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OPERATIVE VERSUS ABSTRACT PHILOSOPHY IN PHYSICS

THE limited usefulness in science of what we may, perhaps, call verbal philosophy has long been recognized, especially in the mathematical sciences. Unfortunately the term verbal philosophy conveys a suggestion of contempt, whereas no contempt whatever is here intended. By verbal philosophy we mean the marvelously effective method of thinking which all men use in their dealings with the complex problems of daily life, a method of which the most striking characteristic is the transformation of the essential phases of a problem into verbal forms, not solely for purposes of articulate speech, by any means, but to facilitate thought.

My own opinion is that the training of the mathematical physicist is vastly inferior to the training of a good lawyer as a preparation for dealing with complex human problems, and the lawyer's training is in verbal philosophy. I must not, however, let this statement stand unqualified, for it needs to be qualified in two ways. In the first place scientific men would like to see the training of a lawyer arranged so as to lead to mental honesty as certainly as the training of the scientist, and in the second place scientific men would like to see a wider recognition among men of affairs (meaning the men who use what we have called verbal philosophy with great success in dealing with the almost infinitely complicated problems of practical life) of the fact that in every problem we face in this world the philosophy of precise ideas has come to have a place and that in most purely physical problems the philosophy of precise ideas is supreme.

Every person with whom I have ever talked, theorist or practician, student-in-general or specialist in whatever line, has exhibited more or less distinctly an attitude of impatience towards this or that phase of the precise modes of thought of the mathematical sciences.

> Da wird der Geist euch wohl dressirt
> In spanische Stiefeln eingeschnürt
> (There, alas, the spirit is constrained
> And laced in a Spanish corselet)

Nothing, however, is so essential in the mathematical sciences as the possession of precise ideas. One must think so and so, there is no other way. And yet there is always a conflict in the mind even of the most willing student because of the narrowing influence which precise ideas exercise over our vivid and primitively adequate sense of physical things. This conflict is perennial, and it is by no means a one-sided conflict between mere crudity and refinement because refinement ignores many things. Precise ideas not only help most wonderfully to form our sense of the world in which we live, but they inhibit sense as well, and their complete and unchallenged rule would be a dreadful thing.

> Grau, theurer Freund, ist alle Theorie,
> Und grün des Lebens goldener Baum.
> (All theory, my friend, is somber, gray;
> And only the tree of life is green.)

It is the purpose of this brief article to set forth some of the little known characteristics of the philosophy of physics; of course it is not necessary to dwell on the best known phase of this philosophy, which is the use of the precise ideas of geometry.

A coin is rubbed on a board, work is expended on the coin and the coin undergoes a thermal change (the coin is heated). Let us suppose, for the sake of simplicity, that the only effect produced by the rubbing is the heating of the coin; then, if the coin were to be brought back to its initial condition by being brought into contact with another cooler body *B*, it would be found that the thermal effect produced in *B* is exactly what would be produced in *B* if the work expended on the coin were expended on *B* directly. Therefore, the coin, by virtue of the thermal change produced in it, has within itself something which is the equivalent of the work which has been expended on it, and this something is called heat. The definite outcome of these somewhat idealized operations involves the complete definition of heat as a form of energy, a definition which is sometimes called the first law of thermodynamics. If you do not believe it, try it! Every definition, every statement of principle or law in physics, rightly understood, is an actual operation, something done with the hands. How would you define a cow pasture? The answer is, by building a fence around it. Even a stupid cow pays attention to such a definition.

I am tempted to show the reduction of the principle of the conservation of energy in its purely mechanical aspects to an actual operation, but it is too long a story;[1] but the purely mechanical principle is the outcome of a very definite group of operations, and the above described operational aspect of the first law of thermodynamics supplements the purely mechanical principle of conservation, giving us the complete principle of the conservation of energy. Most men, most physicists even (for we are all lawyers in our predilection for verbal philosophy), are content to think that they think that "energy can neither be created nor destroyed." Nothing is easier to hold in mind than this verbal statement, and few things are more difficult to hold clearly in mind than the complete operational aspects of the principle of the conservation of energy.

And now for a matter that has been discussed *ad nauseam* by physics people. What is meant by mass? Of course the question so asked would seem to call for an answer covering every known relation of mass; this is a long story, but even so the story should start with a tenable definition. "Mass is quantity of matter"—nonsense! Mass is a physical quantity, and, surely, when we ask about a physical quantity we should consider the measurement of the quantity. Every advanced student of geometry knows, for example, that the meaning of length is bound up in its measurement. The only definition of mass for which one need offer no apology whatever is that the mass of a body is what you get when you weigh the body on a balance; this is the operational definition, but, because mass, like most quantitative ideas in physics, has many relations and because the relations of mass to force and acceleration are so remarkable, we forget ourselves and pretend to define mass in terms of acceleration, whereas neither the workers in the International Bureau of Weights and Measures nor your coal-man measures mass by jerking things around! You can easily frame up an operational definition of mass in terms of jerking, but measurement by the balance is the most precise measurement known, and the operation of weighing by the balance *is* the definition of mass in spite of any amount of reverence for Newton's laws of motion and in spite of any amount of verbal philosophy that may be brought to bear on the question. What you get when you weigh a body on a balance is independent of time and location, it is always the same for the given body, and it is for this reason that this result is a convenient measure for the amount of material in the body. The term weight as used in commerce (forget the spring scale as a device for weighing) means precisely the same thing as the word mass as used in science, and it is very greatly to the discredit of engineers that after agreeing to use the word weight in a different sense (meaning the force with which the earth pulls on a body) they revert to the usage of the coal-man, forgetting that the balance scale *does not* determine the weight of a body in the force sense.

