SCIENCE

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LABORATORY INSTRUCTION IN PHYSICS.

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THERE are various practices, and seemingly but two clearly defined methods of teaching physics in college laboratories. The first method, which may be called the progressive one, treats the general subject of physics by going through its various divisions successively, until the whole ground has been covered, whether thoroughly or superficially. For students who have had no preliminary training in physics, this method is the only practicable one if they are to begin their study in the laboratory. The other may be called the method of analysis. It assumes that the pupil has received a fair course of instruction in the principles of the science before he enters upon laboratory work. Then it is a matter of indifference whether his first exercise is one in optics, or in electricity; in radiation, or in specific gravities. He will examine a body of any sort with reference to its various properties, taking account of as many as he can, which in some instances may embrace nearly the whole range of physics. This method then does not present the different features of physics so much as the physical features of different things.

At first sight it would appear as if the method that is pursued for the direct purpose of learning the science would be the one best fitted to give an acquaintance with it, and perhaps this would be true if sufficient time could be given to it to deal with the various branches of physics with tolerable thoroughness, but laboratory work by an untrained pupil is slow at best, and time is limited. It is important, therefore, to follow the plan that will give good results without loss of time.

If physics as a science were distinctly progressive in its nature, one step being essential to a comprehension of the next, and therefore of necessity a preliminary to it, there could be no question as to the best order of proceeding in teaching or in learning the subject. There would still be room for question as to how much should be done by the teacher in experimental illustration with discussions, before putting the pupil to experimenting on his own account, but the order of dealing with the subject in any case would be determined beforehand. But it is thus progressive to only a limited degree. Except for the principles of mechanics, which permeate the entire science, physics, in all its diversity, may be dealt with regardless of the order in which the subjects are taken up And this exception is not always recognized. Among recent standard text-books which are meant to be especially adapted to laboratory practice, but which mean to omit none of the elementary principles of physics, there is every variety in arrangement of topics. One begins with specific gravity and air pressure, follows with dynamical principles, and presents light as the final subject. Another begins with magnetism, introduces the last third of the work by dynamics, and closes with sound. Still another begins with properties of matter and dynamics and ends with light; while a fourth begins with the mechanical powers and closes with magnetism and electricity. Even the special divisions, as electricity, for example, can scarcely be said to be developed from one principle that necessarily comes first, to another that can be reached only at the end of a well-defined series. Some classification of topics can always be made, but the tendency to-day is to diminish rather than increase the number of classes. Considerations of intrinsic difficulty, or length of time that can be given without interruption, or the season of the year when sunny days may be expected, or other special points may lead to a preference as to the order of subjects, but there is little in the nature of the subjects themselves to determine it.

The status of the student when he is to enter upon the work which this paper is to discuss, will depend upon the manner in which he obtained his first training in physics. He may have acquired his early knowledge by experimentation from the beginning, or he may have been taught from descriptive text-books supplemented by experimental lectures from the teacher, or he may have had a combination of both. In the first case, he had to find out principles and laws as well as (to him) disconnected facts by his own experimentation; in the second, he has been made acquainted with the leading laws and properties and perhaps has had some opportunity to verify and apply them. Whether an attempt to learn physics from the beginning by practice is profitable or advisable has been much discussed, and it is outside of our purpose to enter upon that question. It is a plan that has grown in favor greatly of late, and has been insisted upon by Harvard College, as a preparation for those who are to pursue the subject in college. Let us suppose the pupil to have acquired a general, though elementary, acquaintance with the principles of the science, — that he has reached the standard of at least a well-prepared college junior. For this he has probably been called upon to cover the whole range of the subject whether by experiment, or by recitations and experimental lectures. The advocates of the two methods of preparation will find points to offset one another in the results attained. The experimental student will have acquired his knowledge in a very valuable way, by objective study, by the inductive method. He will have "learned to do by doing." This has become a favorite idea with educators in almost every branch of learning, and its advantages are undeniable in most lines of work, but they are not equally great or equally obvious in all branches or at all stages. It is a most effective way so far as it goes, but in physics the experiments concerning any one point, or involving any law, will have been so small in number under the best opportunities, that the student must infer the law from instances altogether too few and too little varied, to justify an inference. Potent as the inductive method has been in science, its demonstrations are never incontestable, they never rise above a moral certainty, and do not even approach it, if the instances upon which the conclusions are based are not numerous, or else very accurate. The student will in reality have done nothing more than illustrate a point, doing in a crude way what the lecturer before a large class does in a better way. Still the experiment and its results will impress themselves upon him because he did the work himself. In this he will have the advantage of the lecture-taught student. The knowledge of the latter, however, is likely to be more correct as to principles. On the whole, the two classes may be said to approach the higher laboratory practice about equally well equipped: the former better prepared for manipulation with perhaps less readiness to appreciate the science; the latter better prepared to discriminate as to principles, but less expert in determining them. Didactic and experimental instruction are now so well combined in some secondary schools as to make their work superior to that offered in many colleges. Having been fairly well taught by any method, we may suppose the student ready for practical work somewhat more advanced than is to be had in secondary schools, or even in the general course of physics in an average American college. What plan shall be followed in his laboratory work? Presumably that plan is best which is best fitted to accomplish its purpose. What is the purpose of his work? Usually not independent research or original investigation. Work of that class is generally undertaken only by graduates or special students, who are not obliged to accomplish a definite amount in a given time. The higher laboratory work of the college undergraduate is for the purpose of making him practically familiar with physical laws, not in one particular branch of physics, but throughout the whole subject; for training in making and reducing scientific observations; for acquiring skill in manipulating and adjusting apparatus; all which is to result in giving him a good general knowledge of physics, if he follows the study no further, or to fit him for independent research if such is his design for the future. It is thus intermediate in its thoroughness and definiteness between the preparation in elementary general principles of the science, and the work of the graduate or the advanced special student.

