paratus lie in the galvanometer device and in the elimination of the effects of gravity pressure in the bridge itself, as well perhaps as in the self-induction and capacity elements.

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THE ECHELON SPECTROSCOPE.

THE invention of the Echelon spectroscope is the most important advance in optical research which has been made in many years. It has always been the ambition of the physicist to spread the spectrum with which he was working out to the greatest possible length to see if perchance the changes in color are continuous or not. Thus it happened that a single prism gave way to trains of prisms, each member of the train doing its share to wrest asunder the inconceivably minute vibrations which were the objects of study. With this same end in view prisms gave way to diffraction gratings, these latter giving purer and more diffused spectra. Great labor and skill have been expended in improving these gratings until now their perfection has been pushed to well-nigh the limit of human possibility by the masterful work of Professor H. A. Rowland.

It, therefore, becomes evident that if this resolution of the spectrum is to be carried notably further some entirely new means of attaining the end sought must be adopted.

The important discovery by Zeeman last year that the magnetic field alters the nature of the vibrations of light roused physicists generally to a new effort to render visible these changes which are very small, their details lying beyond the reach of the best of Professor Rowland's gratings.

The result of these efforts is the Echelon spectroscope, an instrument beautiful in its simplicity, yet powerful beyond anything ever seen before. To its inventor, Professor A. A. Michelson, belongs the credit of opening the door to a new and hitherto unattainable field of spectroscopic observation, a field which promises to yield much valuable information to mankind regarding the interaction between the infinitely small particles of matter and those unseen forces, electricity and magnetism.

What, then, is the principle of this new instrument? The theory of diffraction gratings tells us that their dispersive power depends on two things: First, on the distance between two consecutive openings; and, second, on the order of the spectrum. The dispersion is greater the smaller the distance between the openings and the higher the order of the spectrum. The efforts of physicists have hitherto been directed towards making the distance between the openings of a grating as small as possible as a means of spreading the spectrum out as far as possible. No attempt has, so far as I know, been made before this to produce spectra of higher order than the fourth.

This is the point of the new instrument. It is capable of giving spectra of almost any order, the limit depending on the accuracy with which the plates composing it can be prepared. In the actual trial instrument made in this laboratory the order of the spectrum given is in the neighborhood of 20,000.

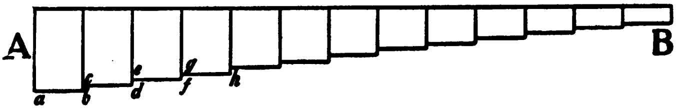
For the mathematical theory of the instrument the reader is referred to Professor Michelson's two articles on the subject.*

One can gain a practical idea of its way of working as follows: A diffraction grating consists essentially, as is well known, of a series of equidistant openings. The spectrum of the first order is formed when the light in going from its source to the

* *American Journal of Science*, March, 1898; *Astrophysical Journal*, June, 1898.

point of observation through one opening in the grating has travelled exactly one wave more than it has in passing from source to point of observation through the next adjacent opening. The spectrum of the second order is that spectrum which is formed when this difference of path amounts to exactly two waves, etc. Thus when one is observing the spectrum of the second order, say, he has matters so arranged that the light from the source is divided into numerous thin beans, each of these beams having to travel two waves farther to reach its goal than its adjacent beam on one side of it, and two waves less than its adjacent beam on the other side of it. If, then, one wishes to obtain spectra of the order 20,000, say, he must arrange the conditions of the experiment so that this difference in the optical path for various sections of the light shall be 20,000 waves instead of two. This result is accomplished in the Echelon spectroscope by building up a flight of steps of optical glass of a given thickness. The diagram (Fig. 1) shows a plan of this arrangement.

Fig. I



polishing a plate of optical glass. until its opposite surfaces are plane and parallel to each other, and then sawing this plate into pieces of the requisite size.

