AN INFRARED SPECTROMETER OF LARGE APERTURE

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Much of the infrared research of this laboratory has been characterized by the use of the maximum dispersion and resolution produced by grating spectrographs in the case of the emission line spectra of elements and by prism-grating instruments for the absorption band spectra of molecules. Until recently the field of the latter work has been limited to a spectral region terminating at 15μ, due to the opacity of the NaCl prism beyond this point. Recently prisms of KCl, KBr and KI made from single crystals grown here have increased the range of this combination instrument to nearly 30μ; the echelette gratings used in connection with the prisms being designed to concentrate energy in each region investigated. It is thus possible now to study the spectrum of any material with the maximum resolution attainable through the use of gratings to about 30μ.

By means of the spectrometer described here it is hoped that the region from 30μ to 500μ may be examined with the same relative resolution. The instrument has in fact been built for some years, but until recently it has not been possible to detect the energy available in this extreme region when sufficiently dispersed to give the high resolution sought. A number of accessory devices have been developed in the last few years which have increased very greatly the possibilities of the exact measurement of minute quantities of radiation. Among these may be mentioned improved vacuum thermopiles, more perfect echelette gratings, better absorbing filters for the removal of short wave-length radiation, and particularly the development of several very efficient amplifying devices by which the extremely small deflections of the galvanometers connected to the thermo elements can be increased many fold. We have now reached the stage where with the aid of these new developments this spectrometer may be used in the long wave region with gratings of far greater dispersion and resolving power than it has hitherto been possible to employ for such work.

The significant feature of the instrument is its large aperture, the concave mirror being 24 inches in diameter, with a focal length of 36 inches. This permits the use of exceptionally large gratings. As these are reflection gratings of the echelette type with the energy located mainly in the single narrow region under examination, it will be evident that this spectrometer receives more energy and conserves it better than other grating instruments have hitherto succeeded in doing. It therefore possesses great possibilities, especially when high resolution is to be used.

The mirror is a parabolic mirror made by the late Professor J. M. Schaeberle, a resident of Ann Arbor, formerly astronomer at Lick Observatory. He had intended to mount it in a telescope he was building for his personal use. The finished mirror which was of exceptional quality was broken when an attempt was made to bore a hole at its center, and the two parts were presented by Professor Schaeberle to the writer who desires to express here his appreciation for this gift and also to express the hope that in the years to come these mirrors may still contribute to the advancement of science, even if in a field quite other than their maker intended.

The break was along a straight line about 2 inches off the center of the mirror, and the larger piece with the straight edge uppermost is being used as the mirror in the present instrument. Its size is sufficient to fill a grating with a ruled surface of 10 by 22 inches. Gratings of this size were first made upon a shaper built over for the purpose, the screw of which had been replaced by a carefully ground and corrected screw. At present they are being made on the ruling machine of the Department. This machine is a large and heavy machine designed by de Khotinsky, and the first gratings were made by him. It was built in the Department shops and will rule gratings of any size up to 10 by 22 inches, with from 25 to 14,400 lines per inch. At present it is in charge of technician Weyrich who rules the gratings under the direction of Professor Barker. Gratings as coarse as are required for this long wave region may have from twenty-five to one thousand lines per inch. To produce these coarse echelette gratings the ruling tool is of steel and cuts out the material from each groove. The blanks consist of castings of an aluminum alloy, deeply ribbed on the rear face, with a thin layer of a lead-tin compound on the front face. This soft metal is poured over the face of the blanks in a molten condition, the aluminum surfaces being first plated and faced with solder. Another method is to groove the surfaces of the blanks on the milling machine; the molten lead-tin mixture solidifying in the dove tail grooves forms a very complete union with the aluminum face. The blanks after being artificially aged, are surfaced accurately on the milling machine and then mounted on the ruling engine in the proper position for ruling. A cutting tool is substituted for the ruling tool and the surface is planed off by a series of thin cuts until the technician is satisfied that he has a surface suitable for ruling. While acting as a planer, the ruling engine has been making the same number of strokes per inch as is to be used in ruling the grating. This prevents introducing a second frequency in the gratings. Surfaces prepared in this way appear to be optically flat, though not optically polished, and are better for such coarse gratings than surfaces of somewhat harder metal which permit grinding and polishing in the usual manner. This is because metals soft enough to permit lines of a definite shape to be either pressed or cut in them also allow the abrasive materials to become imbedded in their surfaces with the result that the ruling tool loses its edge and form before the grating is completed.

A ruling tool is ground so as to cut out a line whose sides are flat and have the required inclinations to the original surface of the blank, so that the radiation is concentrated in the region under examination, and at the same time the dispersion is the maximum permitted by the energy available. The surfaces of these lead-tin mixtures are remarkably brilliant and seem to be permanent. These coarse gratings are very successful in concentrating the energy in a single relatively short region, but this makes necessary a large number of gratings to cover an extended spectral region.

