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PHYSICS IN THE HIGH SCHOOL

BY

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PHYSICS IN THE HIGH SCHOOL

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In the following discussion of certain problems which confront the teacher of physics in the secondary school, the writer wishes merely to call attention to certain matters, a clearer comprehension of which he now sees would have been helpful to him at the beginning of his teaching experience. It is obvious that in treating the subject to this end, many things which are already established must be mentioned, and many points discussed which have been thoroughly debated for years past. It must be remembered, however, that these old questions are recurringly new to a large body of teachers each year. Perhaps it is not presumptuous to hope, therefore, that an attempt to state and answer them may be of value to someone.

To the teacher of physics in the secondary school three matters are of especial and vital interest. They are: (1) the position of physics in the course of study; (2) the selection of the subject-matter to be presented; and (3) the method of instruction to be pursued.

I. The Position of Physics in the Course of Study

Practically all our high schools are today giving a one-year course in physics. In which one of the four years of the high school should this subject be presented? Under present conditions the most sensible and practical answer to this question is obtained from a general consideration of all the science work offered and the determination of the best sequence for these subjects. At the same time some attention must be given to the position of other subjects which have a value in the development of any science.

There has come to exist a general belief that the physical should follow the biological sciences in the high school. This view is held with practical unanimity by the teachers of both of these groups of the sciences, so that by general consent physics and chemistry have come to occupy the third and fourth years of the high school courses.

The question, which one of these subjects should precede the other, has also with the majority of teachers passed the stage of discussion, and the view is commonly held that physics should come in the third and chemistry in the fourth or last year. Some, however, think it desirable to reverse this order and make physics the last science to be encountered.

From the standpoint of the physics teacher, there is certainly much to be said in defense of the latter arrangement, which enables the student to attack the really difficult subject of physics when amply prepared in mathematics and at the time of his greatest mental development. In the epoch-making report of the Committee of Ten, published in 1894, the sub-committee on physical sciences recommended that chemistry precede physics. It is explicitly stated that the committee realized that the order recommended is "plainly not the logical one," but that the recommendation was made in order that students "should have as much mathematical knowledge as possible to enable them to deal satisfactorily with physics." It should be remembered, however, that in the ten years which have elapsed since this report was made, the beginning work in algebra has been shifted from the first year in the high school to the eighth grade, and much of geometry which then was given in the third year is now taught in the second year of the high school course. The specific reason given by the committee for placing physics in the last year has, therefore, much less force today than at the time the recommendation was made.

Moreover, even at that time the committee was not unanimously in favor of the order it recommended, and Prof. Waggoner, in a minority report, opposed his colleagues on what seem excellent psychological grounds. His minority report says:

> "Admitting, of course, the deep mystery which underlies and limits all kinds of knowledge alike, it is still true that a great part of the body of knowledge called physics relates to phenomena wherein the bodies concerned are distinctly perceptible, and their behavior is also directly perceptible to the senses at every stage of the phenomenon.
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> "The behavior of the parts of matter concerned in chemical changes is inferred, not observed. And the conceptions of it are less simple than those of even molecular physics.
>
> "The rational study of chemical phenomena is therefore of a higher order of difficulty than those of physics. To make the study of chemical theory as little artificial and as much rational as possible and to secure intelligent conceptions of its many and close relations to physical laws, a previous training in the conceptions and measurements of such fundamental quantities as mass, density, specific gravity, heat, specific heat, and others would seem practically indispensable. In fact, it seems not unreasonable to suggest that the whole subject of elementary physics forms a desirable basis for the study of the elements of chemistry. On the other hand, a knowledge of elementary chemistry is to but a small extent helpful in getting the knowledge of physics expected from a high school course."

Since all direct observations in chemistry are concerned with physical changes, it is apparent that much of physics must precede chemistry, and if the latter subject precedes the former in the course of study, the teacher must sacrifice much time in teaching the principles of physics in his chemistry classes. Economy of time, then, would seem to require giving the regular course in physics before that in chemistry.* It seems best, on the whole, where one-year courses are offered in both physics and chemistry, that physics should come in the third and chemistry in the fourth year. In schools not offering chemistry, physics may well be placed in the last year, unless an optional advanced course in physics is planned. In such case it is obvious that the elementary course must come in the third year.

