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Prof. H.A. Rowland

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LXI. *Preliminary Notice of the Results accomplished in the Manufacture and Theory of Gratings for Optical purposes. By* Prof. H. A. ROWLAND, *of the Johns Hopkins University, Baltimore**.

IT is not many years since physicists considered that a spectroscope constructed of a large number of prisms was the best and only instrument for viewing the spectrum where great power was required. These instruments were large and expensive, so that few physicists could possess them. Professor Young was the first to discover that some of the gratings of Mr. Rutherfurd showed more than any prism-spectroscope which had then been constructed. But all the gratings which had been made up to that time were quite small, say one inch square, whereas the power of a grating in resolving the lines of the spectrum increases with the size. Mr. Rutherfurd then attempted to make as large gratings as his machine would allow, and produced some which were nearly two inches square, though he was rarely successful above an inch and three quarters, having about thirty thousand lines. These gratings were on speculum-metal, and showed more of the spectrum than had ever before been seen, and have, in the hands of Young, Rutherfurd, Lockyer, and others, done much good work for science. Many mechanics in this country and in France and Germany have sought to equal Mr. Rutherfurd's gratings, but without success.

Under these circumstances I have taken up the subject with the resources at command in the physical laboratory of the Johns Hopkins University.

One of the problems to be solved in making a machine is to make a perfect screw; and this mechanics of all countries have sought to do for over a hundred years, and have failed. On thinking over the matter, I devised a plan whose details I

* Communicated by the Author.

shall soon publish, by which I hoped to make a practically perfect screw; and so important did the problem seem, that I immediately set Mr. Schneider, the instrument-maker of the university, at work at one. The operation seemed so successful that I immediately designed the remainder of the machine, and have now had the pleasure since Christmas of trying it. The screw is practically perfect, not by accident, but because of the new process for making it; and I have not yet been able to detect an error so great as one one-hundred-thousandth part of an inch at any part. Neither has it any appreciable periodic error. By means of this machine I have been able to make gratings with 43,000 lines to the inch, and have made a ruled surface with 160,000 lines on it, having about 29,000 lines to the inch. The capacity of the machine is to rule a surface $6\frac{1}{4} \times 4\frac{1}{4}$ inches with any required number of lines to the inch, the number only being limited by the wear of the diamond. The machine can be set to almost any number of lines to the inch; but I have not hitherto attempted more than 43,000 lines to the inch. It ruled so perfectly at this figure that I see no reason to doubt that at least two or three times that number might be ruled in one inch, though it would be useless for making gratings.

All gratings hitherto made have been ruled on flat surfaces. Such gratings require a pair of telescopes for viewing the spectrum. These telescopes interfere with many experiments, absorbing the extremities of the spectrum strongly; besides, two telescopes of sufficient size to use with six-inch gratings would be very expensive and clumsy affairs. In thinking over what would happen were the grating ruled on a surface not flat, I thought of a new method of attacking the problem; and soon found that if the lines were ruled on a spherical surface, the spectrum would be brought to a focus without any telescope. This discovery of concave gratings is important for many physical investigations, such as the photographing of the spectrum both in the ultra-violet and the ultra-red, the determination of the heating-effect of the different rays, and the determination of the relative wave-lengths of the lines of the spectrum. Furthermore it reduces the spectroscope to its simplest proportions, so that spectroscopes of the highest power may be made at a cost which can place them in the hands of all observers. With one of my new concave gratings I have been able to detect double lines in the spectrum which were never before seen.

The laws of the concave grating are very beautiful on account of their simplicity, especially in the case where it will be used most. Draw the radius of curvature of the mirror

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to the centre of the mirror, and from its central point, with a radius equal to half the radius of curvature draw, a circle; this circle thus passes through the centre of curvature of the mirror and touches the mirror at its centre. Now, if the source of light is anywhere in this circle, the image of this source and the different orders of the spectra are all brought to focus on this circle. The word focus is hardly applicable to the case, however; for if the source of light is a point, the light is not brought to a single point on the circle, but is drawn out into a straight line with its length parallel to the axis of the circle. As the object is to see lines in the spectrum only, this fact is of little consequence provided the slit which is the source of light is parallel to the axis of the circle. Indeed it adds to the beauty of the spectra, as the horizontal lines due to dust in the slit are never present, as the dust has a different focal length from the lines of the spectrum. This action of the concave grating, however, somewhat impairs the light, especially of the higher orders; but the introduction of a cylindrical lens greatly obviates this inconvenience.

