78. *Spectrograph with Strong Illumination.*

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(Comm. Oct. 12, 1936.)

In an ordinary glass spectroscope, a single achromatic lens is used in the collimator, and in a quartz spectrograph, the ray to be analyzed is obtained by means of a single lens of the same material. Usually the focal length of the collimator is equal to, or of the same order of dimension as the objective. For concentrating the light from a source, it is necessary to use such a condensing lens, that nearly all the light passing through the slit should pass through the collimator lens. Generally there is a loss due to the divergence of the light cone issuing from the condenser; for concentrating a large amount of light, the solid angle subtended by the lens at the slit must be increased, by diminishing its focal length. This condition is not usually fulfilled, if the light cone entering the slit is to pass through the collimator lens, as it is intercepted by the walls of the collimator tube; the consequence is the weakening of the light to be analyzed, and the inadequacy of using a strong condenser.

With quartz spectrograph, the light after passing the collimator lens is parallel only for a single ray of particular wave-length, while rays of greater wave-length are divergent and of shorter convergent; in other words, the prismatic dispersion does not satisfy the condition usually given only for parallel rays. The spectrum consequently deviates from the usual case.

Generally, if the material of the lenses with focal lengths f_1 and f_2 be combined to form an achromatic pair, the distance D between them is given by

$$D = \frac{\nu_1 f_1 + \nu_2 f_2}{\nu_1 + \nu_2} \quad (1)$$

where $\nu = -\frac{\mu - 1}{\Delta\mu}$. For the same material, $\nu_1 = \nu_2$, so that

$$D = \frac{f_1 + f_2}{2} \quad (1a)$$

The focal length of the combined system

$$f = \frac{f_1 f_2}{f_1 + f_2} \quad (2)$$

The distance of the front focus f_{12} from the fore-lens is given by

$$f_{12} = \frac{f_1(f_1 - D)}{f_1 + f_2 - D} = -f_1 \left(\frac{f_1 - f_2}{f_1 + f_2} \right) \quad (3)$$

If the slit be placed at the front focus of the combined system, the rays passing through the lenses issue parallel and only the secondary spectrum is present. The ordinary treatment of prismatic dispersion is

consequently applicable to such rays, but if a single lens be used, the rays incident on the prism are far from being parallel, due to chromatic aberration of the collimator lens. For a thin lens,

$$\Delta f = -\frac{\Delta\mu}{\mu-1}f \quad (4)$$

and f is generally equivalent to the length of the collimator. This is sometimes of considerable amount: for quartz $f=30$ cm, $\Delta f=4.1$ cm for λ 2144 and 4861, showing deviation of about 14 per cent.

Similarly

$$\Delta f_{12} \approx -\frac{\Delta\mu}{\mu-1} f_1 \quad (5)$$

for a system of two lenses of the same material. If such a system is to be used, by keeping the slit and the position of the lenses fixed, f_{12} should not vary with wave-length. This cannot be secured at the same time with achromatism; to keep the variation small, f_1 should be short, and the lens kept close to the slit. It has another advantage of receiving large quantity of light falling on the slit, as the solid angle subtended at the slit by the fore-lens (f_1) is much increased than when a single back lens is placed at one end of the collimator. The scheme of the lens system for lenses of the same material, such as quartz, is represented in the figure.

Denoting the semi-vertical angle of the pencil by α , the amount of light is proportional to the solid angle $2\pi(1 - \cos \alpha)$. When α is small, the quantity of light is given by $\pi\alpha^2$, so that the ratio is proportional to the square of the angle of the pencil. Even allowing for the loss by reflection and refraction of the fore-lens, the interception by the diaphragm, and the limit in the dimension of the back-lens, the gain of light is many times over a simple collimator.

Another advantage to be gained by the present arrangement is the shortening of the collimator tube. The length from the slit to the back-lens is f_2 in ordinary spectroscope; in the present case, it is $f_{12} + D$, or $f_{12} + \frac{f_1 + f_2}{2}$. Since f_{12} and f_1 are small compared with f_2 , the tube is much shortened.

It is thus evident that the new arrangement can be profitably used, especially when the source of light is faint, or when the spectrogram is to be secured with short exposure. For some astrophysical investigations, these conditions are to be fulfilled; and especially for stellar spectra, the above arrangement will probably lead to important results.

A powerful monochromator can be constructed on the same standpoint. For microchemistry, only a minute quantity of the sample is available, so that the above arrangement is useful for the analysis. A quartz spectrograph was constructed with a collimator, consisting of two lenses as already mentioned, and tried on various minute samples. The spectrograms indicated the expected results, so that the smallest quantity of various elements, which can be spectroscopically detected, is of the order of 10^{-10} to 10^{-12} grm., thus increasing the accuracy of spectral analysis to a degree not hitherto attained. The results are reserved for future communication.

The advantage of the system may be illustrated by an example. Take the case of quartz lenses $f_1=5$ cm, $f_2=30$ cm for the ray of λ 3400 Å; for the combination $D=17.5$ cm, $f_{12}=3.57$ cm. A pencil of rays from a point source on the slit with vertical angle of 31.3° can pass through the fore-lens forming a circle of 1 cm radius on it. The virtual image of the source formed by the lens is distant by 12.5 cm from it, so that the rays after passing the front lens forms a cone of 9.0° , and enters the back-lens in a circle of 2.4 cm radius. With ordinary spectroscope, i. e. without the fore-lens, an incident pencil, subtending 9.2° can be received on the same surface; in other words, the intensity is increased nearly ten times. The length of the collimator tube is reduced from 30 cm. to 21 cm.

The figures illustrate the spectrograms obtained by using a quartz spectrograph of the following dimensions: f_1 3 cm., f_2 20 cm, effective aperture 2 cm, f. l. of the objective 20 cm; single Cornu prism. The figures are magnified 5 times.

Photographed by K. Toishi.