striking example of the value to science of a policy of non-interference on the part of those in control of the distribution of funds for research. Except for routine annual reports he was never asked for statements of progress or for outlines of projects. The relationship was always one of the utmost mutual confidence and esteem.

The results of Dr. Osborne's investigations were summarized in a monograph, "The Vegetable Proteins," which first appeared in 1909 and was extensively revised in 1924. This slim volume has become the classical publication in the field. His extensive studies of wheat proteins were reviewed in "The Proteins of the Wheat Kernel" (1907), now a standard text among cereal chemists. Including these and a few public addresses and popular articles a complete bibliography of his publications reaches 253 titles, of which about two hundred are journal reports of his personal scientific work.

Dr. Osborne's most marked characteristic was, perhaps, the thoroughness with which his problems were investigated. In the early preparation work each protein was isolated in as many different ways as possible, the composition finally ascribed to it was deduced from a large number of carefully conducted analyses and, where the economic importance of the protein warranted it, he returned again and again to its study. The wheat and maize prolamins received extraordinary attention and the methods of preparing even these well-known substances were recently, with the aid of his assistants, materially improved. Time and again he discarded the whole of his painfully acquired results to make a fresh start, this time to "do it right," as he expressed it. His death removes one of the great pioneers of American biochemistry, a man whose name will always be linked with the subject he made peculiarly his own. He was more fortunate than most men in that advancing years, distinctions and scientific recognition did not bring with them administrative responsibilities that deprived him of the opportunity to share in the daily work of the laboratory. His time was always freely available for discussion, not only with his associates, but with the innumerable investigators from all parts of the world who came to New Haven to see him and ask for advice. Ever kindly and courteous, with keen insight into the problems of others and an extraordinary wealth of experience upon which to form his judgments, he has left a memory that will long be treasured by those who had the privilege of knowing him.

HUBERT B. VICKERY
CONNECTICUT AGRICULTURAL EXPERIMENT STATION

LAFAYETTE B. MENDEL
YALE UNIVERSITY

## THE OBJECTIVES OF UNDERGRADUATE COURSES IN PHYSICS FOR ENGINEERING STUDENTS[1]

FREEING myself, for a moment, from the restrictions implied by the above title, I wish to make some general observations concerning what seem to me to be the two superlatively remarkable aspects of present-day physical science.

(A) The first aspect relates to *the ability of the trained physicist to hold things in mind.* The clear and sharp concepts of the kinetic theory of gases, for example, constitute an actual working model of a gas, a working model which exists in one's head! And every physicist knows how this model helps one to hold gas-facts in mind and how tremendously it helps one to think about gas-facts.

Helmholtz, in commenting on the postulated or assumed elements which enter so largely into our conceptions of physical conditions and things, goes on to say "it is nevertheless a great help if we form in every case the most concrete possible picture, even when the picture contains many an assumption that is not, in all strictness, necessary."

(B) The second aspect relates to *the extent to which quantitative mathematics can be tied to physical conditions and things.* Every quantitative notion in physics *is* or *grows out of* a precise idea. Thus velocity is a precise idea; acceleration is a precise idea; electric current strength is a precise idea. In tying mathematics to physics nothing else is so essential as precise ideas, and it is an extremely remarkable fact that "the possession of precise ideas opens the mind," as Whewell has said, "to an almost endless array of simple perceptions which would be, without the use of precise ideas, non-existent."

Regarding these two things (A) and (B), I believe the time will come when every man who has to deal with physical things will have to be equipped with all of the more important concepts and with all of the more important precise ideas of physics, and trained to use these concepts and ideas effectively.

However remote the realization of this ideal for all working men may be, it is certainly now the main objective of the teaching of physics in the college and the engineering school; and, although the teacher of physics in the college can, perhaps, neglect this objective to some extent, the teacher of physics in the engineering school can not neglect it at all, and it is an objective which holds in the preparation of young men for research, even more rigorously, than in the preparation of young men for practical work.

[1] A paper read before the Summer Conference of Teachers of Physics to Engineering Students, Massachusetts Institute of Technology, July 13, 1928.