Suppose now a beam of parallel light to fall on this pile of plates perpendicular to the face at *A*. In passing through the first block from *a* to *b* the beam will be retarded by, say, 20,000 waves, the number depending on the thickness and the index of refraction of the glass. Part of the light then comes out into air through the narrow opening *bc* and the rest goes on through the block *cd*. The part of the incident beam which comes out through the opening *de* has also been retarded 20,000 waves over the part that came through *bc* and so on. It is thus easily seen that this instrument, when looked through along the axis from *B* to *A*, gives the required conditions for the production of a diffraction spectrum of high order; for we have the light between the source and the point of observation divided into a number of beams, each of these beams having to travel 20,000 waves farther to reach its goal than its adjacent beam on one side of it, and 20,000 waves less than its adjacent beam on the other side of it.

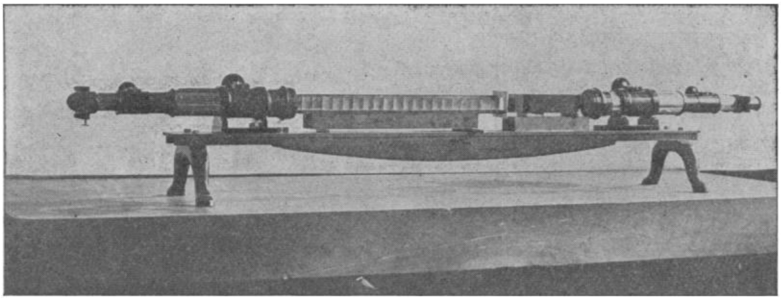


FIG. 2.

The blocks of glass composing this 'staircase' must be of exactly the same thickness, a result which is accomplished by

The cut (Fig. 2) represents a spectroscope built on this plan now in use in this laboratory. Its 'Echelon' consists of twenty plates each 18 mm. thick. Each plate projects 1 mm. beyond the next succeeding plate. It has a resolving power of about 300,000. A larger Echelon with thicker plates is being built here now which will have a still larger resolving power.

It is hard to say when the practical limit of resolving power by this instrument will be reached. But it is quite certain that 500,000 is soon to be attained. When we consider that the best gratings have a resolving power of only 100,000 we see how great an advance has already been made. Zeeman discovered that in the magnetic field the spectral lines were separated into three components, but with the Echelon spectroscope now in use here it is possible to see the doubling and tripling of these components which was discovered by Professor Michelson* by means of visibility curves.

The disadvantage of the instrument is that it will not give a continuous spectrum, but its advantages in cheapness and enormous dispersion for small portions of the spectrum make it an invaluable addition to the means at hand for analyzing vibrations of light.

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THE RELATION OF SCIENCE EDUCATION IN THE SECONDARY SCHOOLS TO THAT IN THE COLLEGE AND THE UNIVERSITY.†

IN discussing the nature and the scope of the science work in the secondary schools one principle, I think, is recognized by all as being fundamental, and this is that the training of specialists is not the function of the high school. Neither is it a part of the college in any but a limited sense, while, on the other hand, it most emphatically does come within the sphere of the university.

In laying down this principle, I am well aware that by far the greater number of high school pupils never intend to continue their education in any other institution of learning, and that their future advance must be made without the aid of professional teachers. To my mind, this makes no difference. There are certain broad foundations which, if the course is to be of lasting benefit, must be laid alike for all.

The development of the pupil's reasoning power and his faculties of observation are the important objects to be attained, and not to fill his mind with masses of facts and figures, which are as surely forgotten as they are learned. Such accumulations are defended only on the ground that they are of so-called 'practical benefit;' in reality, they constitute the most unpractical portion of any school course. Such things belong to the training of specialists, and consequently to the university, and even though the specialist can obtain a great number of necessary data from books and tables, after he has completed his studies he never can acquire the necessary fundamental training in the use of reason and logic, if he has neglected these essentials in the beginning. That which I have said applies to all branches of study—to the languages, to history or to mathematics as well as to the natural sciences; for all of them the same broad pedagogical principles are necessary.

I have used the term 'specialist' in its broadest sense in referring to high school students. It is in my opinion as grave a mistake to develop the pupil's training mainly along the scientific line as it is to confine him to humanistic studies alone. It is just as essential that the student in biology, physics or chemistry should be

* *Philosophical Magazine*, April, 1898.

† Address of the President of the Natural Science Department of the National Educational Association, July, 1898.