SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, MARCH 25, 1904.

CONTENTS:

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

*RECENT ADVANCES IN THE TEACHING OF PHYSICS.**

THIS is an hour when anything but congratulation is impossible, not alone for this queenly city seated at the foot of the majestic Front Range, but for the entire commonwealth. The foresight as well as the generosity of the donor in aiding an institution which had already richly deserved such aid, the skill and taste of the architect, the adaptation of the laboratories to the needs of modern science, these all command our admiration. The manner in which a quarter of a century has transformed a mountain foothill into an educational center challenges the respect of every one.

From a sister university on the eastern slope of the Mississippi I bring to your president and to his staff greetings and all good wishes. I bring them no reminder of the responsibility which always accompanies opportunity such as is represented by this building, for there is probably, in all the land, no group of men more keenly aware of the fact that endowment and duty are close friends. No one knows better than the men who have this work in hand that not to advance is to recede.

Times are not so simple as they were even twenty-five years ago, and we are finding ourselves daily more and more in the position of the red queen in the Alice books where 'it takes all the running you can do to keep in the same place.'

* Paper read before the Science Conference held at the dedication of Palmer Hall, Colorado College, February 22, 1904.

But change does not always spell advance, and not every novelty is an improvement. It may be well, therefore, before we consider progress along any particular line, to recall what constitutes progress in general. The profound studies of Mr. Spencer led him to a very happy definition of progress, namely, 'an increase in the adaptation of man to his environment.' This description would be eminently satisfactory were it not that in another place Mr. Spencer characterizes progress as a 'benevolent necessity,' thus robbing it of every element of human initiative and of conscious endeavor. For this reason many of Mr. Spencer's most ardent admirers—among whom I count myself—while admitting the happiness of his phrasing, will nevertheless prefer the view of Professor Karl Pearson who regards progress as the result of a distinct program, the outcome of plans laid with care and according to the soundest biological principles.

Having in mind this point of view from which progress is a consequence of deliberate forethought, I invite your attention to some of the advances recently made in the teaching of physics to English-speaking students.

Let us use the word 'recently' as referring to the last thirty years and consider *first* some advances in the *teaching* of physics which have resulted from advances in the *science* of physics.

I. IMPROVEMENTS IN MATERIAL.

The purchase by Princeton College of one of the Gramme machines exhibited at the Centennial Exposition in 1876 may, perhaps, be fairly considered as marking the introduction of the modern dynamo into the American physical laboratory. Only five years after this date I found myself a student in this laboratory which had purchased the Gramme machine—an excellently equipped and ably directed laboratory, then as now. A single illustration must suffice to show how matters have changed. On turning the pages of my first-year note-book, I find that one of the experiments assigned me was the measurement of the current furnished by this Gramme machine under certain definite conditions. This was done in two ways: (1) the earth's horizontal magnetic component was determined at a certain point; at this particular point was placed a tangent galvanometer whose constant I had computed; the deflection which the current produced in this instrument completed the data necessary to determine the current in webers. Amperes were yet novelties, not to say mysteries. The graded galvanometer and the ampere-balance of Kelvin were not yet on the market. The beautiful instruments of Weston were unknown. (2) The second method employed was to assume the electro-chemical equivalent of copper and proceed to measure the average current by weighing the amount of metal which it had deposited.

Each of these processes proved highly instructive, and they are cited merely to show the amount of time and detail which the student was driven to consume when for any reason he wished to know the value of the current he was using; for the 'working constant' of the galvanometer carried about the laboratory was by no means so constant as its name might imply.

Another forward step was marked by the introduction of the low-resistance, portable D'Arsonval galvanometer which permits the elementary student, at his own laboratory table, to study practically all the fundamental properties of electric currents; this with an outfit which is simplicity itself, and at a cost which brings the entire equipment easily within the range of the most modest high school. The point here, let me insist, is not the increased convenience and comfort of the student, but rather the power which it confers upon him of devoting his energies to those phases of the subject which are under investigation, those topics which for the time being have become really fundamental.

