; while the cataclysmic theory of Cuvier held that the earth's history had been punctuated by great cataclysms resulting in the destruction of all life upon the globe and followed always by a recreation of new faunas and floras. These doctrines, like those emanating from Germany, were destined to succumb to the rigid tests of the observational methods.

The control of scientific theory by the Church whenever it felt that its doctrines had been invaded was, if less formal and direct, none the less potent even as late as the latter half of the nineteenth century. This became apparent so soon as attacks began to be made upon the theory of catastrophism, for this theory was regarded as harmonizing with the biblical account of the creation. The evidence for the overthrow of this doctrine had been long collecting by a group of giants in science which developed in England toward the middle of the nineteenth century and which included Darwin and Huxley, Wallace, Lyell and Hooker. In the field of geology Lyell's theory of uniformitarianism was the counterpart of evolution in the organic world.

The battle was joined in 1859 with the appearance of the "Origin of Species," and it was fortunate for the scientific world that the crisis brought to the front a Huxley who could face "such a storm of wrath and flood of contumely as might have overwhelmed a less resolute and clear-headed champion." Gifted with a clarity of thought and expression and a vigor of utterance which are without a parallel in the whole field of science, Huxley had an utter contempt for dishonesty in thinking and little patience with mere metaphysical abstractions. To his friend Kingsley in one of the most remarkable of all his writings he says:

> I have champed up all that chaff about the ego and the non-ego, about noumena and phenomena, and all the rest of it, too often not to know that in attempting even to think of these questions the human intellect flounders at once out of its depth.

He correctly gauged the nature of the struggle which was coming and to Darwin he wrote on the appearance of the "Origin of Species":

> I trust you will not allow yourself to be in any way disgusted or annoyed by the considerable abuse and misrepresentation which, unless I greatly mistake, is in store for you. Depend upon it, you have earned the lasting gratitude of all thoughtful men. And as to the curs which will bark and yelp, you must recollect that some of your friends, at any rate, are endowed with an amount of combativeness which (though you have often and justly rebuked it) may stand you in good stead. I am sharpening up my claws and beak in readiness.

It was not long before the stage was set for one of the most dramatic moments in the history of science, for the British Association for the Advancement of Science was to meet at Oxford in 1860, and it had been given out that the Bishop of Oxford had determined to "smash" Darwin. The meeting place in the medieval university building was in consequence crowded to suffocation with even the window ledges occupied by university dons keen for the excitement of the contest. By a mere accident and at the last urgent request of his friends Huxley reluctantly agreed to be present, for he rightly believed that an appeal would be made to the emotions and to prejudice, and he feared no good could come from the scientific argument. It was the tremendous success which he here achieved that fully decided him to take up the cudgels for Darwin, and at the sacrifice of being branded as a heretic during much of his lifetime, he was destined to go down to posterity not only as the magnificent protagonist of the doctrine of evolution, but as the redoubtable champion of freedom of thought within the whole realm of science.

Of the encounter at the Oxford meeting there are a number of contemporary accounts, one of which says of the Bishop's address:

> In a light, scoffing tone, florid and fluent, he assured us that there was nothing in the idea of evolution, rock pigeons were what rock pigeons had always been. Then turning to his antagonist with a smiling insolence, he begged to know, was it through his grandfather or his grandmother that he claimed his descent from a monkey.

Huxley was sitting beside the venerable Sir Benjamin Brodie, and at this descent to personalities he struck his hand upon his knee and turning to his neighbor exclaimed, "The Lord hath delivered him into mine hands." Without at all comprehending, Sir Benjamin stared vacantly and the meaning of Huxley's words did not dawn upon him until Huxley had arrived at his famous retort. When the storm of applause which followed the Bishops's address had subsided the president called upon Huxley to reply.

> On this Mr. Huxley slowly and deliberately arose. A slight tall figure, stern and pale, very quiet and very grave, he stood before us and spoke those tremendous words—words which no one seems sure of now, nor, I think, could remember just after they were spoken, for their meaning took away our breath, though it left us in no doubt as to what it was.

There was first a calm scientific discussion of Darwin's theory after which Huxley turned to the Bishop to say:

> I asserted—and I repeat—that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor whom I should feel shame in recalling it would rather be a man—a man of restless and versatile intellect—who, not content with a success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by an aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions and skilled appeals to religious prejudice.

"No one doubted his meaning, and the effect was tremendous. One lady fainted and had to be carried out; I, for one," says the chronicler, "jumped out of my seat."

If the emancipation of science from coercion or restraint from without had arrived with the final triumph of the doctrine of evolution, can it be truly said that theories are constructed even in this generation as the result of a process of wholly untrammeled reasoning; or, on the other hand, is it the fact that with the frailties inherent in human nature they still embody elements of weakness which are due either to the deficiencies in training of their authors, to prejudices or bias conditioned upon time or place, or to some other cause?

