ADDRESS AT THE EIGHTH ANNUAL COMMENCEMENT
LELAND STANFORD JUNIOR UNIVERSITY
MAY 24, 1899

THE SCIENTIFIC METHOD AND ITS LIMITATIONS

FERNANDO SANFORD

Professor of Physics
Leland Stanford Junior University

PUBLISHED BY THE UNIVERSITY
STANFORD UNIVERSITY PRESS
1899

THE SCIENTIFIC METHOD AND ITS LIMITATIONS.

FERNANDO SANFORD.

The century which is just closing will probably always be remembered as a period of remarkable scientific advancement. This does not imply that there have not been remarkable advancements made in other lines of human activity. Probably in no century has there been such general and substantial progress in all lines of intellectual activity as in the one whose closing year is about to dawn upon us. Much of this activity has been due to the scientific character of the age; much has been in spite of it. Certainly, at no time in the world's history has the general level of literary and musical and artistic culture been so high as at the present time, and the unprejudiced observer will not assuredly attribute this high level of attainment to the scientific character of the age.

But it is also true that not in literary, artistic, nor even philosophical lines has the best work of previous centuries been surpassed, while in every line of proper scientific investigation the knowledge and doctrines of previous centuries have become antiquated. Scarcely a scientific theory held today is as old as the century, and the great generalizations upon which all natural and physical science are now based date back barely fifty years. It is certainly well within the truth to say that the human race has made greater scientific progress in our century than in the whole previous period of its existence upon the earth.

The cause of this remarkable progress must be sought principally in the scientific method of our age; for while experimental science was born about three hundred years ago, it has only reached its mature growth during the present century. A brief comparison of modern experimental science with the older natural philosophy of Aristotle and the middle ages will help make plain the reasons for the relatively great success of the modern methods.

Before attempting any comparison of their method with ours, it is but proper that we should acknowledge the great debt which modern science owes to the Greeks. Not that their scientific knowledge was greatly superior to that of the rest of the world, for it was not; but it has been said of the Greeks that they only, of all the nations of antiquity, seem to have sought for a knowable relation between natural phenomena. They, alone, seem to have recognized that the phenomena of nature bear a causal relation to each other, and without a recognition of this relation no science would be possible. For science is not mere catalogued knowledge of observed facts. Such knowledge must form the groundwork upon which any true science is built; but a knowledge of the causal relations between the observed facts and phenomena is the essential aim of all scientific investigation.

In all ancient nations except the Greeks the speculations concerning nature were of a mystic or a religious character. Supernatural and spiritual powers were supposed to be the causes of physical phenomena, and even the Greek natural philosophy is strongly colored with these oriental superstitions.

But though the Greeks sought for causal relations between natural phenomena, they did not succeed in finding a sure method of discovering these relations. It is true that we are often told that all the great generalizations of modern science were anticipated at one time or another by Greek philosophers; but these so-called anticipations were nothing more than guesses, and had no scientific value whatever. The only authority upon which any of them rested was the philosophical reputation of their authors, and scientific laws are not based upon human opinions.

The method of the Grecian natural philosophy, in so far as the scientific speculations of the philosophers can be characterized by one who is compelled to rely upon the opinions of others for most of his ideas of Greek science as well as Grecian philosophy, was essentially the method of debate or argument, which is so often mistaken for the method of investigation even at the present time. It consisted in stating a general proposition, and then, by means of logic, in drawing all possible legitimate conclusions from it. If the conclusions were not found to be contradictory to known facts, the general proposition was regarded as established. Later, as methods of mathematical analysis were developed, these were used to assist in making deductions from general laws—the method still used in mathematical physics.

In the use of the method of logical argument, no people have ever surpassed, if any have ever equalled, the ancient Greeks, and the reason why they made almost no progress in physical science is evidently because the logical method alone is not capable of discovering scientific truth. The modern scientist still uses the logical method, and as expressed in the form of mathematical analysis it is a very important instrument of modern scientific investigation ; but the great achievements of modern science are due to the fact that man has learned to arbitrarily interfere with natural phenomena for the purpose of collecting and verifying the facts of nature and of discovering their relations to each other. The method of physical experimentation separates the old science from the new. When man first began to bring about physical changes under varying conditions, so that he might estimate the influence of the different elements of a phenomenon upon the result, modern science had a beginning.