Among other improvements in this direction there came after the dynamo, in rapid succession, like a host of beneficent corollaries, the electric motor, the arc lamp, the incandescent lamp, the storage cell, the powerful magnetic field, the transformer, the electric furnace, the electrolytic interrupter, the oscillograph, each opening up hitherto-undreamed-of possibilities in the way of demonstration for elementary students and of investigation for advanced students.

I shall not detain you further to illustrate a point which is, perhaps, more familiar to many of you than to me. Let me only mention, as opening up new possibilities for the student, the platinum thermometer, the high temperature mercury thermometer, the Rowland grating, the Wallace-Thorpe replica, the interferometer, Jena optical glass, quartz ware, the cheap production of aluminium, platinum mirrors, isochromatic dry plates, and so on almost without end.

But if these devices have aided undergraduate instruction, what shall we say of the student advanced to the point where he is ready to take up a piece of research? For him they have rendered problems soluble, by the hundred, which previously lay in the region denoted by Mr. Gladstone as 'outside of practical politics.'

But best of all the discoveries which the last generation has made concerning the merely mechanical side of teaching physics is the fact that practically all the fundamental—and many even of the more recondite—principles may be demonstrated with apparatus of the utmost simplicity. One condition only stands between the simple material outfit and success, namely, an instructor who is so thoroughly master of the subject and of the situation that he will see that the student gets from his outfit all the information and all the training intended. The older any man becomes, the more he admires simplicity, and especially the simplicity of nature (our ever-present model), of whom Fresnel remarked: 'She never balks at the difficulties of analysis, but always hesitates to employ methods which are complicated.'

The nations of light and leading have made a capital discovery just at the close of the nineteenth century; they have just awakened to the fact that they can 'go in and possess the land' more easily when they have at home an intelligent rank and file, an educated parliament, a scientific government, a free and happy electorate. So also in the teaching of physics a capital discovery has, I think, been recently made in the fact that armament is not everything. No number of expensive and elaborate demonstrations, no striking exhibitions of machinery can ever replace the simple experiment, the lucid and orderly presentation of phenomena, the distinct effort made by the student to grasp the essential principle, or the conscious effort at accurate observation and judgment called forth by an ambition to get from a simple device the best attainable result and the simplest possible point of view. There is danger in any instrument when it becomes so perfect and so accurate that the young man who is working with it is tempted to degenerate into an 'organ-grinder.' The accuracy in a laboratory should not all be confined to its machinery; some should be left for the judgment.

It was, therefore, no small step in advance when the instructor came to see clearly that all he can ask of a piece of apparatus is that it shall be capable of yielding the results which he demands of the student, and conversely that he can not hope to train the student in habits of precise thinking without demanding of him nearly the best which the apparatus can give.

With such an undoubted improvement as the advent of the student laboratory, it was inevitable that some enthusiastic admirers should push it too far. In the earlier days mistakes were undoubtedly made in thinking that if once a laboratory could be established and once the student gotten into it, his scientific salvation was immediately insured, if not, indeed, already accomplished.

But now the pendulum has swung back; the days of 'organ grinding' in the laboratory have largely ceased, and I reckon it not least among recent advances in the teaching of physics that the modern instructor has learned that an undergraduate can not be simply turned loose in a laboratory. Much forethought, indeed, is demanded in order that during laboratory hours the instructor may keep quiet and the student keep busy—and keep busy not on any haphazard problem, but keep busy on a *series* of problems so graded that, by solving them in order up to any point, he has developed the power of intelligently undertaking the next. Carefully planned courses of this kind are to be found in many laboratories, every one of them a powerful aid toward putting a young man into a position where he always 'knows what to do next,' which, as President Jordan has admirably remarked, constitutes a liberal education.

II. IMPROVEMENTS IN METHODS.

1. *Introduction of the Energy Treatment.*—Leaving now to one side all questions of material outfit, let us consider some improvements of a still more fundamental nature. I refer to those which have been made in the *method* of teaching. Here it is scarcely possible to believe the changes which a single generation has wrought.

Progress is something to which the Anglo-Saxon takes so kindly that he is apt to forget just what manner of man he was some thirty years ago.