Every one will, I believe, admit that the main objective of physics teaching in the college and engineering school is *training in analytical thinking* as stated above, and my own conviction is that this objective is so all-important that nothing else need be mentioned in a consideration of the objectives of physics teaching. But it must be analytical thinking which relates to actual physical conditions and things, and every physics teacher should therefore give heed to Bacon's admonition as to method. "Our method," says Bacon, "is to dwell among things soberly, without abstracting or setting the mind farther from them than makes their images meet; and the capital precept for the whole undertaking is that the eye of the mind be never taken off from things themselves, but receive their images as they truly are; and God forbid that we should ever offer the dreams of fancy as a model of the world."

### I. The Traditive Lamp

Bacon, in listing the needs of his time, made a quaint statement of one great need, namely, "A Traditive Lamp, or a Proper Method of Handing Down the Sciences to Posterity." Would that we knew the proper method now, after three hundred years! But we do not know the proper method, meaning, of course, the best possible method. Our traditive lamp is at best but a smoky contraption which is not sufficiently guarded, as a good lamp should be, against the uncertain winds of personal whim and fancy among teachers who lack a complete discipline in their chosen field of science. The greatest problem in teaching is the teacher.

### II. What Faculty is of Greatest Importance in the Student of Physics?

One hundred and fifty years ago Pascal made the statement that the only faculty needed in the student if one is to be able to implant precise ideas and fundamental principles in his mind is eyesight; but, as Pascal says, it must be good eyesight because precise ideas and principles are so minute.

To illustrate Pascal's meaning let us consider what is perhaps the most important principle in physics, the principle of work: ($a$) When a body on which a force acts moves in the direction of the force, the force does work, and ($b$) the amount of work done in any given time is equal to $Fd$ where $F$ is the force and $d$ is the distance the body (on which $F$ acts) has moved in the direction of $F$. To make Pascal's meaning clear let us consider two common statements of part $a$ and one common statement of part $b$ of the above definition, for, of course, it is a definition.

($a'$) A force does work when it overcomes resistance.

($a''$) A force does work when it moves a body.

($b'$) The work done by a force is found by multiplying the force by the distance through which it acts.

*Regarding* $a'$: What do you mean by resistance? Did you ever see resistance? Did you ever feel a resistance. For of course when Pascal asks us to "see" a thing he means that we are to apprehend that thing by the senses. Now resistance has nothing whatever to do with the work done by a force $F$ while the body on which $F$ acts moves $d$ feet in the direction of $F$, although resistance does have much to do with what becomes of the work done. When I pull on a body I have a definite muscular sense of the pull, or, in other words, I "see" the pull, and if the body moves in the direction of the pull I do work. It is wholly unnecessary and hopelessly confusing to introduce the word resistance into the definition of work.

*Regarding* $a''$: What do you mean when you say that a force "moves" a body? Do you not know that one of the most troublesome of misconceptions when we begin the study of dynamics is the mistaken idea that the effect of an unbalanced force is to "move" a body? No, the effect of an unbalanced force is to accelerate a body; after a time the body will be in motion, and after another time, as it were, the body will have traveled a certain distance. The double reference to elapsed time in this statement is a very crude and incomplete verbal equivalent for the square of the time in the familiar formula $d = \frac{1}{2}at^2$.

But let us point out another absurdity in statement $a''$. Imagine a mouse and an elephant hitched up as a team and drawing a cart. The mouse of course does work because she pulls on the cart which is moving in the direction in which she pulls, but it would show scant respect for the elephant to say that the mouse does work because she "moves" the cart.

*Regarding* $b'$: The essential absence of meaning of this statement is illustrated by the answer given to the following problem by about 35 per cent. of a group of engineering students studying elementary mechanics in an engineering school. "A 10-foot rope is tied to a post and the post is pulled by a 50-pound force applied to the end of the rope. How much work is done?" The 35 per cent. above mentioned calculated the work as 500 foot-pounds, because, as they sensed the problem, the 50-pound force certainly "acts through a distance of ten feet."