It may be well in conclusion to reassert that the drift of opinion is toward the precedence of physics. Numerous state associations of physics and other science teachers have passed resolutions recommending the placing or retention of physics in the third year. At the last meeting of the physics section of the Central Association of Science and Mathematics Teachers, held in Chicago last November, such a resolution was offered and carried by a unaminous vote.†

II. The Selection of Subject-Matter

Much complaint has been made of the difficulty of physics. The conviction is growing, however, in the minds of good teachers of the subject that much of this alleged difficulty is due to the common attempt to cover too much ground in the time available, rather than to anything inherent in the subject. A year and a half at least is necessary for a thorough course in elementary physics if no part of the subject is slighted. Since in most schools only one year is given to this subject, the teacher encounters a serious problem

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*This subject is fully and ably discussed by Alexander Smith in the "Teaching of Chemistry and Physics," by Smith & Hall; Longmans, Green & Co., 1902. This book is invaluable to teachers of chemistry and physics and has already had a marked and beneficent effect upon the teaching of these subjects in secondary schools.

†See School Science, January, 1905, for the report of the meeting of this section.

when he comes to plan his year's work. He must decide whether to push impartially through the subjects of mechanics, heat, sound, light, and electricity, giving to all approximately equal emphasis and time, or to select certain subjects for more intensive and extensive study than others. If the latter plan is chosen, as it should be, the order in which these subjects shall be taken must be decided, and also what proportion of the whole time available should be given to each subject.

By common consent the fundamental subject of mechanics will be given precedence over sound, light, heat, and electricity, both in the order of presentation and in the matter of time. A full half-year's work is needed for a proper development of mechanics, if an adequate amount of laboratory work is given. Unfortunately it is not practicable to give so much time to one subject, but at least forty per cent. or sixteen of the forty weeks of the school year should be devoted to mechanics. It should be borne in mind that time well-spent here saves time and confusion during the rest of the year.

But when the choice of other subjects to receive especial attention is discussed, we find a great diversity of opinion among teachers. Some hold that sound and light should immediately follow mechanics; others, that they should not come until after the study of heat and electricity. The question really does not seem a vital one. Any one of these subjects offers an admirable field for the application of the principles of the fundamental subject of mechanics. Most teachers will agree, however, that no great amount of time should be devoted to sound and light in a one-year physics course. A series of talks by the instructor, illustrated with numerous lecture-table experiments, will make these subjects intelligible and interesting and yet allow the anxious teacher, hard pressed for time, to cover this part of the year's work in a few weeks. Fifteen per cent. of the year may be given to sound and light and forty-five per cent. will still remain for heat and electricity.

The apportioning of this time to the two subjects will depend largely upon the point of view of the teacher. If the utilitarian value of the subject-matter appeals strongly to him, he will probably give nearly the whole of the available time to work in electricity; for "this is the age of electricity," and the information gained is very "practical." If, on the other hand, the development of scientific method and mental power is his greatest consideration, he may well give to the study of heat a large fraction of the time at his disposal.

In deciding how much time to give to heat, he should be influenced to some extent by the position of chemistry in the school course. If it follows physics, the careful study of heat will be of especial value as a basis for chemistry. The student in chemistry will need clear conceptions of temperature, the effect of heat upon gas volumes, specific heat, heat of fusion and vaporization, and other energy changes involving heat. If these matters have been neglected or hurried over in physics, much valuable time will of necessity be taken for them from that allotted to chemistry. It may be said truthfully that electricity and light are more or less closely related to chemistry and are needed in the study of that subject. But they come into contact with general chemistry less frequently and in a less fundamental way than does heat.

Apart from its value as a tool in further scientific work, a number of strong reasons exist for giving emphasis to heat in a one-year course.

1. The modern conception of the conservation and transformation of energy was originally inspired by some simple experiments in heat. To this day there is no other road to correct notions of energy changes which is so direct and so

easily followed as that blazed out by the pioneers, Rumford and Davy, Mayer and Joule.