Perhaps I can most briefly illustrate by reading a few lines from Tait's review of Balfour Stewart's 'Lessons in Elementary Physics.' Stewart, as many of you know, was one of the first men to treat physics as a single subject—to treat heat, light, sound and mechanics from the energy point of view—the view which, twenty years before, had, as we now believe, been thoroughly established by Joule, Helmholtz and Kelvin. This review was published in *Nature* December 29, 1870. Here is what Tait says: "This is a bold experiment and decidedly deserves to be a successful one. * * * It is scarcely possible to form a judgment as to the probable success of the present work. It is so utterly unlike anything to which we have been accustomed that we can only say that we never saw such a work in English at least. * * * The reign of inartificiality and simplicity must soon be inaugurated and this work will greatly tend to hasten its advent."

These are the remarks of an experienced teacher and able investigator concerning a text-book which to-day we all recognize as eminently natural and simple. So familiar are we with the energy treatment that we are apt to forget how recently these 'water-tight compartments' existed in physics as they yet do, according to the gospel of John Perry, in the department of mathematics.

But, after all, the energy view-point is merely the outcome of the Lagrangian dynamics and Helmholtz's little tract on the 'Conservation of Energy.' Trowbridge's 'New Physics,' appearing some twenty years ago, did excellent service in furthering this standpoint.

The introduction of the energy idea did

more than merely unify the subject; it placed in the hands of the teacher the possibility of making a really simple and logically-arranged presentation of his subject, a presentation which had been in vogue among the classicists for many years, and possibly the only presentation which could make the experimental study of physics a genuine training for power.

In the domain of higher physics, the work of J. J. Thomson, in 1887, on the 'Application of Dynamics to Physics and Chemistry' may fairly be considered as marking an epoch in the energy treatment and in the unification of physical science. Equally impressive are the three volumes containing the proceedings of the International Congress of Physicists at Paris in 1900. One turns the entire two thousand pages of this report without feeling the slightest discontinuity either of subject or of method, from the dynamical papers at the beginning to the electrical papers at the end.

2. *Introduction of the Student Laboratory.*—But of all reforms in method the most revolutionary was the introduction of the student laboratory, which came in at about the same time with the energy treatment.

To be sure, especially favored students have always been admitted to the private workshop of the master, but it is only within the last generation that *students in general* have obtained similar privileges.

In a letter to *Nature,* dated January, 1871, Professor E. C. Pickering describes the new physical laboratory of the Massachusetts Institute of Technology, where he was then an instructor, and proceeds to add: 'There are now in America at least four similar laboratories either in operation or in preparation and the chances are that in a few years this number will be greatly increased.'

How amply this prediction has been fulfilled may be realized when we consider that America has to-day more nearly four hundred fairly equipped physical laboratories.

In this connection it is well for those of us who are inclined to be optimistic to turn now and then to Professor Pickering's 'Physical Manipulation,' the only English laboratory manual available in my undergraduate days, and see how thoroughly modern his treatment remains. Confessedly the problems are not graded exactly as we should do it to-day, yet in spirit, in method, in economy of teaching energy and in sound learning these two volumes may well give us pause, and make even the most sanguine ask whether evolution is not a provokingly tedious process.

Let no one infer, however, that improvements in method are entirely illusory, for the present-day instructor in physics certainly has in mind more clearly than any before him just what the goal is and just what the method of approach. He knows full well that no student can work out his own salvation while seated in a comfortable auditorium chair, observing a speaker manipulate certain curious apparatus with certain curious effects.

3. *Lessons Learned from the Engineer.*—The modern instructor has learned also to take advice from the engineer—this too without bowing to the immediately useful and without substituting mere knowledge for intellectual power. He realizes that centrifugal forces, centrifugal couples and the energy of rotation may quite as well be studied from bicycles and the driving wheels of a locomotive as from an ellipsoid strung on a knitting needle. Electrical *science* and electrical *engineering* were at one time much farther apart than they are to-day; the engineer and the physicist are closer friends than they were twenty-five years ago.

Perhaps neither all the phariseeism nor all the charity has been confined to one side. America's two leading physicists were each educated in engineering schools, the one at Troy, the other at Annapolis.