*Forces are things to be "seen"*: As another example of Pascal's meaning let us consider the idea of force, and let us remember that in every case in simple mechanics a force is exerted on a body by something which is tied to the body and pulls on it, or by something that butts against the body and pushes on it, excepting only the pull of gravity. No one ever saw the "rope" through which the gravity pull of the earth is transmitted to and applied on a body. We have to get into the habit of merely admitting the existence of the gravity pull as one of the forces acting on a body. Of course we are not here concerned with magnetic or electric forces which are like gravity in that their "ropes" are invisible. But how about other forces, how are they to be recognized? The answer is "look—see." A ball is tied to a string and twirled in a circle. What forces act on the ball? Gravity, of course, exerts a downward pull on the ball, the string pulls on the ball, and the air in sweeping past the moving ball exerts a force on the ball, but no other force whatever is acting on the ball. Neglecting gravity and air friction the pull of the string is the only force acting on the ball. If you don't believe it look and see!

### III. THE STUFF OUT OF WHICH PRECISE IDEAS AND CONCEPTS ARE MADE

Precise ideas and fundamental principles, as they are held in the mind, are framed out of sense material, and the truth of what Pascal says about good eyesight as the one essential faculty in the student of physics could be illustrated by many examples in every phase of every branch of physics. Disregarding for the moment the small amount of what may be called word-philosophy which must underlie the discussion of any topic and disregarding for the moment the occasional necessity of explaining a purely mathematical point, *every statement that is made to a beginning student in physics should involve a vivid appeal to sense and to intuition.* I have come to accept this as my rule of procedure in the teaching of elementary physics, and, in my opinion, this rule can not be challenged. To follow this rule one must always be highly specific, one must always have in mind one particular physical condition or thing. One can not follow this rule and indulge in the fallacious procedure which is too commonly followed among teachers of physics, namely, the indulging in premature and meaningless generalizations which overwhelm all sense and bury all meaning.

### IV. THE BUILDING UP OF PRECISE IDEAS AND CONCEPTIONS BY DEFINITION

What is a definition in physics? How would you define a cow pasture? I would advise you, if you would wish the cow to pay any attention to your definition, to define the pasture or fix its boundaries, by building a fence around it! This may seem to be mere cheap humor, but it is not humor, it is physics! Every statement of principle and every definition in physics are actual operations, things done by the hand, when you really come to fathom their meaning; but in very many cases they are such complicated operations that they have to be highly idealized to avoid endless and confusing circumlocutions in specifying them.

Take, for example, the first law of thermodynamics which defines heat as a form of energy. How are we to reduce the statement of this principle to a specification of things done and yet have the things done and our conclusion as to the unvarying result sufficiently general to touch so wide a generalization as the first law of thermodynamics? It is not very difficult to do this, although, of course, when speaking of things done with the hands one should talk partly by hand, and I do not mean by this that a definite experiment be carried out—most assuredly I do not!

Take a body $A$ and produce a definite change in its thermal condition (as indicated, for example, by a thermometer) by doing a certain amount of work on it, and then bring $A$ back to its initial state by bringing it into contact with another cooler body $B$. Then it will be found that the thermal change produced in body $B$ is exactly what would have been produced in $B$ if the original amount of work had been expended on $B$ directly. That is to say, body $A$ by virtue of the change produced in it by the original work "contains something" which is exactly equivalent to the work in the restricted sense that $A$, in being brought back to its initial state, can produce exactly the same thermal change in body $B$ as could be produced by the original work, and this "something" we call *heat*. The definition of heat as a form of energy is completely fixed by the specified result of the specified operation, and if you do not believe the result would be as stated, try the thing out. Only, of course, no laboratory man would advise you to try it out; it requires too many troublesome precautions to be sure that body $A$ gives "heat" to no other body but $B$.