2. The subject of heat furnishes a number of definite concrete problems suitable for individual laboratory work. No problems ordinarily given in elementary laboratory courses require more consistent carefulness than those in calorimetry. Numerous sources of error must be guarded against and vigorous thinking must be done during these operations. Such problems successfully accomplished bring to the student a grasp of the principles involved and a sense of power that cannot fail to stimulate and inspire him.

3. The subject of heat is rich in problems involving deductive reasoning of no mean order, and thus furnishes unsurpassed material for the development of clear and logical thinking.

Should especial prominence be given to heat for the reasons mentioned or others, twenty per cent. of the year's work will be required for it. This will leave one-fourth of the year for work in magnetism and electricity. While a half year at least should be given to this broad subject if the time were available, nevertheless, ten weeks' work, if judiciously chosen, will suffice to give the student clear notions of many of its elements, and will make further reading and study intelligible to him. Opinions vary among teachers as to whether this time should be given principally to theoretical electricity or to the study of practical electrical devices and machines, and as to the character and quantity of the accompanying laboratory work.

The following order of subjects with the time to be given to each, in a year of forty weeks, seems at least as good as any other. (1) Mechanics of solids and fluids, sixteen weeks; (2) Heat, eight weeks; (3) Sound, three weeks; (4) Light, three weeks; (5) Magnetism and Electricity, ten weeks.

III. The Method of Instruction

The introduction of individual laboratory work in physics came some years after that in chemistry. In the past, the experimental work upon which the science of physics is based, in so far as it was repeated, was performed by the instructor before his classes. Such experiments furnished the basis for lectures, and this work was supplemented with study of the text-book. The past twenty years, however, has seen the general introduction of laboratory work of various kinds, and there is no question in the minds of competent judges as to the genuine value of much of the individual experimentation which the new method involves.

The need of such work became evident as the material selected for the teaching of physics became increasingly quantitative in character. So long as mere demonstration of simple and striking phenomena was attempted there was little difference from the pedagogical standpoint, whether the teacher or the student arranged the details and conditions of the experiments. On the other hand, it was possible greatly to economize time and apparatus by using the demonstration method. As the demand for individual laboratory work grew louder and stronger, however, much of this demonstration was transferred to the laboratory. About this time manuals of experiments sprung up in profusion, insisting generally on a more or less strictly "inductive" method of treatment of the subject. Many absurdities appeared; among others, the giving of detailed directions for the performance of simple things of every-day experience, such as "rubbing a match on a piece of sand-paper and noticing the effect." The pitiable weakness of much of the suggested work was apparent from the start, and series of experiments were gradually devised and adopted which met the true ends of laboratory work. In the meantime most of the old qualitative experiments drifted back into the demonstration work, where they very largely belong.

The problems now used in the laboratory are mainly quantitative in character. In addition to giving the benefits which came from the individual performance of the somewhat simpler qualitative experiments, they are believed to be of great value in teaching the necessity for carefulness and accuracy. They also give some notion of the tremendous amount of painstaking labor expended in gathering data upon which great inductions are based, and by means of which these inductions are verified and come to have the dignity and authority of our so-called "physical laws." Thus laboratory work has become rationalized, and by giving a training in correct scientific method meets a need which the older methods of teaching did not recognize.

It must be insisted, however, that the old and new methods are supplementary to each other and that neither is sufficient by itself. The attitude of contempt for the older demonstration and text-book methods, which is often encountered even now, is therefore absurd and to be deplored. It is probable that a fair knowledge of the general subject-matter of physics is more readily gained by the older methods alone than by that of individual experimentation alone. But the happiest results come from a combination of these various forms of attack, and anything else is now generally condemned.

In the discussion of the method of attack of quantitative physical problems, much confusion has arisen from a failure to distinguish clearly between two quite distinct classes of these problems. An examination of the experiments suggested by various authoritative committees and offered in our best laboratory manuals reveals one class of exercises whose object is the determination of certain physical constants or the measurement of physical quantities, and another class intended to establish physical laws. The question of the attitude of the student, as to whether he should "discover" or "verify" the truth which a given problem is to reveal, and as to some "fore-knowledge of the principle involved" is plainly not pertinent to the former class. The measurement of extension and mass with the determination of densities, the measurement of temperatures and heat quantities, of velocity of sound in various substances, and of electrical and magnetic pressures and resistances are examples of this kind of experimentation. In every such case, previous knowledge of the elements involved in the problem and of their relationship is necessary, for without such knowledge the problem is vague and meaningless to the student.