Helmholtz says: 'Action alone gives a man a life worth living, and, therefore, he must aim either at the practical application of his knowledge or at the extension of the limits of science itself.'

Here we have, at once, the justification of the engineer and of the investigator—a view which has, I believe, been accepted by many instructors greatly to the advantage of their method.

Briefly, then, the marked improvements in method have been: (1) The introduction of the energy viewpoint, thus securing unity and simplicity of treatment; (2) the introduction of the student laboratory, and (3) the introduction of more concreteness; this last being a beneficent reflex influence from the engineering side.

III. MEN.

Passing now to the men who have been and are teaching physics in America, the word 'progress' raises a difficult and almost insoluble problem. At any rate, I shall asume that we *all* agree in putting the main emphasis upon the spirit and ability of the instructor. The fundamental difference between laboratories is, indeed, after all a difference between men. What they call at Berlin 'die Glanz-periode der exakten Wissenschaften'—the years immediately following the Franco-Prussian war—was essentially the product of four or five men, Virchow, du Bois-Reymond, Hofmann, Kirchhoff and Helmholtz.

I may as well at the outset confess myself a hero worshiper and say that my respect for the university instructors of the preceding generation—some of whom I met during nine years at Princeton, Berlin and Baltimore—is so nearly unbounded that I dare not think the talent engaged in teaching physics to-day is, in any important respect, superior to that of the recent past.

When, however, we turn to the average college instructor or to the average high school instructor it becomes patent that the entire situation has changed. Recent developments in physical science and the duplication of instructors have driven men to specialize. As Professor Runge once said to a meeting of astrophysicists at the Yerkes Observatory: 'Nature is becoming more and more disorderly every day!' The young teacher without special training navigates uneasily a stream beset with small craft hailing him for information about the trolley line, about the automatic telephone, about the transformer, about liquid air, about radium.

The modern instructor in physics—and I dare say the same change has occurred in other sciences—is first of all a man who has shown his ability to widen the borders of human knowledge. Power to investigate is becoming more and more a first criterion for his ability to teach. (Shortly it will be a necessary criterion.) In any event he is a man who has an intelligent interest in and an active sympathy with physical research.

In the *second* place, he is a man with a keen Greek perception of relative values, a cultivated sense of proportion, always subordinating mere facts to methods, always placing the power of clear thought above any amount of mere knowledge.

Again he is frank and fearless in the confession of ignorance, but only after he has made every effort to bring this ignorance to a minimum.

The modern instructor does not trifle with atoms, molecules and other hypothetical creatures which he has not seen and does not know about. He takes pains to point out the line of demarcation between the known and the unknown, believing that few things are more instructive for the learner than the limitations of human knowledge concerning even household matters. As a boy I was taught to respect Newton as the man who had explained gravitation; to-day the lad is taught that Newton distinctly refused even to make a guess at its explanation. With equal piety, I was taught that there are six kinds of electricity, all mysterious and imperfectly understood; but it was never hinted in those days that we are no less ignorant of what carbon or what copper is than we are as to the nature of electricity.

Illustrating this point, I have long maintained that one of the most scholarly men I ever met was a motorman on a trolley line running out of Denver some thirteen years ago. I was at the time visiting the then new University of Denver. And seeing what appeared to me an *extra* wire suspended above the trolley, I stepped to the forward end of the car and inquired as to its purpose. I shall never forget the reply of the man as he turned his frank countenance toward me and said: 'My dear sir, all I know about this is just enough to turn on the juice and let her buzz!'

Still again the instructor in modern physics is a man who believes in the careful scrutiny of all the data which enter into an argument, and in the avoidance of reasoning from insufficient data—the 'bastard *a priori* method' as described by Spencer. The modern laboratory instructor is a man whose ambition for his student is that in the presence of physical phenomena he shall maintain a certain mental attitude of independence, a habit of observation, inquiry, experiment and judgment, that he shall acquire what is known in military circles as skill in scouting.

The difficulty of these tasks was not first pointed out either by Longfellow or by Goethe; for Hippocrates* had already remarked that: 'Art is long, time is fleeting, opportunity brief, experiment difficult, judgment uncertain.'