It is usually considered to be the special function of a president to recount in his address in particular the great triumphs of science, and to touch but lightly, if at all, upon any less encouraging aspects of his science. I propose in the time that remains to me to pursue a somewhat different course, and by the use of examples selected from the field of my own special studies to discuss what may perhaps be called the psychology of theories and the conditions which determine their acceptance.

To some extent it is inevitable that theories should reflect the individuality or the environment of their authors. This is particularly true in the field of natural science, where the laboratory is the world itself, a portion only of which can be brought under the observation of any one individual. Geological processes are different both in degree and in kind according as they are studied under conditions of aridity or of excessive humidity, under tropic heat or polar cold. It is unquestionable that geology having developed as a science in those temperate regions of moderate humidity which have permitted a high degree of civilization, is correspondingly defective, and must be modified if it is to be universal in its scope. The physical geology of deserts has been studied seriously only during the present generation. It is within the last decade only that the attention of geologists has been focused upon the subpolar latitudes, and the geology of the tropical jungles is yet to be written.

To indicate how the peculiar environment, the conditions of the time, and the special activities of the individual have left their impress upon a well-known theory, I may cite the case of Robert Mallet and his centrum theory of earthquakes, a theory which received general acceptation and was orthodox doctrine among earthquake specialists for full half a century. Robert Mallet was educated as a civil engineer, and in 1831 became a partner with his father in the foundry industry at Dublin. During the Crimean War he constructed monster mortars of thirty-six inch caliber which embodied new ideas and were completed in 1854. Thus becoming interested in ballistics, he made a thorough investigation of the strains developed by explosions in the chambers of guns, and a monograph upon the subject which he published in 1856 brought him general recognition and many honors. A year later, in 1857, occurred the great earthquake in the Basilicata, generally referred to as the "Great Neapolitan Earthquake," since the district was included in the former kingdom of Naples. Believing himself by reason of his studies of explosives to be specially fitted to investigate this disturbance, Mallet applied to the Royal Society for a grant of money, and his request being approved, he visited the Basilicata, and in 1862 in two sumptuous volumes the earthquake was explained as the result of an explosion that had occurred in a cavity beneath the region affected, the damage upon the surface being explained under the laws of transmission of stress such as had applied in his earlier researches upon cannon. No one familiar with these circumstances can reasonably doubt that the trend of his theory was already determined by his life history before his sailing from England. It should be added that through giving to the problem of earthquakes a mathematical treatment, Mallet's study had the effect of removing seismology from the field of geology for the period of nearly half a century, and giving it over to the elasticians.

It has not been altogether uncommon for students of science, and even those of the highest rank, when drawing conclusions, to fail to take proper account of the fact that the observed rates of change, or gradients, perhaps of temperature or pressure, which they have been able to verify for limited distances only, may not be assumed to continue indefinitely without interruption or variation. No less distinguished a physicist than Helmholtz on the basis of the known aero-thermic gradient as determined over Europe to a height of about nine kilometers, declared that the atmosphere could not extend beyond twenty-seven or twenty eight kilometers from the earth's surface, since the absolute zero of temperature would be reached at that level. Sounding of the atmosphere has since been carried to fully twice the limit fixed by Helmholtz, and has revealed the fact that a few kilometers beyond the limit of exploration when he made his prediction, or at an average altitude of eleven kilometers, the aero-thermic gradient is interrupted and succeeded by practically isothermal conditions above.

To-day in reputable treatises one may read in round numbers the supposed temperature at the center of the earth, and based upon what? The geothermic gradient determined for the shell of rock immediately beneath the earth's surface and verified roughly for about one four-thousandths of the entire distance to the earth's center. Can we assume that our yard-stick in this instance is suitable for measurement throughout the entire radial distance, and is there no possibility of abrupt interruptions such as occur in the temperature gradient of the atmosphere?

William Ferrel, much the most distinguished meteorologist that America has produced, and the one to whom we owe the basic principle upon which modern meteorology is founded, predicted as a corollary to his theory of the winds the existence of whirls about the earth's geographic poles surrounding areas of calm and low atmospheric pressure. As these polar calms and whirls are an important feature of the present theory of atmospheric circulation, it will be profitable to examine briefly their evolution as a study in the psychology of theory. In the preface to his general treatise upon the winds, Ferrel tells us how his attention was first directed to this subject through reading Maury's "Physical Geography of the Sea," the first edition of which appeared in 1855, while the first essay of Ferrel was published in 1856. From Maury Ferrel learned, as he has told us, "that the pressure of the atmosphere is less both at the poles and at the equator of the earth than it is over two belts extending around the globe about the parallels of 30° north and south of the equator." On making reference to Maury, we find that upon the basis of recorded observations between the parallels of 40° and 54° south latitude the average barometer reading varies from 29.9 to 29.4 in passing from the lower to the higher latitude. With the gradient obtained from this limited range, Maury has extended the curve as a straight line to the geographic pole through a range of thirty-four degrees of latitude or more than twice the observed distance, and obtained a theoretical reading for the pole of twenty-eight inches of mercury. A similar method applied to the northern polar region has supplied a less marked gradient and a theoretic value for the barometer reading at the northern geographic pole of 29.65 inches of mercury.

