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PRESIDENTIAL ADDRESS.

THE RELATION OF PHYSICS TO THE OTHER MATERIAL SCIENCES.

BY A. A. VEBLEN.

The last year or two of the nineteenth century and this first year of the twentieth have been prolific in literature dealing in one way or another with science topics. There have been addresses before learned and educational gatherings, articles in science journals, and in periodicals of well-nigh all kinds, much of all this writing having been produced by the masters and leaders of science; and the object of these productions has been, generally, to give a view of the present condition and importance of scientific work and knowledge, or to review recent progress either of science in general or of special departments. The condition of science at the beginning has been contrasted with that at the end of the century just past, or the greatest discoveries and most important researches have been passed in review, and the consequences that have followed have been appraised and estimated. The services of the great investigators, whose names adorn the pages of nineteenth century history, have been appreciatively explained, and the debt which humanity owes them has not been forgotten. The comforts and necessities we now possess, which were unknown a hundred years since, and which we owe to scientific discoveries and their application in practical affairs, have formed the burden of some of these writings.

Some of the boldest of this army of authors have ventured to prophesy as to the future of science; or they have discussed the problems which next are to be attacked and

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solved by scientists, and have in some measure endeavored to foreshadow the manner of their solution.

Now, it goes without saying that much good has been accomplished by all this writing and the thought and discussion it has occasioned, and that from it benefits will accrue to us for many years to come.

Science workers themselves have been cheered and inspired by the enormous showing of results that has in this way been presented. The reviews of the difficulties overcome and the success achieved by our predecessors can not fail to strengthen and encourage us; and the essential unity and similarity of all the various and individual lines of research, as it becomes apparent to the thoughtful reader, must have cleared the mental horizon of many a hard working student of nature, who has been perplexed about the outcome of his own efforts.

To science men themselves, therefore, have come and are coming the first and most obvious benefits of the publications under consideration, especially in the proof that their efforts are well worth while, on the one hand, and on the other, in that by the aid of the discerning reviews made by the masters in their respective departments, they are enabled to take their bearings and establish their lines of orientation with greater certainty and confidence.

Perhaps no less important is the effect upon the mass of the non-scientific public, who have certainly come to see more clearly than ever before the debt which the race owes the indefatigable scientist, and who have thus come to place a higher value upon his work, to sympathize with him, and to assume an attitude of friendliness and become imbued with a desire to aid and comfort and applaud him. The cause of science education has already received an added impetus plainly traceable to this increased popular interest; and this is only the beginning of a movement which it cannot be doubted will be of large proportions and great benefit. Bequests and gifts for the endowment or establishment of schools of all grades and kinds, and of libraries and museums, and for the promotion of research, exploration, and discovery, are multiplying day by day and surprise us by their munificence and freedom from hampering conditions. Governments and parliaments have felt the influence and have made enactments and appropriations greatly favoring and aiding the advancement of pure science and promoting the extension of the benefits resulting from its practical application to industrial affairs. It is especially pleasant to me to be able to speak my appreciation of the magnificent manner in which Congress responded to the appeal for a standardizing bureau, a movement which was set on foot, fostered and pushed by the science men of the country, and to which this academy gave its earnest, and, as it proved, most effective support and aid.

This same popular interest in science and science education has also loosened the purse-strings of many state legislatures and caused them to become more liberal toward their universities and other scientific schools and establishments. Our own law-givers, the men who officially reflect the popular disposition and give formal expression to the popular sentiment in our commonwealth, will honor themselves by dealing with our institutions of learning in a manner entirely befitting the dignity and wealth of the state, the standing of her scholars and science men, and the acknowledged eminence of her whole people in respect to intelligence and enterprise.

One matter suggested by this mass of writing on science progress, is the relationship and interdependence of the different sciences. This would however, form too vast a subject for a single short paper.

A sufficiently ambitious theme for the present occasion may be found in the relation of physics to the other branches of natural science, and her position among them, let us say, as a sister and servant. Noticing briefly some of the more salient and obvious points of contact, certain contrasts will doubtless become apparent, but in the main there will be found similarity and substantial identity in aims and methods.

Such a study, in which the aims of a large body of workers in a given line, their methods and standards, the development of principles recognized by them as essential or fundamental, and the practical value of the results achieved by them, are reviewed or scanned, comparisons being made in these respects with the activity of those engaged in other and related departments of study, should result in considerable gain to all concerned. It should bring them together in mutual appreciation, and promote co-operation and sympathy. And if such an inquiry is carried out faithfully and thoroughly, it may be the means of preventing such waste of energy as surely takes place many a time because investigators lack knowledge of failure or success that has attended the employment of this or that method in other fields of work.

