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WHAT IS THE MATTER WITH PHYSICS TEACHING?[1]

THE recent appointment by the National Research Council and by the American Physical Society of committees on the teaching of physics shows that our physicists who are primarily interested in research are beginning to see that something is the matter with the college teaching of physics. The question in everyone's mind is "Why the widespread dislike of physics by college students?" As a long-time member of this society I have had much intercourse with engineering teachers, and I have long had in mind an additional question: "Why the widespread contempt of physics teaching among engineering faculties?"

Before giving my answer to those questions I must point out that there is one kind of contempt of physics teaching among engineering teachers which is to the discredit of engineering teachers themselves, namely, the contempt which many of them have for straight and accurate thinking which does not conform to their own careless ways. When I meet with this contempt, which is much too often, I am sorry to say, I always think of a phrase P. G. Tait used in a discussion he gave many years ago of the perennial question of elementary mechanics. "In defense of accuracy," says Tait, "we must be zealous, even unto slaying." It must be conceded that P. G. Tait's ideas concerning elementary mechanics were and are absolutely correct as far as they go, and, after agreeing to use the word weight to designate the pull of the earth on a body, he never reverted to the usage of the grocer and the coal man. This is a thing many of our en-

[1] The opening of a discussion of physics teaching at the Orono meeting of the New England Section of the Society for the Promotion of Engineering Education; autumn, 1921.

gineering teachers do, and it is a thing many of us physics teachers never will do.

Concerning physics teaching, my own opinion is that students dislike physics because they accomplish so little in the study of it in our elementary college courses; and I believe that they accomplish little because the simple, fundamental mathematical ideas and methods which constitute elementary physics are not sufficiently stressed in the class room and not set forth with clearness and brevity in our text-books.

"The instantaneous acceleration of a body is the limit of the ratio $\Delta v/\Delta t$ as Δt approaches zero, where Δv is the change of velocity in time Δt"; but the limit of $\Delta v/\Delta t$ is unthinkable unless one knows the manner in which Δv and Δt approach zero. Advanced students supply this deficiency, as they look backwards at such a definition, by thinking that they think of the so-called principle of continuity! But what is the principle of continuity to a beginner? And what is the beginner to do? The definition of instantaneous acceleration can not be given either logically or intelligibly except in terms of a specific algebraic example where the manner in which Δv and Δt approach zero is clearly evident. I mention this definition of instantaneous acceleration because it is given as stated in nearly every physics text known to me; and yet we ask why students dislike physics. Many physics teachers maintain that it is the business of our mathematics teachers to clear up all mathematical difficulties; but I believe, most decidedly, that the main business of the physics teacher is to cooperate with mathematics teachers in this extremely important matter. I am here considering mathematics largely as a method of thinking, and, surely, if all the difficulties in this method of thinking were cleared up by our mathematics teachers there would be but little left for us physics teachers to do.

Let us consider another example. A fluid at rest pushes normally on an exposed surface, or the exposed surface pushes normally against the fluid. Most of our physics text-books attempt to explain this fact by stating that the **shear modulus of a fluid** is zero! Or by the following pseudo argument: "If the force exerted on the fluid by an element of the surface were inclined to the surface it would have a component parallel to the surface, and this tangential force would set the fluid in motion; therefore, etc., etc." Now it is absurd to say what this tangential force will do to the small adjacent portion of the fluid without considering the forces exerted on the portion by the surrounding fluid. Many such pseudo arguments may be found in almost any of our physics texts, and I believe they account in large part for the difficulties our mathematics teachers have in the teaching of mathematics. Our physics teachers not only do not help in the important matter of mathematical training but they sometimes hinder this highly important business.

But slovenliness in mathematics is not the only fault in our physics texts. Many a student comes from his boarding house to the class room to hear his physics teacher formalize about position and displacement, although not one of the formalities needs to be used, because the student's already existing knowledge of coming and going is fully sufficient for everything his physics teacher will give him. No wonder that a student never *goes* from the class-room to his study to read about position and displacement in his physics text, even if there should be the grain of a new idea mixed up with the intolerably stupid and immediately purposeless discussion.

A young man from the high school is expected to be edified by the study in college of a physics text which discusses levers of the first, second and third classes, which gives all the old stuff about "simple machines"; and which contains little else that is clear and concise and correct and purposeful!

In the technical school the student is scheduled to study such things as water wheels, and pumps, and engines, and yet he is expected to study a physics text in which all these things are set forth, but no more completely than in his high-school physics

text. This surely is a side-stepping procedure on the part of the physics teacher, because the student's burning need is to be trained in mathematical thinking, and it is absurd to waste time in any descriptive study unless it be with some immediate and attainable analytical end in view.