In this modern definition of the term, Archimedes of Syracuse is generally regarded as the first physical scientist. The Greeks were philosophers, the Alexandrians were mathematicians, but Archimedes was an engineer and a physicist. He united with his knowledge of the Greek philosophy and the Egyptian mathematics the practice of testing his conclusions by experiment, and he accordingly made more scientific discoveries and more mechanical inventions than almost all his predecessors combined.

But the world was slow to take advantage of the method used with such wonderful success by Archimedes. Now and then a single investigator would undertake to bring physical experimentation to the aid of his natural philosophy, and invariably with startling results in the way of discovery; but the natural philosophy of Aristotle furnished the principal method of acquiring knowledge in the entire civilized world for about two thousand years.

In this entire period, including the first sixteen hundred years of the Christian Era, the few men whose names have come down to us in connection with important discoveries in physical science were invariably the men who undertook the study of nature by the experimental method. This was a period of the greatest possible activity in philosophical and theological controversy, and yet it was in these very subjects that the human race seems to have made the least improvement during the greater part of that time. On the other hand, every serious attempt at scientific investigation by the experimental method seems to have led to an increase of our knowledge of natural phenomena.

The great modern awakening of scientific investigation may be said to date back to the year 1600, and can be attributed largely to the work of Gilbert in England and Galileo in Italy. In that year William Gilbert published his great work on Magnetism and Electricity, in which he not only taught, but successfully illustrated, the only method of scientific research which has ever led to definite results.

The scientific work of Gilbert is not only important in that he was the first experimental investigator of magnetic phenomena, and that he discovered much more about magnetism than all those who had preceded him, but because he discovered nearly all about magnetism that the world yet knows, and because his theory of a magnetic field, after being disregarded for nearly three hundred years, has, in a modified form, come into general acceptance within the last twenty years. It would seem that a method of scientific research which in the hands of a single investigator could accomplish so much must have in it something of value to the world, and it was of great importance to succeeding investigators that Gibert explained his method so clearly.

Gilbert recognized the fact that he was dealing with a new manner of investigation, and that his methods would be subjected to unfavorable criticism by the philosophers of his day. In the opening paragraph of his preface he says: "Since in the discovery of secret things and in the investigation of hidden causes, stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators of the common sort; therefore, to the end that the noble substance of that great loadstone, our common mother (the earth), still quite unknown, and also the forces extraordinary and exalted of this globe may the better be understood, we have decided first to begin with the common stony and ferruginous matter, and magnetic bodies, and the parts of the earth that we may handle and may perceive with the senses; then to proceed with plain magnetic experiments and to penetrate to the inner parts of the earth."

In another place he says: "This natural philosophy is almost a new thing, unheard of before; a very few writers have simply published some meager accounts of certain magnetic forces. Therefore we do not at all quote the ancients and the Greeks as our supporters, for neither can paltry Greek argumentation demonstrate the truth more subtly nor Greek terms more effectively, nor can both elucidate it better. Our doctrine of the loadstone is contradictory of most of the principles and axioms of the Greeks."

In his defense for offering this new method of research to the world he says: "To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science—a new style of philosophizing. But if any see fit not to agree with the opinions here expressed and not to accept certain of my paradoxes, still let them note the great multitude of experiments and discoveries—these it is chiefly that cause all philosophy to flourish ; and we have dug them up and demonstrated them with much pains and sleepless nights and great money expense. Enjoy them you, and, if ye can, employ them for better purposes."

I have referred especially to Gilbert's great work because, to the English speaking race, he is the father of experimental science. At the time when his work was published, however, Galileo, though at the beginning of his career, had already made his memorable experiments on falling bodies, and was lecturing in the University of Padua and laying the foundation of the science of mechanics. For the first time in the history of the world two great experimental scientists were living and working at the same time, and to their combined influence we are largely indebted for the rapid development of the experimental method in science which has since followed.

The method of scientific investigation to which our century owes its wonderful progress is the method of Gilbert and Galileo, and has never been more clearly stated nor more successfully exemplified than by these two men. It consists :

First—In collecting carefully authenticated facts as the basis of all generalization ;

Second—In looking for some common causal relation between these facts, which relation is stated in the form of a general proposition, or a so-called law of nature ;

Third—In deducing by the methods of both formal logic and mathematical conclusions concerning other phemonena which have not yet been observed ; and

Fourth—In experimenting to see if these conclusions are correct.