The beautiful simplicity of the fact that the line of foci of the different orders of the spectra are on the circle described above, leads immediately to a mechanical contrivance by which we can move from one spectrum to the next and yet have the apparatus always in focus; for we only have to attach the slit, the eye-piece, and the grating to three arms of equal length, which are pivoted together at their other ends, and the conditions are satisfied. However we move the three arms, the spectra are always in focus. The most interesting case of this contrivance is when the bars carrying the eye-piece and grating are attached end to end, thus forming a diameter of the circle, with the eye-piece at the centre of curvature of the mirror, and the rod carrying the slit alone movable. In this case the spectrum as viewed by the eye-piece is normal; and when a micrometer is used, the value of a division of its head in wave-lengths does not depend on the position of the slit, but is simply proportional to the order of the spectrum, so that it need be determined once only. Furthermore, if the eye-piece is replaced by a photographic camera, the photographic spectrum is a normal one. The mechanical means of keeping the focus is especially important when investigating the ultra-violet and ultra-red portions of the solar spectrum.

Another important property of the concave grating is that all the superimposed spectra are in exactly the same focus. When viewing such superimposed spectra, it is a most beautiful sight to see the lines appear coloured on a nearly white ground. By micrometric measurement of such superimposed spectra, we have a most beautiful method of determining the relative wave-lengths of the different portions of the spectrum, which far exceeds in accuracy any other method yet devised. In working in the ultra-violet or ultra-red portions of the spectrum, we can also focus on the superimposed spectrum, and so get the focus for the portion experimented on.

The fact that the light has to pass through no glass in the concave grating makes it important in the examination of the extremities of the spectrum, where the glass might absorb very much.

There is one important research in which the concave grating in its present form does not seem to be of much use; and that is in the examination of the solar protuberances; an instrument can only be used for this purpose in which the dust in the slit and the lines of the spectrum are in focus at once. It might be possible to introduce a cylindrical lens in such a way as to obviate this difficulty. But for other work on the sun the concave grating will be found very useful. But its principal use will be to get the relative wave-lengths of the lines of the spectrum, and so to map the spectrum; to divide lines of the spectrum which are very near together, and so to see as much as possible of the spectrum; to photograph the spectrum so that it shall be normal; to investigate the portions of the spectrum beyond the range of vision; and, lastly, to put into the hands of any physicist at a moderate cost such a powerful instrument as could only hitherto be purchased by wealthy individuals or institutions.

To give further information of what can be done in the way of gratings I will state the following particulars:—

The dividing-engine can rule a space $6\frac{1}{4}$ inches long and $4\frac{1}{4}$ inches wide. The lines, which can be $4\frac{1}{4}$ inches long, do not depart from a straight line so much as $\frac{1}{100000}$ inch, and the carriage moves forward in an equally straight line. The screw is practically perfect, and has been tested to $\frac{1}{100000}$ inch without showing error. Neither does it have any appreciable periodic error; and the periodic error due to the mounting and graduated head can be entirely eliminated by a suitable attachment. For showing the production of ghosts by a periodic error, such an error can be introduced to any reasonable amount. Every grating made by the machine is a good one, dividing the 1474 line with ease; but some are better than others. Rutherfurd's machine only made one in every four good, and only one in a long time which might be called first-class. One division of the head of the screw makes 14,438 lines to the inch. Any fraction of this number in which the numerator is not greater than, say, 20 or 30 can be

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ruled. Some exact numbers to the millimetre, such as 400, 800, 1200, etc., can also be ruled. For the finest definition either 14,438 or 28,876 lines to the inch are recommended—the first for ordinary use, and the second for examining the extremities of the spectrum. Extremely brilliant gratings have been made with 43,314 lines to the inch; and there is little difficulty in ruling more if desired. The following show some results obtained:—

Flat grating, 1 inch square, 43,000 lines to the inch. Divides the 1474 line in the first spectrum.