To illustrate faults of physics teaching by examples chosen from mechanics is comparatively easy; but to illustrate by examples chosen from the equally important subject of electricity and magnetism is very difficult. One reason for this difficulty is, of course, evident; but, in my opinion, the chief reason of the difficulty is that the usual presentation of the elements of electricity and magnetism is so bad as to be beyond the range of intelligible illustration, so bad as to be actually unthinkable! Here is an attempt at an example, and I might attempt a great many as unthinkable as this! Any wheelbarrow pusher may, if he chooses, think that when he stops a wheelbarrow he does not simply stop it, but he imparts to it an "extra velocity" in a backward direction. No one would quarrel with such a wheelbarrow pusher, much as one might be tempted to poke fun at him. But what of the text-book-writing physics teacher who injects into a many-page discussion of self-induction the essentially useless idea of "extra current," and in a way which, when reduced to wheelbarrow language, is exactly equivalent to thinking that he thinks that the "extra velocity" to be imparted to a stopping wheelbarrow is a forward velocity! And yet we ask why students dislike physics.

The above examples of unintelligible halfway mathematics, of fallacious argument, of purposeless formality, of tiresome repetition and of easy side-stepping have been chosen from the subject of mechanics, and the one attempt to illustrate the futilities which ordinarily pass as the *elements* of electricity and magnetism has led us back again to mechanics! Why? Because mechanics is the only branch of physics in which a real beginning has been made in the use of precise ideas by common men.

I know, from experience, that most of our students like physics when the teaching is directed insistently towards the development and use of precise ideas, and I know that the majority of our students can be carried a long way in this difficult but highly profitable business.

But the greatest difficulty in the teaching of physics is to persuade the student to study his text book, and in the face of this difficulty physics teaching has degenerated into interminable class-room coaching, making our teaching not only very exhausting but also frightfully expensive, and greatly weakening the morale of our students. What are we to do about it?

President Hadley made a statement in a brief address before the New Haven Convention of this Society in June, which alone would justify the Convention if it could be taken to heart by our teachers. He said that, although at one time, many years ago, books were used too much, at least, too slavishly, they are now used too little; and the most pressing present need in education work is to place more dependence on books. What are we to do about it?

No one would wish a student to use a book unless he can be led to use it effectively, and the trouble, in physics, at least, is that our text-books can not be used effectively. I am, of course, familiar with what is usually considered to be an effective use of a physics text in our non-exacting college courses in physics which run largely to appreciation-stuff, but I do not consider such use to be effective, most emphatically I do not.

I have discussed college physics teaching with a great many men, and when the discussion has turned to the question of the text book I have always been struck by the tendency of those whom I have known to be the best of teachers to point out the contrast between what they say and do in the class-room and what stands in the text-book. Most of our physics teachers seem to think that a text should be a compendium of all the manifold allusions, suggestions, plausibilities, comparisons, analogies, cross-refer-

ences and explanations which enliven the recitation and lecture and which serve as nothing else can serve to stimulate the student's imagination; but no student can work on such things, and the text-book must be something on which he can work.

The idea is somehow widely prevalent among students, and also among teachers, that the understanding rather than the memory should function in the study of physics; but no one can understand anything until many things are fixed in the mind. The student should be required to burn into his memory all definitions, all statements of principles and laws, all elementary proportions with their proofs and all important equations with their derivations. When he does this he will get a hundred times as much as he can otherwise get from his lectures and recitations, the sum total of his effort will be reduced, and his worry will cease to exist.

The most distressing idolatry the world has ever seen is the modern, popular, science-worship which pays no tithes and takes no pains. It is our Great Religion. Its catechism is science teaching which abhors exactions; its litany is the semi-serious wail of regret of our easier college graduates that a silver-spoon smartness was not transmuted by a pleasant college course into what they conceive the talents of its priesthood to be; and its beatitudes are the above-mentioned appreciation-stuff which imbues every easy-going dilettante with a false sense of understanding the universe and encourages every would-be parasite to think exaltingly that science is the building of steamships to carry him where he has no need to go, of railways to bring him things he could do better without and of airplanes to carry quickly his letters which could not lose in meaning if their time of transit were to take a thousand years!

Most people think of science in terms of its results, chiefly, indeed, in terms of results which facilitate joy riding of all kinds, including easy orgies of near-thinking; but science is Finding Out and Learning How, its great gift to those of us who live inside of its frontiers is an understanding of the things which surround us and of the things we have to do, and its price is pains.

