THE TEACHER'S CONCEPTION OF PHYSICS.¹

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Perhaps none of us have forgotten the days of athletic contests in which we had a part. In those contests our errors were satisfactorily explained by defects in our equipment or lapses in the quality of the game played by our team-mates, and, indeed, so biased were our judgments that the errors of opponents were interpreted as excellent performances on our own part. As teachers of physics today we are just as fallible. If we do not succeed in our teaching it is the equipment, the text, the laboratory manual, or a new method that is at fault. The limited horizon of our vision of physics is never the admitted secret of failure, and yet that vision is the most fundamental of all factors that we can discuss. The selection of my title, "The teacher's conception of physics" is a recognition of this entirely natural and ever-present condition. I should not be willing to attempt to impart information as to how the members of this Association should teach physics, but I ought to possess a degree of confidence in a discussion of the actual attitude of the teacher or anyone else toward this great study, physics. My desire is, therefore, that in this discussion we abandon concrete problems of physics teaching and attempt to form a vision of that attitude toward physics which should be the chosen one for the physics teacher.

What should be the teacher's conception of physics? This query cannot be answered in a few sentences, for there are many aspects of physics, and the differences in our conceptions are largely due to the differences in the relative emphases which we place upon these aspects. It will be necessary to discuss separately several of the more important phases of physics if we are to secure an appreciation of the proper balance of emphasis for which this paper contends.

Most elementary text-books of physics discuss units and measurements in the first chapters; most laboratories ask the student to perform experiments in measurement as an appropriate introduction to laboratory work. A consideration of possible accuracy in physical measurement has always been attractive to the student because it has presented achievements of physics in a form capable of ready appreciation. But do not teachers as well as pupils acquire an appreciation of accuracy of measurement so marked that

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an unconscious and yet an overshadowing emphasis is placed upon that feature of physics? Is this emphasis justified? Is accurate measurement the real heart of physics or is it an accompanying necessity? Let us turn to our research laboratories for the answer. Examine the contributions fresh from these laboratories and you will conclude that physicists actually avoid accurate measurements. The research physicist attempts to go straight to the essentials of the matter under investigation, he makes only measurements that are necessary, and he seeks an accuracy no greater than the desired results demand. True, new discoveries have been made through sheer accuracy, but this is certainly not *the* method of extending our knowledge. Indeed, physical research is merely the tracing of clues by the use of any method and every method that promises a result. The real work in physics is then not accuracy of measurement but the pursuit of truth. This is well illustrated by the progress made in radioactivity and in the study of atomic structure. Here one forgets human skill in manipulation and marvels only at the ability of the mind to press forward into an apparently impenetrable unknown. Emphasize accurate measurement because of certain educational value if you will; but you thereby endanger the correctness of the vision of the student. One cannot justify practice in accurate measurement upon the ground that such practice will some day be of direct service to those of your students who will become engineers or scientists or will enter the field of research.

Another aspect of physics, emphasized by all text-books, is its classification of present knowledge. Undoubtedly classification is necessary, but it should be regarded as a method devised for the sake of expediency and not for the purpose of giving the student a keen appreciation of physics as it appears in the world about him. That there is a strong tendency to look upon physics as essentially a classification, seems indubitable. Can there be any real value in learning the description of a lever of the "first class?" I fail to detect such a value. As a matter of fact we should be somewhat ashamed of our own minds if they grasped at such valueless classification. Physics in nature is not classified. Mechanics, heat, light, electricity, etc., are quite likely to appear simultaneously not only in nature but everywhere, and the conception of physics as a classification would close our minds to the appeal of omnipresent physics. Classification is essential if we are to convey information the most rapidly, but we sometimes act as if our function was to create encyclopaedic minds rather

than to invigorate and to inspire the normal minds that have real tasks to do. Encyclopaedias are cheap, but men and women who are able to solve the everyday problems which come before them are rare. The greatest asset of the problem-solver is the correct attitude of mind. Our effort should then be directed in the creation of this attitude and in the relegation of classification to its function as a necessary means, the use of which is to be reduced to a minimum.