A conscious and consistent method of attack upon the problems presented in the study of any part or phase of nature's plan and operations, and the presence of a body of formulated principles and laws, which do not deny the regular operations of man's intelligence or the truthful action of his senses, may be taken as criteria by which any department of knowledge may be judged to have established itself as a science, or to have entered upon the beginning of its career as one. Judged on this basis physics certainly is one of the pioneer departments of science, and on this basis none can claim a higher and more honorable antiquity.

It appears that the earliest development of science was along physical rather than biological lines. Yet it would seem reasonable to expect that a systematic or exact study of the plants and animals, especially such as were essential to his very existence, would mark the first important step in man's entrance upon the condition known as civilized. This was probably the case; but it seems that this study was not carried beyond the requirements of immediate needs. Perhaps biological study was early tabooed, as too practical, and therefore vulgar. Man early became interested in the things farthest out of his reach; and astronomy perhaps must be considered the first branch of human research, if research is a proper term to apply to the astronomy of the ancients. The positions and motions of the heavenly bodies were long observed and a mass of information about them accumulated and handed down. Theories were formulated about them; and plans of the universe were conceived. It was unfortunate that man began his scientific studies with astronomy; for he did not see things as they are, and the theories he formed were therefore all wrong. He carried his errors and false theories and unnatural conceptions in astronomy into his early study of terrestrial phenomena. The botany and zoology of antiquity were, like ancient astronomy, the results of observation. The habits of animals and the properties of plants were no doubt investigated with patience and accuracy; but as astronomy did not invite men to experimental tests, and as astronomers were perhaps the model and famous scientists of those times, it was perhaps too much to expect that methods independent of theirs should be developed in biological or natural history research. Whatever the cause, biology did not develop to any such extent as the opportunities for study would seem to warrant us in supposing. Astronomy had moreover the aid of mathematics, which in this science found useful and interesting applications. In physics the conditions were different. It was necessary that man should understand the laws of inamimate nature and be able to trace the connection between cause and effect, that he might be able to subjugate the animal kingdom, and in order to provide food and shelter and make his condition comfortable. As he advanced in his development these same motives led to more systematic and searching study; and mathematics found more obvious application than in biology. Mathematics might reasonably be expected to grow on the material furnished by astronomy and physics, while mathematics would in turn furnish solutions for new problems in the physical branches. Accordingly physics developed first along the lines of optics and mechanics. Without extensive and correct knowledge of physical laws and of the properties of matter, the wonderful achievements of the ancients in the arts and industries would have been impossible.

Ancient chemistry was a cult rather than a science. It was a study in which influences of an occult and mysterious kind were invoked. It was largely a supernatural line of inquiry. And it was late before anything like a rational body of principles or laws was formulated. While chemistry or alchemy was the only department of study in which experiment played any important part, the experiments were devised not to exclude unknown and uncontrolled conditions, but rather to include as many unknown factors or agencies as could be brought into play. And experimentation on that basis would do little to promote discoveries.

What we know of the science of antiquity has come to us almost wholly from the Greeks. The Romans seem to have let pure science alone. In the middle ages there was of course some progress, but it was slow and tedious. There was no notable change in processes. The more ancient the method the more highly it was prized.

But the scientific method of the ancients was characterized by certain serious shortcomings, which were at least partly responsible for the painfully slow progress made among them. Men were in early times handicapped in a manner now difficult to appreciate, by a lack of most of the ingenious devices and instrumental aids to research which we possess. But if their methods had been right they would have acquired these means as men acquired them later, because modern scientific methods led to the discoveries which made these aids possible.

The science of antiquity grew by the often treacherous method of deduction, and by what we may by courtesy call observation. Such was the mental bondage of men at the close of the middle ages, that when observations revealed natural conditions which were at variance with the dicta of earlier authorities, the evidence was disregarded or discredited as being but deception of the senses, and the phenomena were frequently ascribed to the agency of the evil one.

Of course when men would not believe the evidence of their senses if it contradicted any of the standard authorities, there could be little scientific observation. And under such a despotic rule of authority experiment would be useless and would be calculated to bring men into trouble. It was when authority was deposed and experimental research was enthroned in its place, that modern science had its beginning. Four hundred years ago many men had begun to acknowledge the inadequacy of the old methods; and the real war of intellectual independence was waged during the century that followed. A long time was spent by men in striving to free themselves from the despotism of the ancient philosophers, which even after the seventeenth century claimed its victims, and sacrifices.