In the first and last steps only does experimental science differ from the old natural philosophy. The generalizations of the philosophers were as legitimate from the data upon which they were based as are any of our own.

Their logical accuracy has never been surpassed. But the supposed facts upon which their generalizations were based were not carefully collected and authenticated, and either were not facts at all, or were true only under special conditions which were not understood. Even the simplest phenomena of nature are so obscured by other phenomena which frequently occur along with them that without some artificial method of separating them we cannot tell which relations are casual and which are merely accidental. It is the artificial separation of phenomena in the laboratory that has made the generalizations of the scientist more valid than those of the philosopher.

The fourth step, viz., the testing of the final deductions by artificial means, was also unknown to the natural philosophers, and without this final step science could have made little advancement. Nearly all the generalizations of science which have yet been made, no matter how carefully the data have been collected, have had to be abandoned when the legitimate deductions from them have been subjected to the test of experiment. Only a few of the millions of such generalizations which have been attempted are now accepted. The reason for this is plain. Induction can, at the best, only consider a few of the many possible instances which are included under the general law. If from these few a generalization has been made which will still hold when all the included instances are known, it may almost be regarded as a lucky accident, even in men of the greatest scientific insight. In fact, as Jevons has said, "In all probability the errors of the great mind exceed in number those of the less vigorous one. Fertility of imagination and abundance of guesses at truth are among the first requisites of discovery ; but the erroneous guesses must be many times as numerous as those which prove well founded."

It is this fact which makes the fourth step in the modern scientific method so important, and it is because this test of experiment cannot be applied in many of the fields of human investigation that our knowledge in those fields still remains so uncertain.

My justification for this somewhat lengthy consideration of the methods of modern physical and natural science must be found in the fact that many prominent writers on educational topics seem to still believe in the efficacy of the methods of the old natural philosophy for scientific discovery, while others think they are employing the methods of experimental science in fields of research where, from the nature of the phenomena involved, experiment is impossible.

The tendency to mix the results of scientific investigation and metaphysical speculation has always existed among men trained especially along lines of metaphysical thinking. In the early part of the present century the philosopher Hegel lived and taught in Heidelberg and Berlin, and through his teaching and his published works succeeded in building up a school of philosophy which still has many prominent adherents. The general proposition of Hegel's philosophy which especially concerns our subject is his assumption that both the spiritual and the physical universe are the result of an act of thought by a creative mind, identical, in at least many respects, with the human mind; and that it is accordingly possible for the human mind, without any experience whatever of natural phenomena, to think over again the thoughts of the Creator, and hence by its own activity to rediscover those relations between phenomena which we call natural laws.

It was believed by many of the educated men of the time that Hegel did succeed to a large extent in constructing *a priori* the leading principles of ethics and theology, but his system of nature deduced from the same hypothesis, was, according to Helmholtz, regarded by the scientific investigators of the period as absolutely insane. Hegel realized that if his system of philosophy was to win final recognition it must succeed in explaining the phenomena of nature as well as of mental and moral science, and he made a vigorous attack upon the scientific methods of Newton and his successors. This led to a bitter controversy between the students of science and the philosophers, and caused many of the keenest scientific minds of the century to totally reject philosophy as a means of acquiring knowledge of any kind, while many of the followers of Hegel still regard scientific investigators as a class of narrow specialists who fail to use the means offered by philosophy for advancing their knowledge of the universe.