What is likely to be the experience of a student in the college laboratory under what we have called the progressive method, supposing he has time enough in prospect to cover the entire field? He will begin probably with a dozen companions in his division, with the topic placed first in the order chosen, say properties of matter, and dynamics. One of the first operations he will be called upon to perform will be that of weighing a body. The skillful use of a delicate balance, will involve the critical study of the balance itself. This will afford a good exercise in dynamics. To reduce to weight *in vacuo*, will necessitate the reading of the barometer, and an application of the laws of Boyle and of Charles, for the effect of temperature and pressure upon gases. Thus he will have been carried at once beyond the immediate subject of physics to which he was intending to apply himself. However, it was merely an excursion. He may continue with this work until he has learned several modes of weighing, and with several types of apparatus. He must learn to measure time. Here he will be introduced to the use of the pendulum, perhaps the chronograph, and other devices for comparing intervals of time. The method of coincidences will be especially serviceable, if he has a seconds clock and a reversible pendulum, by which to determine the accelerative force of gravity. Atwood's machine, besides illustrating the laws of falling bodies, will serve for critical work in mechanics, if the effect of friction, and the mass of the large pulley are to be considered. Various other exercises in mechanics may be given him; he will hardly go on with less than these, and to each of these he will have given enough time and attention to become proficient in work of this kind, and will have given attention to as little else in physics as possible.

If he passes next to the subject of heat, he will probably remain at this until he has dealt, if possible, as fully with its various phenomena. So far as these phenomena involve mechanics he will have had some especial preparation by his previous work, and now he will be doing that work over again. For instance, in hygrometry the same principles relating to the effect of temperature and pressure upon the volume of a gas, will have to be considered. In specific heats, he will again go over the same kind of work as to masses and densities that he performed with the balance, and so on. But he will do nothing in electricity, even with the heating effect of an electric current, because he has not yet come to electricity. He will do heat pretty thoroughly but not completely. It will be so in each branch he studies. In every one, to do an exercise which is nominally one of a particular class, he must employ principles of classes previously studied. Not until he has gone over the entire range of topics, from the first to the last, will he have taken account of all the principles meant to be included in his course, but when he has done so he will have had a most exhaustive training, for he will then have done nearly everything, not once or twice only, but very many times. His training by that time ought to be excellent, and his knowledge extensive and acute. But to reach such a stage would require longer time or more exclusive devotion to physics than is usually provided for in an undergraduate course. If any thing less is done, however, it means not the omission of certain exercises, but of all the exercises pertaining to one or another entire class of topics. For instance, he may omit sound, or light, wholly. That would make a serious break in his course. By any of the usual arrangements, therefore, the whole subject will be obviously more or less disjointed if it is regarded as made up of members. Fortunately, the highest treatises seek to unify it instead of to dismember it.