Since this theory was promulgated, exploration has been extended to both poles of the earth and has shown that but a short distance beyond the latitudes which limited the data employed by Ferrel, the steadily lowering pressure gives place to a rising barometer in the direction of the poles. Studies of the free atmosphere by means of balloons in the same high latitudes also indicate pretty clearly that no such whirls as Ferrel assumed can exist. Yet so great has been the success of Ferrel's theory as a whole that despite their contradiction by the facts, the polar calms and whirls are still treated in the latest text-books of meteorology.

The polar whirls of Ferrel are by no means a unique example of a large conception in science receiving general support because however carelessly constructed it was an attachment or rider to a still larger theory. The triumph of the larger idea or the prestige of the author due to some other achievement, has by its inertia carried the smaller conception to general acceptance.

So fundamental a theory as that of Laplace to explain the origin of the universe, a theory which has been standard doctrine for more than a century and is only now being replaced as a result of rigidly applied tests, appears never to have been very seriously considered by its author, but was thrown off as a brief appendix or postscript to a general work on astronomy. It has the curious title "Note VII. and Last" and Laplace says of it that the hypothesis must be received "with the distrust with which everything should be regarded that is not the result of observation or calculation." Moreover, so far as known, Laplace never subjected the theory to the test of well-known mathematical principles which were involved, although this was his usual habit. The success and general acceptance of the theory seem to have been due to the altogether remarkable prestige of its author as the greatest mathematician since Newton, and as the author of the "Mécanique Céleste," a work which has never been rivaled in its field, and of which it has been said that any one of its twenty-four parts would have made the reputation of a man of science.

Though primarily a theory of the origin of the universe and thus in the realm of astronomy, Laplace's nebular hypothesis left its impress upon geology and particularly upon geophysics, in that it gave continued standing and scientific respectability to the notion that the earth has a liquid interior. It would be somewhat difficult to trace the origin of this belief, which naturally grew up from the observations of volcanic eruptions—no uncommon event in the Grecian Archipelago and in Italy, the regions where science had its beginnings. After the studies of combustion had exploded the notion of "internal fires," the theory took the form which it has retained to our day, little affected at first by the proofs of earth rigidity which were brought forward by Kelvin. With little doubt the associated idea of a congealed crust floating upon a liquid interior is based upon the analogy with the winter cover of ice which forms over our lakes and rivers. This analogy supplies, therefore, a striking instance of the influence of climate in giving complexion to a fundamental theory, and the fact that rock, unlike water, is heavier in the solid than in the liquid state, is a very recent discovery. Save for its intimate relation to Laplace's theory, the conception of the liquid core to the earth must have long since been relegated to the limbo of exploded doctrines, to the great benefit of more than one of the physical sciences.

It would be easy to show that well-known scientific theories have embodied fatal defects, in that assumptions of vital importance have been introduced quite unconsciously by their authors. I have believed, and have elsewhere attempted to show, that the Pratt-Hayford theory of isostatic compensation, which assumes for every mountain a necessary defect of mass directly below, and for the column below every depression of the earth's surface a corresponding excess of mass; that this theory has been set up without due regard to the dominating effect of any hidden masses of unusually high density which may lie near the observing station. This view seems now to have found confirmation in recent studies carried out by the United States Coast and Geodetic Survey. I may perhaps best illustrate what is here meant by the use of an example taken from a related field of study. If one should ascribe the strong magnetic attraction which is exercised by local masses of iron ore in the Northern Peninsula of Michigan to the effect of such an extended system of smaller masses distributed throughout a large district, as might produce the same effect at a given station, the error would be of the same nature as that which must result from ignoring the effect at the gravity stations of any local and very dense masses which may be hidden beneath the surface.

Does prejudice, either national or racial, ever influence the thinking of men of science? I ask you to look back over the history of the past two and a half years and for the answer examine some of the statements which have been signed by men who were counted among the master scientists of their generation. These sweeping statements were many of them false; and if not known to be by those who subscribed to them, it is clear that an unbiased inquiry must either have revealed the truth or have indicated the necessity for withholding a verdict. This *débâcle* of science which came at the outbreak of the present war is one not easily to be retrieved.