* 'Aphorisms,' T. I.

In conclusion we find that improvements in the teaching of physics have come from three directions, improvements in *material*, improvements in *method* and improvements in *men*. But unfortunately the greatest changes appear to have occurred in the least important direction, namely, that of material; while the least change is visible in the most important direction, namely, in the teaching staff.

So much for the past, but what of the future? The physical and biological sciences have changed the entire face of civilization; they have ameliorated human suffering, they have prevented disease, they have set us free from a thousand and one painful superstitions. Does any one imagine their career at an end? The fact appears to be that in the immediate future these sciences are to become the determining factor in deciding the superiority of nations. Numbers are a *potent* factor, but they are not everything. What a host of phenomena in the South African War are explained by the incident of the Boer father who handed his boy a single cartridge and instructed him to go out and bring in an antelope!

Two duties would, therefore, appear to thrust themselves upon every instructor, every investigator and every patron of science. The first is to see that science is taught in a still more effective manner. The test of effectiveness we must find in the students' ability to *do* something; he must either help us to use the energies of nature to make life easier or he must join the pioneer corps and show us new properties of matter and energy whose usefulness no one to-day will question.

And secondly we who have faith in the scientific method must exhibit the courage of our convictions in seeing that science becomes the handmaid, or better still the adviser, of the state.

More than a quarter of a century ago it became evident that stone fortifications are worse than useless in the presence of modern armaments; but as a people we have yet to learn that the stone building which is about to be dedicated is one of the bulwarks of the nation. The executive branch of our government has learned it partially; the legislative branch not at all. I look forward with hope—and even confidence—to the day when science will be in in the saddle, not for science's sake so much as for America's sake.

And it is precisely in Palmer Hall that young men and young women are going to learn that accuracy of speech and thought which is at once the first step in morality and the best preparation for action. *Here, if anywhere,* will be acquired productive scholarship.

Could we have with us the man whose life and character is celebrated to-day throughout this broad land no one would be more enthusiastic than he in applauding the purposes of this institution and in acknowledging our national indebtedness to this and to similar foundations.

Upon the teacher of science, perhaps, above all others falls the duty of insisting with Lotze that 'while the scientific method may not be the royal road to salvation it will at least keep us from straying very far from the path.'

And when on the morrow Old Glory is raised above this beautiful structure let us salute her as marking one of our national defenses.

HENRY CREW.
NORTHWESTERN UNIVERSITY.

THE SCIENCE OF SMOKE PREVENTION.

PERHAPS a better statement of the subject would be 'The Science of Perfect Combustion,' for perfect combustion is attended by no visible smoke. It is always best in a discussion of this kind to define terms before making statements. The Century Dictionary says that smoke is 'the exhalation, visible vapor, or material that escapes or is expelled from a burning substance during combustion' while the Encyclopedia Britannica states that 'Usually the name smoke is applied to this vaporous mixture discharged from a chimney only when it contains a sufficient amount of finely divided carbon to render it dark-colored and distinctly visible.' For us who live in the soft-coal belt the definition may be further narrowed down, for when we say smoke we mean the densely-laden fumes from the combustion of soft coal which deposit thick layers of soot on all exposed surfaces. The smoke from hard coal, coke and wood is so innocuous compared with that just mentioned that it may be entirely disregarded in the discussion.

The occasional production of dense black smoke is peculiar to that group of fuels known as hydrocarbons, of which the more common are the petroleums and bituminous coal. The combustion of hydrocarbons seems to be always complete at first. If one watches the slow burning of a lump of cannel in the open grate he will see a whitish or yellowish vapor expelled from the coal by the gradual heat of the fire. This is the carbon and hydrogen combined which is distilled by the heat and leaves behind the free carbon as coke. While the escape of this vapor unburned represents a distinct loss of heat, the vapor is not smoke as we understand it. It does not deposit soot and will not stain or disfigure surfaces in its path.

As the heat increases and air is supplied the vapor ignites and burns with a yellow flame showing the presence of solid particles. If the temperature remains high and the air supply continues, the combustion is complete and the colorless carbon dioxide and water vapor pass up the chim-