It will probably be admitted by one who gives the subject unprejudiced consideration that the opposition between natural science and the subjects classed under the head of mental and moral science, while it was greatly exaggerated by the Hegelian controversy, still has some foundation in the nature of the phenomena under investigation and the intellectual processes involved in the two groups of study. Most of the phenomena involved in the mental and moral sciences are incapable of being artificially isolated from the other phenomena which invariably accompany them in nature ; hence the laboratory method of study cannot be applied to them. In these fields of investigation, where knowledge often seems to us to be more important than in any other, and where many of the dearest interests of life are involved, we are still dependent upon the old method of natural philosophy, which has proved so inadequate as a means of acquiring a knowledge of nature. It is not to be wondered at that the experimental scientist who has been compelled to abandon one theory after another which has seemed to him to be based upon as sure a foundation as the principles of the metaphysician and theologian, should become skeptical in regard to these principles. Neither is it strange that the student of ethics and social phenomena, who is accustomed to deal with subjects of the most vital human interest, should look upon the natural sciences, concerned as they seem to be with lifeless, indifferent matter and unintelligent forces, as mere utilitarian subjects, beneath the consideration of one devoted to culture and intellectual development. In thus underrating other fields of investigation than their own both parties are alike open to the charge of narrowness. It does not necessarily follow that a method of investigation which has utterly failed to give exact knowledge of physical nature may not give more reliable knowledge when the phenomena under investigation are the actions of the human mind. It is not *a priori* impossible that an accurate knowledge of the human mind, if such knowledge can be had apart from a knowledge of physical phenomena, may enable one to recognize the principles of those sciences whose phenomena are the activities of the human mind. Whether or not such an achievement be possible, no one who does not believe in the absolute identity of mental and physical phenomena can derive any argument for the employment of the philosophical method in natural science from its supposed successful use in the mental and moral sciences.

But the tendency to depreciate the methods of experimental science which was so strong in the followers of Hegel is now quite insignificant, while, on the other hand, the investigators in nearly all lines of intellectual activity have learned to use the language and to adopt the name of the scientific method. That there may be no misunderstanding of what scientific method they claim to have adopted, we are told by those who wish to appear especially progressive that history, sociology, philology, and even elementary Latin are now studied by the "laboratory method."

This, to the worker in experimental science, is a mere confusion of terms that ought to be kept distinct. Neither the historian nor the philologist nor the sociologist can have anything corresponding to the scientific laboratory. A laboratory, in the scientific sense, is a place devoted exclusively to the study of phenomena. It is not a library nor a museum. Does the historian have some place where he can bring about artificial changes in government or study armies upon the field of action? Does the philologist bring the nations of antiquity before him where he can produce artificial changes in their environment or artificial intermingling of races, that he may note the modifications made in language by these changes? Unfortunately, they do not. Both are limited to the study of the records of the past as preserved in libraries and museums. The scientist also uses libraries and museums, and he uses them for exactly the same purpose as do other scholars. He may sometimes even use the historical method of studying physics or chemistry, but when he wishes to verify the statements which he reads, he has recourse, not to other manuscripts of the period, but to his laboratory.

Much of this cant about scientific method in other subjects comes from the attempts which are being continually made to apply the laws of the physical universe to phenomena which are usually classed as mental or spiritual. Exaggerated examples of this tendency are found in such books as "Natural Law in the Spiritual World." In writings of this class the terms of experimental science are used with a meaning wholly foreign to their scientific use. We hear much today about the study of human society as an "organism," that is, a living individual, and the logical inference is that the methods of botany and zoology, which have been used with some success in the study of living organisms, are in the same way applicable to the study of society. From a recent article on "How to Study History" in a leading educational journal I quote the following statement of this generalization: "The laws of thought force us to the conclusion that man, as the totality of individuals, is by nature one and undivided. One mighty, composite personality who differentiates himself into men that he may better help himself: an organism whose multiform members appear as men. And just as in any organism, the existence of each member is conditioned by the existence of the whole, so the existence of each man depends upon the existence of all other men."

A little farther along in the same article I read: "The individual is the specific aspect, tone, color, in which God would see the divine life; he is the utterance of God himself at a given point of time and space. Hence individuality has the very sacredness of God, and to unfold it is the final cause of our existence." Evidently the author has failed to consider the result upon this mighty, composite organism when each of his hundreds of millions of members begins to unfold its sacred individuality.

The distinction between such sciences as sociology and ethics and the sciences which are classed as natural or physical has been further emphasized by the scientific investigation of our century. To make this clear it will be necessary for me to give a somewhat technical discussion of some of the changes which have taken place in our conception of the physical universe during the last hundred years.