The pioneer army of modern science included many illustrious names, but no single leader can be said to have earned greater credit than Galileo. He lived and worked in the most critical period, saw most clearly the inadequacy of the old methods, and gave the most striking illustrations of the new processes. The importance of his experiments and discoveries and the principles he established and formulated were great enough to entitle him fairly to the name of the father of modern science. Though his brilliant astronomical discoveries made him immediately famous, it is what he did for physics that constitutes his chief claim to greatness and fame.

The experimental method, of which Galileo was the first conspicuous exponent, was the agency that gave new life to science progress. By it nature was made to allow the secrets of her processes to be laid bare, by being compelled to repeat them under restrictions and simplified conditions imposed by man. When the unequal weights, dropped from the Leaning Tower, were seen to strike the ground together, the old theory of gravitation was disproved, not because men saw the action of the experiment, but because the conditions were such that they were bound to trust the evidence of their own eyes. The experimental method aided by mathematics rapidly extended the domain of physics; and physical methods were adopted in other lines of research. The apparatus and appliances of physics were borrowed and adopted in natural history, astronomy, and chemistry to their great advantage.

The knowledge gained of natural laws through laboratory methods led to inventions of new working devices, which in turn further extended man's power of research. Application of this knowledge to practical affairs followed closely.

New branches of science have been created by the extension and application of the new methods of research. Speaking of methods, we must not forget that they are in their general features identical for all the sciences; yet it is to be expected that the individual lines of scientific investigation must to a considerable extent differ among themselves in the minutiæ of their modes of work. Indeed, no line of research deserves the name of science until it has worked out methods somewhat distinct and characteristic, and its material aids and implements have begun to assume special and individual modifications.

By reason of its catholic and general character, and because it deals particularly with the more elementary and salient phenomena and natural laws, physics has necessarily developed methods of the most direct and simple type; and the devices and appliances of its invention are characterized by the same directness and simplicity; and in general the whole universe of science is indebted to physics for the invention and production of the elementary and essential mechanisms from which has been constructed its instrumental equipment.

It is certainly true of the early days of modern physics, that the problems attacked and solved, while difficult and formidable enough, were of a peculiarly simple and explicit character. And the genius with which great masters from Galileo to Franklin separated from the essential part of any research all that had none but an apparent connection with the principle to be sought out, fills us with wonder and compels our admiration. Doubtless the tasks of the physicist have gradually assumed greater complexity, and his mechanical aids have become more and more intricate. But the same elementary directness of method, and the same ingenuity in discerning exactly what must be included in a line of inquiry, and what may be safely left out, have also distinguished the later physicists from Davy to Rowland.

The simple and elementary nature of physical research has no doubt also given character to the mental habits of the physicist. Concentration on such simple, definite problems as he deals with has tended to make him penetrating and critical in judging of the value of the evidence brought to light in research. He has set up for himself standards and adopted criteria as exacting and vigorous as those of the mathematician.

If I have been just and fair in drawing this outline sketch of the physicist, his field of work, his habits, methods and standards, it should represent the scientist in whatever department we look for him. It is indeed of the highest importance in any scientific inquiry that the investigator knows the exact scope of his problem, and is discriminating and unsparing in weighing the evidence that his search has found, in just the way here made out to be necessary for the physicist.

It seems to have been inevitable, however, that physics should have been the first of the material sciences to develop the modern methods of research and to provide modern aids. It was in the search for truth in regard to physical laws especially that men first broke away from the time honored servitude to the authority of the old philosophers, and added experiment to observation and mathematics, as the means of this search, and thus pointed the way for modern scientific progress in all lines of mental activity.

From prehistoric antiquity astronomers had patiently observed and handed down their data. Mathematics aided in the solution of the difficult problems that arose and the greatest intellects had formulated theories of the construction and mechanism of the universe. Yet little of the truth was actually known. When, however, the methods of the new physics were adopted and the new appliances came into use, then the wonderful plan and vastness of material creation began to unfold itself to man. The alliance between astronomy and physics has grown closer, and striking and brilliant discoveries have resulted from it. Out of the physical laboratory have come the instrumental aids by which the astronomer reaches out into the confines of the infinite heavens.

Another study of physical laws and the results of their action on a grand scale and in almost hopeless intricacy and complicaticn, is the physics of the earth, as geology now has come to be named. Eminently a science of very patient and discriminating observation, comparisons and classification, it was at a late day in the eighteenth century that it assumed a place as a respectable science. Geology draws with great freedom upon all other sciences for its aid. Physical laboratory methods find no great application, but familiarity with the principles and laws of physics are so much the more necessary here. The great length of time required for the processes he investigates, and the complex character of the evidence presented to him, demands of the geologist not only a clear knowledge of all forms of force and energy but an especially critical and discerning mental quality. And to attain or heighten this characteristic he needs thorough training in physics.