How will the student fare by the method of analysis? For an example, give him a piece of plate glass of convenient size. Of the various determinations regarding this specimen, some will be qualitative, others quantitative. Let him determine:

1. Whether it is regular, and if so, its form.......	Qualitative
2. Its dimensions, giving area, thickness and volume....................................	Quantitative
3 Its mass (weighing)........................	Quantitative
4. If C.G.S. units are employed, this leads at once by dividing mass by volume, to density.....	Quantitative
5. But check this by weighing in water, for sp. gr.	Quantitative
6. If the plate is of considerable size, say 25 cms. × 30 cms. and a small spherometer is available, test the surface for flatness, and map out irregularities.............................. (This will serve to show the meaning of instrumental limitations as to precision and accuracy)	Quantitative
7. If possible, compare this with the irregularities of surface, shown by reflection of light, with telescope, or by interference bands when in contact with true "flat."...................	Qualitative
8. Determine its index of refraction....	Quantitative
9. Its hardness................................	Qualitative
10. Its color, by absorption in spectrum....	Qualitative
11. Whether it is homogeneous, by transmission of polarized light............................	Qualitative
12. Its specific heat.....	Quantitative

Some of these may be out of the reach of many laboratory equipments or only determinable with the help of instruments too delicate to be put into the hands of any but the best students, but still other determinations might be made. Undoubtedly by the time the student has finished such an analysis he will have a very complete knowledge of the specimen he has been working upon, and although, in the instance here cited, the object under scrutiny may seem a trivial one, and the knowledge of its properties no useful addition to his stock of information, not every one may be so. Yet what a range of physics was involved even in this apparently useless analysis! In scientific training it will not have been useless.

As another example, suppose a steel rod be given him to examine. Cutting off a piece about 10 cms. in length, he might determine its dimensions, mass, density, and specific heat. With the long portion he can ascertain its rigidity (by torsion), Young's modulus (by flexure), velocity of sound in it (by longitudinal vibrations), and compare this with the velocity determined from the ratio of elasticity to density. He might magnetize a short piece, say 20 cms., by permanent magnets, and by timing its oscillations, and observing the deflection it gives a needle, determine its magnetic moment, strength of pole, and strength of field in which it swung. Let him then demagnetize it by heating, remagnetize by electric current, and compare its moment now with what it was before. These latter, though not properties of the steel itself, are obtained as consequences of its magnetic character. He might also employ such a magnetized bar to determine its moment of inertia experimentally, and check by calculation from its mass and dimensions. Thus he will have brought into application numerous principles of mechanics, of acoustics, of heat and of magnetism, each of which gives opportunity for work of any required degree of care and precision, involving all the fundamental operations of weighing, measuring, and timing. By the former method he will learn to what extent any one quality is found in numerous specimens examined; by the latter, to what extent these numerous and varied qualities are found in the one specimen examined; by the former he learns one feature of many things, by the latter, many features of one thing. But in learning the one feature he confines his attention chiefly to a few principles of science and needs extend his knowledge of physics no further than to apply these few principles, no matter to how many objects, and there is always the danger of breaking off his work with only a partial view of the science; whereas in learning many features, though confined to only one object, each feature involves one or more distinct principles of science, and the many of them represent a wide range of scientific knowledge. This gives to the student, therefore, indeed it imposes upon him, a broad culture none the less deep because of its breadth, even if he has had time for the analysis of but one specimen, while the other almost inevitably results in confining his labors and his attainments within narrow limits. Whenever it can be done, a determination of any sort should be made by two processes as nearly independent of each other as possible. For example, the radius of curvature of a lens might be determined by comparing the size of an object, as a scale, with that of its image formed by reflection from the lens surface; and it might be calculated from spherometer measurements. While there are some points in physics which the progressive method would reach and the method of analysis miss, the latter would the more readily lend itself to such twofold determinations.

There are operations such as the calibration of a thermometer, determining a rate of vibration, adjusting special forms of apparatus and determining their constants, etc., that cannot be classified in any simple manner. An attempt to adhere strictly to any clearly defined method throughout the whole course of physics would be unwise and unprofitable. The recognition of a method and of its legitimate limits, however, cannot fail to be of service to a judicious instructor. The limitations of the laboratories themselves in many cases compel a departure from any method and cause the work to degenerate into an unsystematic performing of experiments. It must be admitted, too, that such is the character of the work in some instances where the equipment is very complete.

A NEW METHOD OF CHILD STUDY.

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THE current discussions of the more elementary mental processes show that we lack clearness in our conceptions of the earlier stages of mental life. This is evident enough to call out frequent appeals for "scientific" child study. The word "scientific" is all right, as far as it goes; but as soon as we come to ask what constitutes scientific child study, and why it is that we have so little of it, we find no clear answer, and we go on as before accepting the same anecdotes of fond mothers and repeating the inane observations of Egger and Max Müller.