Three hundred years ago Galileo investigated with great success the laws of motion of material bodies, and half a century later these laws were stated by Newton in the same form in which they are taught today. Galileo first assumed the existence of forces as the cause of acceleration. Gilbert supposed one magnet or electric charge to act upon another magnet or charge by means of some kind of invisible medium existing between them ; but Galileo and his successors assumed that bodies may act directly upon each other without the intervention of any substance whatever, and Lord Kelvin tells us that before the end of the eighteenth century this idea of action at a distance through absolute vacuum had become so firmly established that the notion of the propagation of electric or magnetic action by means of an intervening medium seemed utterly wild, even to scientific investigators.

The legitimate result of this doctrine of forces was the assumption that every particle in the universe was acted upon by numberless forces. If the particle remained at rest, it was because these forces balanced each other. If one force came to overbalance its opponents, the body moved. A body once in motion could only be brought to rest by a force acting in a direction opposite to the motion of the body. Thus all the phenomena of physical nature resulted from the warfare of an infinite number of forces.

These forces, themselves, were incapable of any further physical explanation, since they were utterly independent of mechanism of any kind. An attractive or repulsive force could act between bodies when there was nothing whatever between them. Manifestly, the only explanation for a force of this kind must be a metaphysical explanation, and the phenomena of the physical universe were apparently due to influences not of themselves physical.

Then, since the phenomena of nature are of many different kinds, they must result from many different kinds of forces. Thus the existence of the human body was conditioned upon the equilibrium between the vital forces, which were regarded as different from mere physical forces, and the forces of decay, which were chemical forces. The movements of the body were regarded as the over-balancing of physical forces by mental or spiritual forces. This led to the notion of certain superior grades of force, as spiritual or mental, capable when properly exerted of over-mastering ordinary physical forces, and the probability of any phenomenon in the physical universe being the result of physical forces became very remote. A physical phenomenon might be due either to physical, vital, or spiritual forces, or it might result at one time from one kind of force and at another time from another kind. In other words, there was no certainty of uniformity in natural phenomena, and an impossibility of telling what particular force had been efficient in producing a given phenomenon.

But all of this notion of forces as the cause of phenomena has been changed by the physics of the present century. One hundred and one years ago, Benjamin Thompson, Count Rumford, performed his memorable experiment on the generation of heat by friction, in which he showed that the quantity of heat produced was proportional to the work expended in its production. The following year, Humphrey Davy succeeded in melting ice by friction in a vacuum at a temperature lower than the freezing point. Previous to this time heat had been regarded as an imponderable fluid which could pass from one body to another at a lower temperature; but these experiments showed that an indefinite quantity of heat could be obtained from bodies at a low temperature without in any way lowering their capacity for giving off more heat. Rumford and Davy both conclude that the cause of heat is motion and that to heat a body is merely to set in motion the ultimate particles of the body.

But if this were true, the heat produced should be proportional to the quantity of motion expended in its production, and this was found not to be the case. The quantity of motion of a body had, since Newton's time, been measured by the product of its mass into its velocity. Measured in this way, its heating effect bore no relation to its quantity of motion. Evidently, heat could not be a mere mode of motion.

It took fifty years of investigation by the physicists of the entire world to find the relation between the heating capacity of a moving body and its mass and velocity. Carnot, in France, writing about 1830, says: "Heat is simply motive power, or rather motion which has changed form. . . . Wherever there is a destruction of motive power, there is at the same time a production of heat exactly proportional to the quantity of motive power destroyed. Reciprocally, whenever there is a destruction of heat, there is production of motive power. We can then establish the general proposition that motive power is in quantity invariable in nature —that is, correctly speaking, never either produced or destroyed." This is the first statement of the greatest generalization of physics. But Carnot failed to show how to measure motive power so that it should always be proportional to the heat expended in its production, and his generalization was not placed upon a thoroughly satisfactory theoretical basis until the great work of Helmholtz in 1847, and its complete experimental verification by Joule was not finished until two years later, just fifty years ago. Then the word energy came to be used for motive power, and the generalization of Carnot and Helmholtz came to be known as the Doctrine of the Conservation of Energy.

The establishment of this theory is undoubtedly the greatest achievement of physical science up to the present time. It necessarily led to an entirely new conception of the physical universe. If this doctrine of the conservation of energy was to be accepted, no such thing as a force of any kind would be left in that part of the universe properly called physical. In place of all the conflicting forces of the earlier physics, there would be left merely a definite quantity of energy, something as indestructible as matter, and with matter making up the sum total of the materials of which the physical universe is composed. A physical change merely involves a redistribution of the energy in that part of the physical universe in which the change takes place. Some mass, or molecule, or atom gives up its energy to some other mass, or molecule, or atom, and that is all. The quantity of matter, as we measure matter, is not changed. The quantity of energy, measured by its capacity for doing work, is not changed. What we previously called the force acting between the different parts of matter is merely the measure of the rate at which the energy is being transferred from the one to the other.