SOME STATEMENTS CONCERNING THE TEACHING OF PHYSICS

Arranged to Promote Discussion at the Orono Meeting of the New England Section of the S. P. E. E.

The teacher must not mistake the fixity of an idea as its *raison d'être*. As relating to ideas fixity and reason are not the same thing, especially when it comes to transmitting ideas to students.

The teacher who mistakes fixity for reason does not, as a rule, exercise himself greatly in his teaching; and the teacher who does put energy into his teaching needs, above all things, to guard against what may be called the "illusion of activity" which is the feeling that one is doing a thing well when one is doing it with all one's might! When a teacher does a lesson with all his might, the students may be doing nothing at all.

It is not the teacher's business to promote the use of the metric system, partly because any effort he may make in this direction is pretty nearly sure to be wasted, and partly because he has too much else to do.

Let the teacher use familiar units wherever possible. In mechanics let him use English units and refer briefly to c.g.s. units. In electricity and magnetism let him use the units of the volt-ampere-ohm system wherever these units can be used, and let him use the electromagnetic c.g.s. units where it is necessary to use them.

Nothing in the teaching of physics is of greater importance than to frame numerical problems so that the data as given might be determined by actual laboratory test. The consistent following of this rule will do much to develop physical sense in the student; and neglect of this rule is sure to leave the student "up in the air."

Ask a student about the effect of an unbalanced force on a body and he is apt to make the

following sounds in answer: *eff equals emm aye!* Do not tolerate the mere reading of an equation in answer to a physical question.

Do not tolerate vague statements. It is physically meaningless to say, for example, that acceleration is gain of velocity divided by time." The proper statement is that the average acceleration *of a body during a given time* is equal to the velocity gained *by the body during the given time* divided by the time. It is meaningless to say that "density is mass divided by volume." The proper statement is that the density of a body is equal to the mass of the body divided by its volume.

Require the student to make every statement of definition, every statement of principle, every explanation of an equation, etc., as relating explicitly to a particular condition or thing.

The natural desire for brevity of statement is often allowed to go much farther than the elimination of the important element of explicitness as above pointed out, and lead to complete obscurity of meaning as illustrated by the following example: A string 10 feet long is tied to a post and a force of 5 "pounds" is exerted on the post by pulling the string. This force certainly "acts through a distance of 10 feet," and, the work done is 50 foot-"pounds" because "work is done when a force acts through a distance." This argument is found to be acceptable to about 60 per cent. of the men beginning a college course in mechanics! No! *Work is done when a body on which a force acts moves in the direction of the force,* and no dictionary ever defined the word *through* in a way to justify the use of the word to abbreviate this 18-word statement as it is usually abbreviated in the study of physics (?) in school and college. Language has been developed as a medium for dickering, quarreling and love-making, and language as used in precise physical specifications is always more or less awkward and more or less strained; but it is a serious mistake to obviate these things by using meaningless expressions and phrases.

I have never talked with an electrical engineer who retained any helpful knowledge or understanding whatever from the study of electrostatics in his college course in physics; and every electrical engineering teacher will tell you that he cannot count on any knowledge or understanding, even incipient knowledge and understanding, of electrostatics among students who have just finished their college course in physics.

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REQUIREMENTS OF A MONOGRAPH ON THE CHEMISTRY OF CELLULOSE[1]

IN a seminar devoted exclusively to the chemistry of cellulose certain topical assignments were made to the students, who, after a careful and critical survey of the literature, reported their findings. The course served to emphasize a number of sad facts that are undoubtedly known to all students in the field of cellulose chemistry. We were impressed by the enormous number of undigested, uncorrelated facts that had been amassed apparently as a result of technological studies. We were further impressed by the relatively small number of fundamental studies (bearing the earmarks of painstaking critique on the part of the investigator) that had a direct bearing on the constitution of cellulose, and by the amazing method of presenting these facts in our best English text. It became quite evident as our course proceeded, that there was a lack of vision in the interpretation of noteworthy results in the literature; that little attention had been paid to the methods employed or judgment exercised by investigators in the experimental portions of their work; that scant attention had been given to the correlation of isolated experimental data, and that little differentiation had been made between qualitative and quantitative data in the formulation of hypotheses. To present the case briefly—it became very apparent that a *critical* monograph in the English language was little less than a necessity. Since the close of our seminar, Heuser's new "Lehrbuch der Cellulose Chemie" has appeared, and this splendid work will receive further mention.

A few examples will serve to illustrate the various points previously raised. Take the

[1] Read at the meeting of the American Chemical Society, New York, September 9.