Of course there are only two ways of studying a child, as of studying any other object—observation and experiment. But who can observe, and who can experiment? Who can look through a telescope and "observe" a new satalite? Only a skillful astronomer. Who can hear a patient's hesitating speech and "observe" aphasia? Only a neurologist. Observation means the acutest exercise of the discriminating faculty of the scientific specialist. And yet most of the observations which we have in this field were made by girls who, before their marriage, knew less about the human body than they did about the moon or a wild flower (having got this latter information from Steele's "Thirteen Weeks") or by a father who sees his child when the boy is dressed up, for an hour a day, and who has never slept in the same room with him in his life; by people who never heard the distinction between reflex and voluntary action, or that between nervous adaptation and conscious selection. Only the psychologist can "observe" the child, and he must be so saturated with his information and his theories that the conduct of the child becomes instinct with meaning for mind and body.

And as for "experiment," greater still is the need. Many a thing a child is said to do—a little judicious experimenting—a little arrangement of the essential requirements of the act in question—shows it is altogether incapable of doing. But to do this we must have our theories, and have our critical moulds arranged beforehand. That most vicious and Philistine attempt in some quarters to put science in the straight-jacket of barren observation, to shut out the life-blood of all science—speculative advance into the secrets of things—this ultra positivistic cry has come here as everywhere else, and put a ban upon theory. On the contrary give us theories, theories, always theories! Let every man who has a theory pronounce his theory! This is just the difference between the mother and the psychologist—she has no theories, he has. She may bring up a family of a dozen and not be able to make a single thrustworthy observation: he may be able from one sound of one yearling to confirm theories of the neurologist and educator, which are momentous for the future training and welfare of the child.

In the matter of experimenting with children, therefore, our theories must guide our work—guide it into channels which are safe for the growth of the child, stimulating to his powers, definite and enlightening in the outcome. All this has been largely lacking, I think, so far, both in scientific psychology and in applied pedagogy. The implication of physiological and mental is so close in infancy, the mere animal can do so much to ape reason, and the rational is so helpless under the leading of instince, impulse, and external necessity, that the task is excessively difficult—to say nothing of the extreme delicacy and tenderness of the budding tendrils of the mind. Experiment? Every time we send a child out of the home to the school, we subject him to experiment of the most serious and alarming kind. He goes into the hands of a teacher who is not only not wise unto the child's salvation, but who is on the contrary a machine for administering a single experiment, to an infinite variety of children. It is perfectly certain that two in every three children are irretrievably damaged in their mental and moral development in the school; but I am not at all sure that they would fare any better if they stayed at home! The children are experimented with so much and so unwisely, anyhow, that it is possible that a little experiment, intentionally guided by real insight and psychological information, would do them good.

With this preamble, I wish to call attention to a possible method of experimenting with young children, which has not been before noted to my knowledge. In endeavoring to bring questions like the degree of memory, recognition, association, etc., present in an infant to a practical test, considerable embarrassment has always been experienced in construing safely the child's responses. Of course the only way a child's mind can be studied is through its expression—facial, lingual, vocal, muscular; and the first question, i.e., What did the infant do? must be followed by a second, i.e., What did his doing that mean? And the second question is, as I have said, the harder question, and the one which requires more knowledge and insight. It is evident, on the surface, that the farther away we get in the child's life from simple inherited or reflex responses, the more complicated do the responsive processes become, and the greater becomes the difficulty of analysing them, and arriving at a true picture of the real mental condition which lies back of them.

To illustrate this confusion, I may cite about the one problem which psychologists have attempted to solve by experiments on children, i.e., the determination of the order of rise of the child's perception of the different spectral colors. Preyer starts the series of experiments by showing a child various colors and requiring the child to name them, the results being expressed in percentages of true answers to the whole number. Now this experiment involves no less than four different questions, and the results give absolutely no clue to their analysis. It involves, 1, the child's distinguishing different colors simultaneously displayed before it (i.e., the complete development of the child's color sensation apparatus); 2, the child's ability to recognize or identify a color after having seen it once; 3, an association between the child's color-seeing and word-hearing memories, by which the name is brought up; 4, equally ready facility in the pronunciation of the various color names which the child recognizes: and there is the further embarrassment, that any such process which involves association, is as varied as the lives of children. The single fact that speech is acquired long after objects and some colors are distinguished, shows that Preyer's results are worthless as far as the problem of color perception is concerned.

That the fourth element pointed out above is a real source of confusion is shown by the fact that children recognize many words which they cannot pronounce readily. Binet, who represents the second phase in the development of this experimental problem, realized this, and varied the conditions by naming a color and then requiring the child to pick out the correspondingo color. This gave results different not only from Preyer's, but also