In many cases the operational aspects of a principle or definition are difficult to hold in mind, thinking in terms of actual operations is very difficult; but operational philosophy *is* physics, and the diffi-

[1] See pages 68 to 70 of Franklin & MacNutt's "General Physics," McGraw Hill Co., New York, 1916.

culty of thinking in terms of operations is the difficulty of physics. What are you going to do about it? One thing we all do is to introduce terms and phrases, such as electric current, voltage, resistance, candle-power, 100° C., which relieve us of the necessity of long wordy specifications of underlying operations in making statements of physical facts, and which, unfortunately, mislead many men into the easy acceptance of physics as a purely verbal philosophy; and the utmost limit of this pseudo physics is reached when in answer to a question as to the behavior of a body when acted upon by an unbalanced force the student answers *eff equals em aye!*

The most needed thing in physics is a logical scheme for facilitating our thinking in terms of operations, and it looks as if the phase of mathematics which is called the group theory might some day supply the much needed scheme. At any rate the operational aspect of physics sets physics apart from the familiar kind of pure mathematics, and, whereas, pure mathematics is the philosophy of precise ideas, physics is a philosophy of precise ideas and of operations. In both of these respects physics is to be contrasted with the age-old type of human philosophy in which the well-trained lawyer and the man of affairs excel.

An extremely remarkable thing in science is that highly complex and penetrating interpretations are forced upon the almost unthinkably meager data which we obtain directly through our senses. An astronomer, for example, *looks at a speck of light* as it crosses the field of his telescope and he *listens to the beats of a clock,* noting the time of day when the speck of light crosses the center of the field. He then *looks at a set of finely engraved lines* on a divided circle, noting the angular distance of the speck of light above the horizon. All this he does three times in succession. Then, proceeding to interpret his data, he calculates when the speck of light (a comet) will be nearest the sun, how far it will then be from the sun, how fast it will be moving, and when it will return, perhaps a hundred years hence. This kind of forced interpretation is very common in physics and chemistry, and in most cases the actual sense data are so extremely meager that to the layman they seem to be absurdly inadequate.

Another equally remarkable thing in the physical sciences is that we have learned to exercise over physical things a kind of rational control which greatly transcends the cunning of the most skilful hand. A generation or two ago the most remarkable physical things grew out of manual skill; but the most remarkable physical things are now such things as the Boston Edison System, the modern steamship and the complicated radio set, and, as everyone knows, the design, construction and operation of such things depends so largely on the understanding that we almost forget the element of manual skill.

Francis Bacon long ago listed in his quaint way the things which seemed to him most needful for the advancement of human knowledge or power. Among other things, he mentioned "A New Engine or a help to the mind corresponding to tools for the hand"; and the most important aspect of the modern mathematical sciences is the aspect in which they constitute a realization of Bacon's idea. These sciences do certainly constitute a new engine which helps the mind as a tool helps the hand, and it is this engine which makes possible all forced interpretation and all rational control.

This new engine is in part a *mechanical structure.* Consider, for example, the carefully planned arrangement of apparatus and the wide variety of related operations that are involved in any experimental study in the physical or chemical laboratory. The experimental data of the physicist and chemist are as meager as the astronomer's data and they take on meaning and bear a complex interpretation very largely because of the complex arrangement of apparatus and because of the inter-related operations, and, of course, the scheme of operations as well as the arrangement of apparatus is a mechanical structure.

The new engine is also in part a *logical structure,* that is to say, a closely reasoned body of mathematical and conceptual theory.

These two structures do indeed constitute a new engine, and the teaching of the physical sciences is the building of this engine: (a) By developing the logical structure of the sciences in the mind of a young man, (b) by training in the use of measuring instruments and in the performance of ordered operations, and (c) by exercise in the application of these things to the phenomena of physics and chemistry at every step, and all the time, with every possible variation. Let one reflect how very different this all is from the training of a lawyer; and let us remember that the scientist is a man and sure to be proficient, according to his native ability, in the type of philosophy that is needful in human affairs. It would seem that some training in science, some training in the only ways in which we can think about and deal with physical things, is needful for the lawyer and for the man of affairs.

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