The most highly generalized statement of the principle of the conservation of energy is that "energy can be neither created nor destroyed," and this is a statement that no one can possibly understand although it is easy to make use of it in many physical problems without understanding it. If one wishes to know precisely what the statement means one must specify the underlying operations, and inasmuch as the first law of thermodynamics has been cleared up we need only consider the principle of the conservation of energy from the purely mechanical point of view.[2]

[2] This story occupies only two pages (68–70) of Franklin and MacNutt's "General Physics," McGraw-Hill Book Co., N. Y., 1916. It is, however, too long to reproduce here.

### V. Mathematical Formulations and Mathematical Developments

The most vitally important parts of any physics text for beginners are the parts that are introductory to mathematical formulations; note that I say *mathematical formulations,* not *mathematical developments,* for it is the actual tying of mathematics to physics that is all-important. Mathematical developments *follow* mathematical formulations, and mathematical developments are easy.

Of course much use must be made of precise ideas and conceptions in the important business of reducing physics to mathematical forms, and what is said in Section III applies here also. The parts of a text that are introductory to mathematical formulations must be highly specific, they must have a vivid appeal to sense and to intuition, and they must be free from premature and meaningless (for the immediate purpose) generalizations. These vitally important parts of a physics text (which are introductory to mathematical formulations) are (a) often non-existent; (b) they are sometimes present in a text but rendered ineffective by premature generalizations, and (c) they are sometimes completely submerged and lost in elaborate mathematical developments. I could give extreme examples of all three cases, but I refrain from doing so.

Of all the generalizations of physics the principle of the conservation of energy and the closely associated ideas of energy transformation lend themselves most easily to verbal discussion, and in my opinion purely verbal allusions to energy conservation and energy transformations make for unintelligibility more than anything else in elementary physics discussions. Physics is, after all, *mechanism,* and if you do not "look at" the mechanism you get nowhere.

### VI. Real and Adventitious Difficulties Encountered by the Student of Physics

Professor P. G. Tait says in the preface to his small book on heat that "the student who expects to find this book, elementary though it is, everywhere easy reading will be deservedly disappointed. No branch of science is without real difficulties even in its elements."

This is certainly true, but many elementary analytical texts are unnecessarily difficult, and the unnecessary difficulties are nearly always due to unintelligibility. The student does not "see" what the author is talking about. One must talk sense if one is to build up precise ideas and conceptions; one must talk sense if one is to establish mathematical formulations; one must talk sense if one is to lead a student to apply to a new problem the precise ideas and concepts that already exist in his mind; and, however far a student is carried forward in his analytical studies, one must continue to dwell among things without abstracting or setting the mind farther from them than makes their images meet.

### VII. The Arousing of Interest among Students of Physics

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 or towards what may be called training in analytical thinking; and I know that our students can be carried far in this mildly difficult but highly profitable business. In fact I have always found my students to be so eager and enthusiastic that I could not wish them to be more eager or more enthusiastic.

In my opinion and according to my experience interest in the study of physics is *not* dependent upon the introduction of descriptive physics or on the application of any of the principles to practical engineering problems except of the simplest and most familiar kind; an almost purely analytical course in elementary physics arouses intense interest if one heeds Bacon's admonition and connects every detail of analytical method with actual conditions and things. The greatest fault of an earnest, hard-working teacher is to be exacting—and unintelligible.

### VIII. The Objective of Undergraduate Courses in Physics for Engineering Students

Every good musical composition is supposed always to come back at the end to the initial chord, and I end this brief discussion after the canons of musical art, changing only the plural *objectives* to the singular form. The only objective worth talking about is training in analytical thinking. Increase of our powers of thought is the greatest gift of the sciences to mankind.

William S. Franklin
Department of Physics,
Massachusetts Institute of Technology

## SCIENTIFIC EVENTS

### INCREASE OF NATIONAL FOREST UNITS

Plans for the acquisition of 9,600,000 acres of land in accordance with the general program of national-forest purchases are being completed, according to an oral statement made by L. F. Kneipp, Assistant Forester in charge of the branch of lands of the Forest Service, and reported in the *U. S. Daily.*

Mr. Kneipp pointed out that the areas for purchase are approved by the National Forest Reserva-