Flat grating, 2 × 3 inches, 14,438 lines to the inch, total 43,314. Divides 1474 in the first spectrum, the E line (Ångström 5269·4) in the second, and is good in the fourth and in even the fifth spectrum.

Flat grating, 2 × 3 inches, 1200 lines to 1 millimetre. Shows very many more lines in B and A groups than were ever before seen.

Flat grating, 2 × 3¼ inches, 14,438 lines to the inch. This has most wonderful brilliancy in one of the first spectra, so that I have seen the Z line, wave-length 8240 (see Abney's map of the ultra-red region), and determined its wave-length roughly, and have seen much further below the A line than the B line is above the A line. The same may be said of the violet end of the spectrum. But such gratings are only obtained by accident.

Concave grating, 2 × 3 inches, 7 feet radius of curvature, 4818 lines to the inch. The coincidences of the spectra can be observed to the tenth or twelfth spectrum.

Concave grating, 2 × 3 inches, 14,438 lines to the inch, radius of curvature 8 feet. Divides the 1474 line in the first spectrum, the E line in the second, and is good in the third or fourth.

Concave grating, 3 × 5½ inches, 17 feet radius of curvature, 28,876 lines to the inch, and thus nearly 160,000 lines in all. This shows more in the first spectrum than was ever seen before. Divides 1474_0 and E very widely, and shows the stronger component of Ångström 5275 double. Second spectrum not tried.

Concave grating, 4 × 5¾ inches, 3610 lines to the inch, radius of curvature 5 feet 4 inches. This grating was made for Professor Langley's experiments on the ultra-red portion of the spectrum, and was thus made very bright in the first spectrum. The definition seems to be very fine, notwithstanding the short focus, and divides the 1474 line with ease. But it is difficult to rule so concave a grating, as the diamond marks differently on the different parts of the plate.

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These give illustrations of the results accomplished; but of course many other experiments have been made. I have not yet been able to decide whether the definition of the concave grating fully comes up to that of a flat grating; but it evidently does so very nearly.

Baltimore, May 25, 1882.

LXII. *Crystallographic Notes. By* L. Fletcher, *M.A., of the Mineral Department, British Museum**.

[Plate X.]

IX. *Skutterudite.*

THE first mention of this mineral was made in 1827 by Breithaupt†, to whom it had been submitted by his brother-in-law on returning from a voyage in Norway. Though none of the specimens presented crystal-faces, Breithaupt found that there were distinct cleavages parallel to the sides of a cube, for which reason he assigned to the species the name of Tesseral-Kies. Cleavages, more or less interrupted and indistinct, were found to exist parallel to planes truncating the edges and quoins of this cube, indicating that the crystallisation was that characteristic of the cubic system. Breithaupt went a step further, and, from traces of separation which manifested themselves in the direction of the octahedral planes, hazarded the conjecture, since (curious to say) verified, that the crystals would prove to present the octahedron as the predominant form. The specimens were of a bright metallic lustre and of a tin-white colour. The specific gravities of five different fragments were determined to be 6·659, 6·681, 6·718, 6·748, 6·848, and thus had a considerable range. As, however, after breaking up the fragments, it was seen that the first three included particles of quartz and actinolite, Breithaupt regarded the true specific gravity as lying between 6·748 and 6·848. The hardness was greater than that of cobaltite or Cobaltkies; and as blowpipe examination had indicated that cobalt and arsenic were the chief constituents, Breithaupt suggested the secondary title of Hartkobaltkies. The associated minerals were cobaltine, copper pyrites, glassy actinolite, serpentine, quartz, and sometimes also cobalt-bloom.

* Communicated by the Author, having been read before the Crystallological Society, May 30, 1881.

† "Ueber eine neue Kies-Species von Skutterud," Pogg. *Ann.* vol. ix. p. 115 (1827).

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