In this connection it may be said that a study of the construction and use of an instrument of precision, such as the micrometer screw or verniered caliper, is not, properly speaking, a problem in physics. The measurement of extension by means of such an instrument is, however, a physical problem. While the mastering of the principle of the instrument may be more difficult than the measuring process which follows, the former process should be treated as distinct from the latter, and recorded as a preliminary exercise.

Concerning the attitude of the student to problems which help to establish physical laws, much has been said. The general belief seems to be that the student should not be forced into the attitude of merely verifying laws which he has learned previously from some authoritative source, but that he should attack such problems with only such knowledge of the principles involved and such directions for carrying out the work as are necessary for its intelligent performance without an unreasonable expenditure of time and energy. To illustrate this point the problem devised to show the "law of lengths" of the pendulum may be considered. It is absurd to give the student an adjustable pendulum and ask him "to discover the laws of the pendulum." On the other hand, it is not wise to ask him to prove that the period of vibration of a pendulum varies as the square root of its length. In the first case the whole problem would be vague and "up in the air;" in the second case the work would be definite and tangible enough, but there would be constant temptation to make the observed results tally with those obtained deductively by a use of the law. The rational method of procedure seems to be to ask the student to find the period of vibration of his pendulum for each of a number of different lengths and determine whether any relation exists between these lengths and periods. Having discovered and stated this relation, the student could, with profit, repeat the experiment, using a new set of lengths, first computing the periods from his proposed law and then finding these periods experimentally, each result serving to verify his law. Thus he would employ both inductive and deductive reasoning and follow the necessary steps that occur in the final establishment of any physical law.

One other method of attacking this problem is possible. The instructor can perform the first part of the work just described before his classes. Taking lengths that are perfect squares he can determine with the class the period of vibration for each length. The class will soon detect the general relation between these quantities. The class may then be told to test this induction rigidly, using a large number of lengths, and to determine whether the law is "exactly" or only approximately true. This subterfuge to avoid working to theoretical results is often absolutely necessary, as students quite frequently know enough of the law that is sought to enable them to forecast results. No good reason exists, however, for a feeling of abhorrence, such as appears in some quarters, for the term "verification," or for avoiding exercises involving the verification of laws, as every natural law has been finally established only after being tried and verified by experiments in almost endless detail.

There are, indeed, some problems commonly given in laboratory classes in which it seems best candidly to abandon the attitude of research and seek only to verify the laws as established by others. For example, with the time available and the form of apparatus in most common use today—some form of Atwood's machine—it is practically impossible to get results from which the inductions known as the laws of falling bodies can be fairly derived. It is possible, however, with such apparatus, to show quickly that these laws are at least approximately true, and this exercise of verification seems valuable although it does fail to "exercise the scientific imagination." It is true that this problem can be performed by the teacher in the lecture-room; and perhaps nothing is lost by such a transfer.

But in so far as possible, without too great sacrifice of time, laboratory problems should involve simple inductive reasoning, and students should be seeking to discover the relations existing between their data, rather than to verify what others have said these relations to be. And where the laboratory work does follow instead of preceding the learning of the principle or law involved, it must be insisted upon that the experimental demonstration by the instructor in introducing the principle be complete enough to serve as a basis for belief in it.

It is desirable, if not indispensable, that laboratory work be given in double periods. Many problems are too long and complex to be performed in a single period, and it is fatal to good results to carry a problem involving careful measurements and connected reasoning over from one day to another. Moreover, experience shows that there is considerable economy of time in taking two consecutive and unbroken periods of work.

It is generally recommended that two days each week be given to laboratory work and three to the class room. With two double periods in the laboratory each week it is possible to give a sufficient amount of work in a very thorough manner. It is true that many excellent schools have only one double period in the laboratory each week and get good results, for good results from laboratory work depend more on the quality than the quantity of the work performed by the student. For a good training in scientific method, however, it is necessary to cover considerable ground; and the student should not be too greatly hurried in his work. Where it is at all possible, therefore, two double periods should be given to laboratory work each week.