Let us turn to another aspect of physics. This one is found to be due to a characteristic common to human nature. Always have men welcomed revelation as complete and final. There seems to be an innate desire to place revealed science as well as revealed religion upon the pedestal of infallibility. We do not desire to mislead our students in regard to physics, and yet unless we are especially warned and are unusually cautious we will give them a conception of physics as a fixed body of knowledge, indeed, fixed because no modifications can be made in the "fundamental laws" and because the chief facts to be learned have been already accumulated and classified. We teach our students the "principles" of physics and by this term we mean the fundamental truths in that subject. As a matter of fact they are neither fundamental nor are they probably truths. A fundamental truth once ascertained needs no further investigation, for it is fundamental, and that which does not need investigation is of no special interest to the scientist or to an inquiring student. It is true that the student naturally seeks explanations in final terms and an attempt to satisfy him by a proximate explanation ends in a certain type of failure. To some that failure is a matter of regret, but we ought rather to believe that the complete satisfaction of the student's mind would be a great disaster. A course in physics is not for the purpose of satisfying the student's mind, but it is rather for the purpose of conveying to him a true but simple picture of physics and our present knowledge of it. We do not wish our students to believe that these so-called "laws" are accurate statements of the actual physical laws, for this belief would cause them to have less of an appreciation for and an interest in the physical phenomena of the world about, and it would dull their spirit of inquiry. Attaching the discoverer's name, as in Boyle's law, does not seem to be an effective method of preventing these influences which are detrimental to the cultivation of the appreciative and inquiring mind. Our only salvation is in a correct conception and in a determined resistance to the student's desire

for accurate and unchanging information. The most elementary "laws" in physics are of great interest to the physicist because they are but approximations of great truths, and because in each there is mystery so profound that we cannot hope for its solution within any finite time. An appreciation of this interest does not require a knowledge of more than the most elementary facts.

But it is very easy to convey a false impression not only as to the nature of our "laws" but also as to the actual quantity of knowledge that is today in our possession. Is it not a student's right to have the opportunity to cultivate the correct perspective, to see that in the future our knowledge of the principles of physics will be greatly extended and to realize that in every portion of physics the quantity of the known is exceedingly small when compared with the unknown? The usual perspective that we give our students is confined solely to the region existing between the covers of our texts, and the resulting vision is not wholly unlike a painting of a beautiful landscape by an inartistic novice. There are enough strokes of the brush, and there is enough paint, but there is no vision and hence no landscape. We teach enough, but we need to give the vision.

Our discussion of the nature of our so-called "laws" and the student's demand for unchanging information at every point in his study of physics leads to comment concerning physical theory. Many teachers are much annoyed by threatened changes in any theory, for these produce a fear which destroys complete reliance. Some would prefer to teach the electromagnetic theory of light as the final word. But unfortunately, certain facts indicate that it is not true. What ought they to do? The answer is simple. They should teach that which is in best accord with experimental evidence, namely, the electromagnetic theory of light. But they would reply, "How can I teach a theory that is not true?" I answer by the question, "How can you teach a theory as true?" Theories in physics are not given us as infallible doctrines but as aids to the acquisition of new knowledge. They will change continually, only so will physics ever evolve into a greater and more profound science. The students may not prefer this conception. In fact, another impression of physics would win a greater respect on their part. But we must have confidence that the correct conception, though not so welcome, will in the end give our students greater power.

Let us turn to the consideration of another aspect of our in-

struction in physics. We do not study physics by a method similar to what is known as "the case-method" now adopted by most colleges of law. We do not ask the student to ascertain a principle from the study of "cases" or phenomena but from the study of a book, and the subsequent experiments in the laboratory serve as a verification of the book. The result is that not only the students but we ourselves have come to regard physics as a thing in the book, as a record of what we have learned and classified. This conception of physics is in harmony with the definition of "physics" in our best dictionaries, yet it is this conception against which I wish to protest. In "physics" we should include all physical law, known and unknown, and physical law exists where the phenomena occur and nowhere else. But the immediate environment of the teacher directs his attention to the laboratory and to the text. In the former he finds the operation of the experiments are not like the actual phenomena in nature and in the latter the definitions and descriptions are not closely related to the world about him. So we teachers fall very quickly into the serious fault of confining our interest in physics to our laboratory and to our textbooks. Our students are thus deprived of the helpfulness of the best sort of illustrative material and they fail to gain that increased interest in the wonder of the world about them which is an essential part of their education. It is also true that their knowledge, because less related to their environment, is thereby less available for service.