Thus, instead of a heterogeneous universe, made up of many different kinds of matter and innumerable forces, we have come to believe in a physical universe in which only matter and energy exist. Every change in the physical universe follows the same law as any other change. The "uniformity" of physical nature is established.

Our definition of natural law is also influenced by this conception of the universe. A natural law, in the physical universe, can mean nothing more than an observed order of events. It is a natural law that bodies unsupported fall to the earth ; that a cold body may acquire heat from a warmer body, and the like. That is, these transformations or transferences of energy which are associated with physical phenomena always take place in a definite way. The physical changes are always in a definite direction. There are no reversible processes in nature. The physical universe itself is apparently not a reversible phenomenon. It came from a condition essentially different from the present. It is passing into a condition essentially different from the present. It is but a phase of some immensely greater system.

And it is not only the physical sciences which have been revolutionized by the doctrine of the conservation of energy, but the sciences of life as well. Hardly had the uniformity of natural processes been established for physics and chemistry when it was recognized in geology and biology. The geology of cataclysms and special creations gave way to the geology of slow, continuous changes. The doctrine of special creation of species gave place to the theory of evolution of organic forms from older and simpler forms. Helmholtz's "Erhaltung der Kraft" was followed in only twelve years by Darwin's "Origin of Species."

The influence of this work upon the thought of the world has certainly not been equalled by that of any other book of the century. Professor Jackman, in a recent number of the *Educational Review*, truly says: "The dominating influence in the world's thought at the present time is the doctrine of evolution. Beginning its conquest but a generation ago with what seemed to be chiefly the question of man's physical or corporeal relationships, it has penetrated little by little his intellectual and moral domains so completely that today there is not a phase of thought or a human activity that has not been stimulated and vivified by this greatest of all human conceptions. With the advent of this idea, chaos and chance went out and the reign of order and universal law was ushered in."

But the doctrine of evolution represents an attempt on the part of the biologist to include the phenomena of life under the generalization of physics. If the *origin* of life, as well as the origin of species, be included in the doctrine, then is it asserted that all the phenomena of life are physical phenomena, that is, that they result from physical changes alone, and physiology becomes merely the application of the laws of physics and chemistry to a special class of phenomena.

In this sense we must remember that the theory of evolution lacks the experimental evidence of the doctrine of the conservation of energy in the physical world. While it is known that most, if not all, physiological processes are accompanied by a transformation and redistribution of energy, it is not yet possible to measure the quantities of energy transformed in the different operations and to show a definite proportionality between the energy transformed and the results accomplished. Likewise, we know of no case where any organization of matter and energy has resulted in the generation of life *de novo*. The living being takes energy from other parts of the physical universe and transforms it into the energy of muscular contraction and returns it again to the physical universe in the form of work accomplished or of heat given off; but the power to do this is always, in our experience, acquired from another living being. There is no experimental proof of the origin of life by means of evolution.

But it is not only in those departments of science where the uniformity of natural law would seem to be a legitimate deduction that the scientific method has found favor with investigators, for at the present time many of the writers on ethics and sociology and theology are attempting to apply the methods and the laws of physical science in their fields of investigation. It is noticeable, however, that it is not the new physics of energy, but the old physics of forces, which is being thus applied. The physics which has been rendered obsolete by the investigation of the century has been taken up by the sociologist, and we have this mighty organism, man, still struggling with as many forces as were formerly supposed to battle for the control of the physical bodies of his individual members.