These large echelette gratings when examined with the microscope show exceedingly regular grooves. Other tests, and the actual measurements with these gratings all indicate that they possess an accuracy of construction relative to the wave lengths they are to measure, entirely comparable with the best optical gratings. Their great length gives them a resolving power quite beyond anything used hitherto in this region.

Possessing a mirror of exceptional qualities for this work and gratings capable of realizing the full possibilities of the mirror, it remains so to arrange them in the spectrograph as to make the most of the advantages the combination offers. The gratings are mounted on the table of a large Fuess spectrometer, their upper edges being in the same horizontal plane which contains the mirror center. The entrance and emergent slits S and S' placed 6 cm apart, are directly above the grating G, with only enough clearance to permit free rotation of the latter. This makes the axes of the entering and emergent beams as well as the axis of the parabolic mirror M nearly coincident, with the result that there is a minimum of distortion of the image formed on the emergent slit S'. A plane mirror M' behind this slit bends the beam at right angles to fill an eliptical mirror M'' whose foci are respectively 17 1/2 and

3 1/2 inches from the mirror. With the emergent slit at the first focus and the receiving thermopile at the other there is a five fold reduction in the size of the slit image upon the thermo element, a result which has been shown to be desirable. Here also the axes of the beam and the mirror coincide so that there is no distortion of the image upon the thermo element. The optical arrangement is thus very simple but at the same time very free from defects.

That the various optical parts may remain fixed with respect to each other, the spectrometer carrying the gratings and the tripod carrying the heavy mirror are mounted on a mason-work pier, each at a height

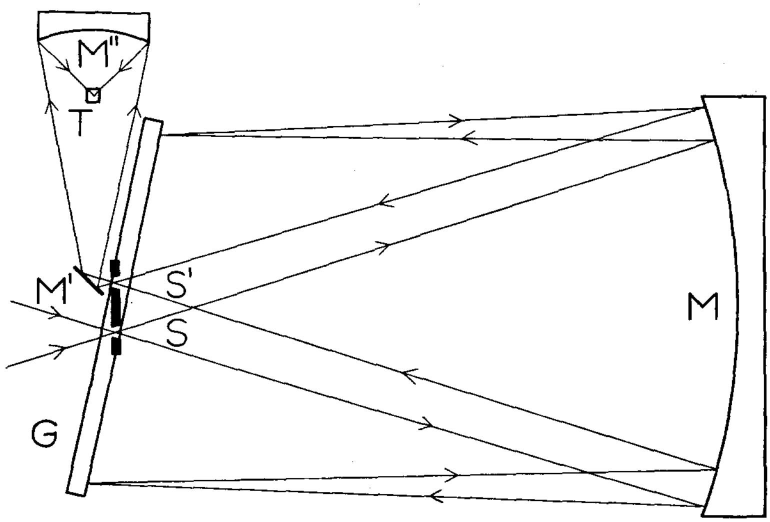

FIG. 1. *A horizontal cross section of the spectrometer in the plane containing mirror center.*

to give the adjustment of grating and mirror just described. The slits and thermopile with its focusing mirrors are all mounted on a very heavy iron frame work which is rigidly braced and firmly fastened to the same mason-work pier. The optical parts of the spectrometer are enclosed by a box of sheet steel with openings in the bottom through which extend the columns carrying the spectrometer table and the semicircular iron band which holds the large mirror. The openings between these columns and the bottom are closed with sheet rubber. This arrangement leaves the spectrometer circle and its reading microscope readily accessible to the observer. A third aperture is immediately before the entrance slit, while the top of the box has a removable window over the thermopile. On the side where the observer sits there is another window large enough to permit the adjustment of the gratings on the spectrometer table. Shields within the case, particularly about the thermopile, prevent a disturbing circulation of the air. Outside, the box is covered by sheets of celotex about 1/2 inch thick. As the instrument is mounted in a room in the second basement, conditions are very favorable, temperature changes and vibrations being reduced to a minimum.

The slits are adjustable bi-lateral slits, the maximum opening being 10 mm. The thermopile is evacuated and permanently connected by stop cocks to a charcoal liquid air trap and an oil pump. The transmitting plate before the element is of quartz, KBr, or paraffin depending upon the spectral region under investigation. The pile may have one or more junctions, the absorbing coatings varying with the spectral region. The spectrometer is of the largest size made by Fuess and carries the large gratings without trouble. The circle, divided directly into 5 minute divisions, may be read to seconds by micrometer eyepieces. Tests have shown that the calibration is good enough to justify readings to seconds. Either a Moll or Firestone[1] amplifier is used giving an amplification up to 100 fold or more if desired. All the circuits leading from the spectrograph to this amplifier are copper sheathed, and all switches as well as the galvanometer directly connected with the pile are in metal boxes. This generally gives quite adequate protection against electric disturbances. The galvanometers stand upon firm shelves mounted on the heavy columns of the second basement and are very free from mechanical vibrations. After further use of the instrument has developed more fully its possibilities and the technique required, the optical parts will be inclosed in a case permitting evacuation and the advantages of a vacuum instrument will be added to those arising from the very large aperture.

[1] F. A. Firestone, This Journal, *3*, p. 163; 1932.