The discussion of the view of physics as knowledge in books leads us naturally to a brief consideration of the teacher's attitude toward applied physics, for the attitude will be determined by the teacher's conception of physics. Toward applied physics many teachers are unsympathetic. This feeling is in some cases born of ignorance, but in others is caused by the incorrect notion that physics which occurs in the many devices of man is not actually physics, but engineering. But engineering is physics; indeed it is part of the fruit of many years of valuable scientific effort. The achievements of engineering should be an inspiration to every teacher and should give the student a vision of the perspective of the real scientist, the man who labors unostentatiously in his laboratory with a vision that the knowledge he gains will some day be of direct service to society. Let none of us fear to draw upon the field of engineering for illustrative material in our class-rooms, for the difference between pure science and applied science is merely one of perspective, the former having a vision of tomor-

row and the many centuries to come, and the latter having its attention focused more closely upon the problems of immediate importance today.

The discussions in the physics section of this meeting will emphasize vocational physics. Inasmuch as our conception of physics has a direct influence upon our attitude toward vocational physics, we ought to be able to derive certain conclusions from our present discussion. Some teachers object to teaching vocational physics on the ground that such a course is not really physics but merely a collection of practical facts which, although interesting and immediately helpful to the student, cannot give him a broad basis for growth. The fault with such an argument rests in its assumptions that it is possible to teach the subject of physics in a year's work, and that the function of all education is to give a broad basis for growth. The first assumption is the only one I shall attempt to discuss. From our previous discussion the error in that assumption should be obvious, for no one teaches in any year's course more than a minute fraction of even the known physics. As a matter of fact, every course is one in selected physics. The selection which we choose to offer our students should depend entirely upon those students, their ability, their probable future and their immediate interest. I fail to see how a teacher is degrading either himself or his subject if he makes a serious effort to accommodate himself to the students, perchance by teaching several courses adapted to various needs, provided that the teacher in each course gives the student that vision which will be appreciated and which will mean the greatest growth. Teaching without a vision is always degrading no matter how advanced or how difficult the subject. But teaching with a vision is always elevating no matter how elementary the course may be. Of course I do not contend that in our decision as to the needs of the students we think only of today, for education for any specific career must always be broader than the immediate demands of that career. But when the needs of our students have been determined there is no objection to the selection of a course in physics that will satisfy those needs.

There is an aspect of physics that is the cause of many troubles in our teaching. I refer to the difficulties arising in the mathematical formulae and the solving of numerical problems. There is much that can be said concerning these difficulties, but the conclusions can be reduced to a few simple statements. Physical law exists irrespective of mathematical symbols and processes. In

our attempts to state physical law briefly and to propose new theories which will lead to progress in physics, we are compelled to use mathematics. It is indispensable. But we must clearly see that the use of mathematics arises because of our need of such assistance. The function of mathematics in physics is not to confuse, but to enlighten, not to make physics more difficult, but to make progress easier. Why not use mathematics in all physics teaching in precisely the same manner? The answer is obvious. The adoption of this view of the function of mathematics in physics will certainly not remove all our difficulties arising in the mathematical aspect of physics, but it will give us a basis for guidance in our insertion or rejection of mathematical formulae in our teaching.

You have in mind that I have described a conception of physics that demands of each teacher the spirit of the physicist, and you are at once ready to assert that the average physics teacher cannot possibly secure the training requisite for the cultivation of the proper conception of physics. Perhaps your assertion is true. It is for us, however, to set the standards of our own profession. That man who does not recognize his own limitations and who permits himself to be swayed by his environment is an object of pity to his friends and a cause of discredit to his profession. It is to our own interests and to the interests of our profession that we place our ideals high and then strive with all our might to reach them. We must not be content to permit the teaching of physics to be domineered by wrong conceptions. The more we specialize in our teaching the greater the responsibility we have toward the proper conceptions of our subjects. Those who teach physics as one of several subjects should attempt to get a vision of each of them by studying in the summer sessions in departments alive with research. Those whose time is devoted solely to physics should by all means have the experience of actual research, which means approximately the attainment of the Master's degree. We must not blame method, the text-book, the laboratory, but we must determine upon the necessity of our own growth.