It is here, if I may be allowed to prophesy, that the intellectual battles of the first half of the coming century will be fought. When the doctrine of the evolution of organic life was first proposed it was bitterly opposed by philosophers and theologians who thought they saw in it an attempt to enlarge the domains of the physical universe so as to include all the phenomena which had heretofore been regarded as mental or spiritual. Finally, when the battle had been won by evolution, it was seen that the question was not whether there are both a spiritual and a physical universe, but whether the special phenomena of animal life should be classed as spiritual or physical. But the question raised by the attempts to apply the laws of physics to ethics and sociology is an entirely different one. If there is any spiritual universe, the phenomena of ethics are spiritual phenomena. The assumption of natural law, that is, physical law, in the spiritual universe means that there is no spiritual universe. A universe governed by the laws of physics is a universe in which there is no right or wrong, justice or injustice, reward or punishment: nothing but inevitable consequences. A physical universe is one in which no force or influence whatever exists, nothing but the unvarying transformation of energy, always in one direction and according to definite methods; for if a single atom in the universe can be moved by any force whatever, either mental, moral, or spiritual, except by the transference of energy from some other atom, then is it not a physical universe.

If the physics of the present century has established anything, it is that the physical world is made up of matter and energy alone. If the laws of the physical universe apply to sociology and ethics, it is reasonable to suppose that only matter and energy are involved in the phenomena treated in these sciences. If, on the other hand, the development of society and the development of human character are dependent upon spiritual influences, there is manifestly no probability that the processes which take place as a result of these influences will bear any analogy to physical phenomena. If such an analogy be shown to exist, it will serve as an argument against the supposition of spiritual influences.

Whether such an analogy really exists or not is not a question for the physicist to decide. This question can only be determined by the careful observation of many men who are trained to observe and to analyze social phenomena, and who are at the same time familiar with the laws of the physical universe. This much, at least, is certain: if there is not a uniformity of nature in social phenomena so that effects follow causes with the same certainty as they do in the physical universe, then is there no science of sociology, and no such thing as a moral or social law. In so far as man is a free, moral agent, capable of determining his own conduct, all attempts at predicting what he will do under given circumstances must fall. Only in so far as man is *governed*, not merely influenced, by laws as unalterable and unvarying as are the laws of the physical universe, can his actions furnish the materials of scientific study. If, on the other hand, there are such laws, then all attempts of man at influencing the social order will be as successful as would attempts at revising the law of gravitation.

Apparently, the kind of questions for the sociologist to study are: What, if any, are the established orders of development of society and human institutions? What conditions always precede and what conditions accompany the development of what we regard as the higher civilization, and what conditions always accompany the decadence of social institutions?

These questions will not be answered by looking for analogies between the growth of nations and the growth of trees or animals. They must be answered, if answered at all, by the careful collection and verification of facts, and by making generalizations based upon facts after the facts are known. It must be remembered, too, that a law of nature is not, like a law of grammar, subject to exceptions. "A law of nature," says Helmholtz, "is not a mere logical conception that we have adopted as a kind of *memoria technica* to enable us more readily to remember facts. We of the present day have already sufficient insight to know that the laws of nature are not things which we can evolve by any speculative method. On the contrary, we have to *discover* them in facts; we have to test them by repeated observation or experiment, in constantly new cases, under ever varying circumstances; and in proportion only as they hold good under a constantly increasing change of conditions, in a constantly increasing number of cases, and with greater delicacy in the means of observation, does our confidence in their trustworthiness rise.

"Thus the laws of nature occupy the position of a power with which we are not familiar, not to be arbitrarily selected and determined in our minds, as one might devise various systems of animals and plants, one after another, so long as the object is only one of classification. Before we can say that our knowledge of any one law of nature is complete, we must see that *it holds good without exception,* and make this the test of its correctness. If we can be assured that the conditions under which the law operates have presented themselves, the result must ensue, without arbitrariness, without choice, without our co-operation, and from the very necessity which regulates the things of the external world as well as our perception."

It is upon such laws as these that any true science must be based, and it is only to subjects of investigation in which some such laws have been established that the name science can be properly applied. Apparently, we have discovered a method of finally arriving at a knowledge of such laws in the physical universe. That this method in its entirety cannot be applied to the mental and moral sciences, I have tried to show. That it cannot be used at all in the study of language or literature or mathematics would seem self-evident. The discovery and adoption of the scientific method represents the greatest intellectual acquirement of the last three centuries, and it is only in those departments of human knowledge to which the scientific method can be wholly or in part applied that the intellectual achievements of our century surpass those of former centuries. It yet remains for investigators in other subjects to find a method of research which will lead to the same relatively sure results in their fields of investigation.