There is some difference of opinion as to whether all the students in a laboratory section should be working on the same problem at the same time. Where a school is unable to provide apparatus in duplicate in sufficient quantities, this method is impossible. It is desirable to have each student thrown upon his own resources, and it is possible, as is sometimes claimed, that there is danger of neighboring groups getting some help from one another when working on the same problem simultaneously. But where the sections are not too large and the right spirit exists in the class this danger is small, and it is more than offset by the saving of time which results from the giving of directions and instructions to the section as a whole. But the best reason for marching forward abreast in the laboratory is that the problems given generally belong in groups and that the problems in each group have a natural order in which they should be attacked, if a logical and complete development of the general subject treated in that group is obtained. When students change around from one set of apparatus to another, it is impossible for all of them to get these problems in the right order.

Many problems are best performed by two students working together. Indeed there is no serious objection to having all laboratory work done by groups of two, provided the supervision is close enough to prevent loafing on the part of either member of such a group and it is insisted upon that each student makes all his computations for himself.

The heaviest burden which must be carried by the teacher of physics is the examination of laboratory note books. It is indispensable to good laboratory work that clear, concise notes and records be made of every problem that is solved. It must be insisted upon that these records be faultless in English, neat in appearance, and logical in argument. To achieve this end the teacher must spend many hours not provided in the programme in reading and criticising notes and in personal consultation with students. Fortunately, if this work is conscientiously performed at the beginning of the year, it grows lighter as the weeks pass and students become more careful and efficient in making their records.

The class room work in physics should include demonstrations and explanations of principles and phenomena by the instructor, as already indicated, and recitations based upon such "lectures," the text-book, and laboratory work. Accurate definitions must be insisted upon, and those given in text-books should be carefully examined and criticised. One of our best high school text-books in physics defines specific heat as the thermal capacity of a unit of mass of a substance, making the specific heat of a substance a concrete number. Many cases of such loose or careless statements may be found. It is in the recitation that the knowledge gained from the various sources mentioned must be classified and correlated and unified, that seeming discrepancies must disappear, and the mind of the student, more or less befogged with details, must be clarified.

After principles have been mastered, numerous problems to be solved deductively by their application should be given. These problems should be somewhat varied in form, giving some opportunity for originality and ingenuity in the student, but not so complicated and involved as to confuse him.

Such work affords the teacher a means of determining the efficiency of the student and the thoroughness of his work if the problems are given and worked out in the class. In the study of any principle in physics, at least in an elementary course, the development of the formula should be the final step. The value of the formula as an abbreviated, concise statement of the relation of the quantities involved is unquestioned. But dangers attend its introduction before the significance of the relations it expresses have been grasped by the student. It is unfortunate if the student is allowed to solve problems by merely substituting values in a formula and then reducing his expression to the simplest form. This process, if repeated a hundred times, involves no use of the reasoning powers and gives no stronger grasp of the principles involved; the partial results have no significance to the student, who wonders vaguely what the denomination of each result may be, and is much relieved to find that the expression, when solved, brings him the right answer. If, however, as the result of real mental labor, the significance of the quantities used and of their relations to one another is first comprehended, the formulation of an abbreviated expression of those relations is a simple matter, and the expression itself becomes pregnant with meaning.

It would seem that a course in physics such as has been suggested and discussed, while not exhaustive, is rational, and that the work proposed can be successfully digested and assimilated by the average serious student. It should serve as an excellent introduction to the great science of physics and prepare the student for further intelligent acquisition of the principles of that science, whether it be gained in the college or university, or in connection with the practical work of the factory or shop.

The School Calendar

Winter Term

Twelve Weeks—1906

January 2, Tuesday—Entrance examinations and classification. Class-work assigned at 9:00 A. M.

March 23, Friday—Winter Term ends.

Spring Term

Eleven Weeks—1906

April 3, Tuesday—Class-work assigned at 9:00 A. M.

June 15, Friday—Spring Term ends.

Summer Term

Six Weeks—1906

June 18, Monday—Classification. Class-work assigned at 2:00 P. M.

July 27, Friday—Summer Term ends.