You have been asked to consider several aspects of physics and perhaps the criticisms offered have pictured to you the conception that is desired for the possession of every teacher of physics. But let us review them. The teacher cannot permit the interest in accuracy of measurements to deprive him of an interest in what might be called "real" physics. He will not allow the subject of physics to be divided into six or seven parts which are to be placed

in separate compartments in the mind, unless the confining walls of these compartments are no more than the thinnest of fabrics inserted only at the demand of pedagogical efficiency. He will think of physics in its proper relation to the achievements of the past and the possibilities of the future. To him the interesting and highly important applications of physical law in our complex life are but glimpses of the unlimited attainments of the future. He will not be content with physics as represented in many-volumed libraries but will have a vision of physics as universal physical law, which we understand only in a small part. Such a teacher cannot get his inspiration from a printed page whose content is presented in a form to satisfy the educational requirement that our students learn facts rather than that they contemplate important and partially understood truths. His inspiration comes from the world about him where is the dwelling place of omnipresent physical law. Our contention is that the present limited knowledge of physics must not be believed to comprehend the real physics, but only to contain approximations in that small part of physical law which has come under our observation. Our known physics should not be likened to a pier of solid masonry which grows year by year, each addition becoming a permanent portion of the structure, for then we would lose interest in past achievements and look only towards discoveries in new fields. But our known physics is more like a fibrous ramification into the truth, the real physics, at no point coinciding with the truth, and at all points of its many branches furnishing the seeker merely an approach to truth. Text-book physics is not a collection of dogmas which because of their infallibility must attract men, but it is a distinctly human document inspiring because its limitations arouse hope and zeal in the heart. And it is the dependence everywhere of the material universe upon physical law that produces in the teacher an intense yearning to penetrate behind those general and proximate statements recorded in our texts. This yearning is not without hope, for a realization of the meagerness of our comprehension will cause him to expect the discovery of many unsuspected truths in his own generation. Much of the progress of our day is made possible by steps so simple that they are readily understood by a high school student, and this encourages us to believe that in our own class-rooms there are boys and girls whose contemplation may some day lead to discoveries of great importance. In the advances of the past few years we have been taught the possibility and indeed the probability of explaining matter in terms of the invisible atom of electrici-

ty and we have thus been led to regard the realm of sense perception as but an expression of the unsensed and unexplained. The real physics thus appears not to be further removed from our daily lives but to be growing in our appreciation as a group of fundamental relations which, though realized but in part, must comprise an immanent and all important reality. And how can a subject of such significance and such incompleteness become common-place in the minds of the students? Only through the commonness of the mind of the teacher; only through a vision on his part that does not measure up to the conception we have discussed.

In our presentation much has been said of a negative character. Let us repeat some of the positive suggestions. The teacher of physics sees the limitation of text-book physics both in scope and meaning; he realizes that the known physics is but an approach to truth and that the real physics exists where the phenomena are, indeed that physics is an immanent thing; he recognizes the value of contemplation of partially understood truths and the relation of these to the achievements of the past and the future, and he believes that our knowledge, though meager, should inspire every student.

This paper cannot be brought to a close without the frank admission that a discussion of this kind seems to many not sufficiently definite, and hence not clearly helpful in everyday teaching. The only defense to be offered is that the paper proposed to discuss a conception of physics as the most fundamental factor in teaching, and this with full recognition that the discussion would prove helpful only where it encouraged the possession of that conception. The preparation of the paper indicates my own belief; your approval or disapproval of the various opinions stated indicates your belief. But the vision does not need believers; it needs possessors. The possession of the vision is a most practical thing. Physics is a great field for human endeavor and we must cultivate the possession of a vision that will measure up to it. Then, though we may have many imperfections in our methods of teaching, we can inspire minds to serious contemplation and encourage our students to become men and women of power in whatever field they may enter.