Chemistry is perhaps the nearest of kin to physics, both in respect to subject matter of investigation and in the minute accuracy of its processes. The boundary between their provinces is indefinite, and where physics ends and chemistry begins, it is often impossible to tell. The latter has become the more special and restricted both in methods and in the extent of its field. Chemistry, however, attained to the mental majority of a modern science much later than physics, and did so through the aids furnished by the physicists, and by assimilating their methods and adopting their standards of testing evidence.

The material equipment of the chemist is not only extensive but very special, yet most of his aids of the more general application were first employed by the physicist or came from his laboratory. Chemistry recognizes its relation to physics with characteristic clearness, and a large department of the science is given the name of chemical physics or physical chemistry.

The biological sciences form a group by themselves, and stand prominently contrasted with those so far passed in rapid review. There are, no doubt, great and organic differences between the biological and the physical sciences. But their general differences are often more purely apparent than real. Classification is generally a distinguishing feature of these, and this is their oldest inheritance, except perhaps, observation, that fundamental and most ancient process in all science study. Classification, which, of course, rests upon well-nigh endless comparison, is a feature more strongly in evidence in some of these branches than others; but it appears to the physicist that this is their distinguishing characteristic, as measurement is that of the physical branches. This does not imply that the one group does not employ measurement nor the other classification. It is simply intended to convey the idea of the general feature which is most accentuated in each group. When this is said, the essential difference has perhaps been stated. But these sciences employ more and more of experimentation and measurement, and their great discoveries are worked out in the laboratory; and of some of them this is as true as it is of physics and chemistry. Bacteriology is a laboratory product; and morphological inquiry is prosecuted by the most delicate and searching laboratory means.

But without the appliances which the chemist and especially the physicist have developed and elaborated for their own use, the biologists would practically lack the implements of their occupation. Their methods are largely identical with those of the former, but are more restricted and special in any given case. The criteria of evidence are the same as in the physical sciences; but in many cases, probably because of the nature of the problems involved, the validity of a conclusion is established with greater difficulty and less certainty as to its correctness than in many a physical research, for instance. This is no doubt owing to the greater difficulty in arranging experiments that shall exclude all but a certain number or group of forces and agencies from the action to be observed. This condition calls for ingenuity of the highest order, and demands patience without limit. But this peculiarity of biological research emphasizes the need of frequently recurring to the consideration of physical methods of excluding from an experiment all but certain known and definite influences, and of the relentless rigor with which the physicist has been compelled to learn to cast out all evidence which can be at all called into question. As the biologist has advanced in the manner and direction here indicated he has penetrated deeper into those elusive unknowns which are of so much interest and concern to us, and which obscure the ever interesting problems in regard to the processes of life and the mechanism of vital actions.

The debt which physics owes to the other sciences is unquestionably great, whether regard is had to the material aids in research that have been borrowed by physicists, or whether one considers the problems furnished, or the suggestions of methods of work that have come from the discoveries, or even the failures of other investigators.

But physics stands in the relation of an elder sister to the other branches. This department of science has enjoyed the privilege of first establishing and defending the methods and criteria which must surely prevail until science shall undergo some radical and now unsuspected change in its essentials. Until such a time arrives, physics will continue to be at once the most severely exact of the sciences and the one among them whose privilege it is to lend and to give in the most unstinted measure both methods and means for their growth and perfection.

The object of all devotees of science is the same; truth — the truth in regard to nature, that nature and natural system of which we are a small and humble part. A recent writer considers science not as a body of exact knowledge, but a "devotion to truth," the truth that is the object of search, and which is still unknown and undiscovered. The scientist is not a defender or guardian of truth; the truth that has been found and made known needs no defense nor does it require champions. The twentieth century scientist will indeed be devoted to the truth that is, but which he has not yet been able to search out, and which with the strength of his whole soul he strives to reach.

Such then is science, a vocation, a devotion of one's self to that which alone is worth while. And the scientist has consecrated himself to this unknown truth. In this conception of science, and scientists, there can scarcely be degrees of merit, nor can the searchers after any form or manifestation of truth claim greater merit than those seeking some other form of it. All are equally noble, and all departments of science must be equally free and generous with their aid to any other branch, to further its object and to cheer its devotees.