If I have succeeded in my endeavor, I have shown that scientific theories as they are constructed even to-day with the aid of all modern equipment and inheritance, may contain fatal elements of weakness though they be promulgated by scientific men of the highest rank and attainments. Fortunately the student of science to-day enjoys an independence which was never vouchsafed him in the past, when the learner was by the conditions under which he studied an advocate of the doctrines of his master. There are to-day no dictators in science such as were Werner in Germany, de Beaumont in France, Murchison in England, or Agassiz, the "pope of American science." For what he accepts and teaches the student of science is to-day responsible, and it devolves upon him not merely to examine each theory as regards its inherent plausibility and the degree to which it has been confirmed, but to inquire also into the human and other factors which have entered into it or which have accounted for its acceptance into the body of doctrine of science.

It has seemed to me that the excessive stress which in our science training we now lay upon the careful balancing of evidence, has in a measure taken away our capacity for making decisions. The cult of being open-minded has been elevated into a fetich, with the result that the really vital considerations are often hopelessly entangled with non-essentials. A little reflection must show that upon the principle of chances the weight of evidence in the case of but few problems can be evenly balanced; but a clever exaggeration of the non-essentials seldom fails to raise serious doubts in the minds of a considerable proportion of those considered qualified to reach a decision. Why, if this be not so, have so many of our highly trained scholars failed to see that the events which are now transpiring have long been clearly foreshadowed, and were inevitable results of observed conditions in a world controlled by natural laws. This is due to a lack of vision—of prescience—which above all is dependent upon first clearing away from a question the rubbish which has accumulated about it, and then focusing the attention unerringly upon the heart of the problem.

Lack of vision largely explains the great inertia of science which causes the retention of useless or harmful theories long after their inadequacy or falsity has been exposed, and this inertia is greatly aggravated by potent accessory influences. Any successful theory which occupies a basic position in science, is sure to be built upon as a foundation for other theories, and these are likely to crumble with its collapse. Much money and labor are now invested in treatises and popular works, the income from which becomes seriously affected whenever their reliability is brought into question. The ultra-conservative attitude of scientists which results from these and other causes is as obvious as it is deplorable.

As we look back over the past and, studying the advances of science, mark off upon the way the stations at each of which a new horizon has opened, it is easy to see that the successive marches, like the halts between, have been far too long. The attempt to reproduce from each station the entire panorama of the horizon has led to a sketchiness and an inaccuracy in the depicting of all remoter portions of the field, which might have been avoided had the viewpoint been promptly moved forward so soon as the nature of the nearer terrane had become firmly established. My appeal is, therefore, for an individual study of those theories of science with which each worker is concerned, and for an early decision upon their availability whenever a judgment is warranted. Accepted, if necessary, as working hypotheses to be rigidly tested by observation and experiment, the new ideas are infinitely to be preferred to those theories which have been found wanting under the tests either of experiment or of searching observation.

It might perhaps be asserted that the picture which I have drawn of the past and present of scientific theories is one not calculated to cause entire satisfaction; and I could hardly deny the truth of the assertion; but when, I would ask, has either an institution or an individual been other than benefited through a searching self-examination? Even the shock to our self-pride which came with the revelations of this bellum period is not fraught with permanent disaster. Since the condition existed, it is far better that we should know it, and so far as may be possible provide against its recurrence in the future.

The encouraging feature of our entire survey is the evidence which it shows of a steady evolution toward better conditions; for no one can truthfully deny that the scientific world is to-day in a far better position than it has ever occupied in the past; and the outlook for the future is so much the more encouraging.

WILLIAM H. HOBBS
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HERBERT W. CONN

IT has been said of America that it is peculiarly able to produce the right man at the right time when emergency calls. Herbert W. Conn was not only a cultivated scientist, but a personality, because he embodied in himself the initiation of a great movement in America. The science of bacteriology as developed in Europe through Pasteur and Koch attracted his attention in the early years of his education, and led him to feel that this science had a great function to perform in connection with milk and dairy products in America. In the early eighties his pioneer work was begun in milk bacteriology and was developed in his laboratory in Wesleyan University, and under his supervision in Storrs Agricultural Experiment Station, Connecticut. Whatever lines of influence have been developed through later years in the improvement of municipal milk supplies and in the improvement of sanitary conditions on dairy farms, when traced back to their sources, will show a connection with and a stimulation from the early milk bacteriology of Herbert W. Conn. He took part in the councils of those who established the certified milk industry, and assisted in framing the regulations which were first drawn up in the early nineties for the control of certified dairies. He suggested the production of sanitary butter through the pasteurization of cream, and the use of pure cultures of lactic acid bacteria. He was among the first to show the close relationship between unsanitary con-