A QUARTZ COMPENSATING POLARISCOPE WITH ADJUSTABLE SENSIBILITY.

By Frederick Bates.

All of the polarizing systems so far devised for quartz wedge polariscopes have been defective for one of two reasons; either the sensibility of the instrument can not be varied or it can be used only with monochromatic light. The system which has given the best results and is in general use at the present time is the so-called half-shade. It introduces into polarimetry the photometric principle, inasmuch as the angular position of the analyzing nicol is determined by bringing the two halves of the field of the instrument to a condition of uniform illumination. In any half-shade system the light from the polarizer is plane polarized in two planes which make an angle α, called the polarization angle, with each other. All of the light illuminating either half of the field is thus polarized in one of these planes, and when a setting is made the polarization plane of the analyzer makes approximately a right angle with the bisector of α. Upon the magnitude of α depends the accuracy with which settings can be made; the sensibility for any given light source being an inverse function of that magnitude. Hence it is exceedingly desirable that a polarizing system permit α to be varied as the observer may desire.

A monochromatic light-source of sufficient intensity and suitable for the average work for which quartz compensating polariscopes are used is yet to be obtained. In order to obviate this difficulty the rotation produced by the substance being examined is compensated as completely as possible by the use of oppositely rotating quartz. Since the polarization planes of the different wave-lengths are thus returned to their original positions, white light can be used. This, however, makes it necessary for the polarizing system and the analyzer to be mounted so as to be immovable. The polarization plane of the analyzer then makes approximately a right angle with the bisector of a.

The systems most used in polariscopes are the Laurent, the Jellet, and the Lippich. In the former a thin plate of quartz cut parallel to the optic axis covers one-half the field of the polarizing nicol. In order that the two rays of the doubly refracting quartz may combine to give plane polarized light in the analyzer they must have an optical difference of path equal to $\frac{\lambda}{2}$. Thus the thickness of the quartz must be such as to make it a half-wave plate and its use is then limited to a light source giving only that particular wave-length. The advantage of this system is due to its adjustable sensibility, a being twice the angle between the optic axis of the plate and the plane perpendicular to the principal section of the polarizer, can be readily varied by rotating the polarizer. The Jellet system consists of a twin nicol so made that the principal sections form the angle a. Since the different sections are cemented together the sensibility can not be varied. It can, however, be used with white light. In the Lippich system a is formed by two beams of plain polarized light which come from two separate nicols, one of which covers but one-half the aperture of the larger nicol. By rotating either of these nicols a can be varied as in the Laurent polarizing system.

In designing quartz compensating polariscopes the best results so far have been obtained by using a Lippich polarizing system and a white light-source. The greatest weakness has been the lack of an adjustable sensibility. Only one value of a can be used and it must necessarily be large enough to give sufficient light to read for example the darkest colored raw sugar solutions. When polarizing substances having a small coefficient of light absorption, as the better grade of sugars, and the observer has more light than he needs he still has available only the sensibility which corresponds to that value of a which gives sufficient light to polarize substances with a relatively large coefficient of absorption, such as very dark raw sugars. If then it were pos-

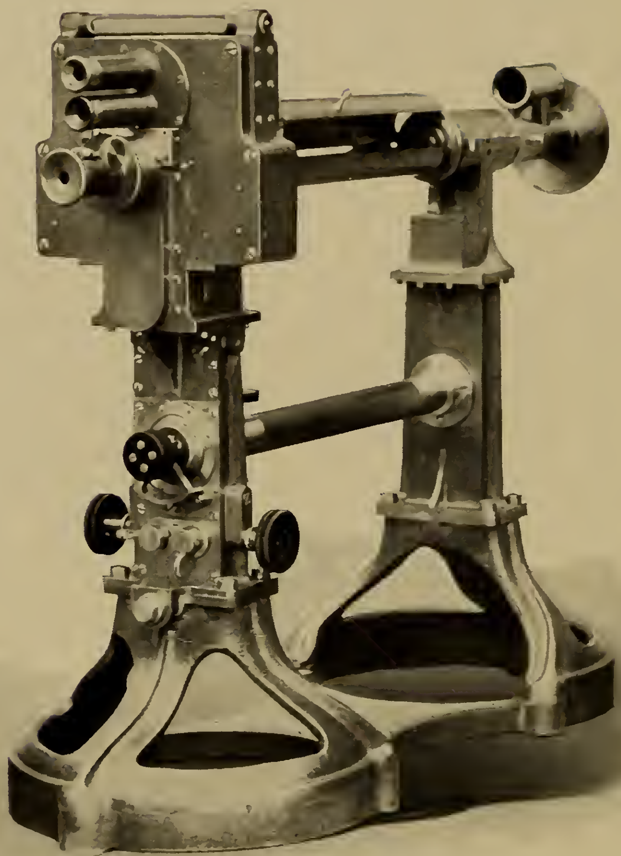

Fig. 3.—*Quartz Compensating Polariscope.*

sible to retain the white-light source and at the same time have a adjustable, a distinct advance in polariscope construction would be made.

Let OB and OB', figure 1, be the traces of the polarization planes of the large and small nicols of a half-shade polarizing system. If the intensities of the light in OB and OB' are equal, the polarization plane EE' of the analyzing nicol will be at right angles with OH, the bisection of a. If a be increased or diminished by displacing OB' about the point O it is evident that when a match is again obtained EE' will have suffered one-half the angular displacement through which OB' has been rotated. However, in the Lippich system, since the smaller nicol covers one-half the field of the larger, we do not have the two beams OB and OB' of equal intensity. If the intensity of OB is A, the intensity of OB' is $A \cos^2 a$. When EE' is set for a match the angle between EE' and OH is therefore never 90° for any value of a except O.

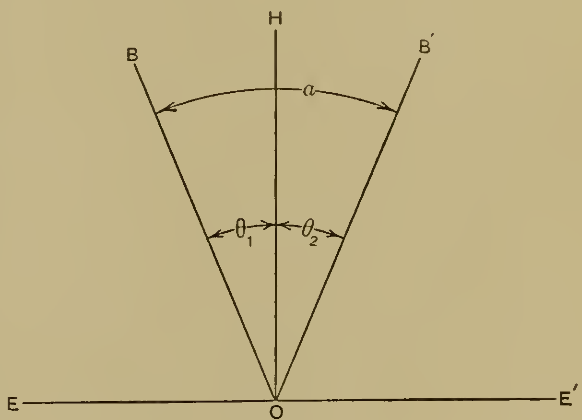

Fig. 1.

The condition for equal illumination with a half-shade system is

$$A_1 \sin^2 \theta_1 - A_2 \sin^2 \theta_2 = O \qquad (1)$$

where A_1 and A_2 are the intensities of their respective halves of the field and θ_1, and θ_2 are the angles HOB and HOB'.

Let

$$\theta_1 = \phi \pm \delta$$
$$\theta_2 = \phi \mp \delta$$

Equation (1) becomes

$$A_1 \sin^2 (\phi \pm \delta) = A_2 \sin^2 (\phi \mp \delta)$$

From (2) we obtain

$$\tan \delta = \pm \frac{\sqrt{K} - 1}{\sqrt{K} + 1} \tan \phi$$

or since

$$\theta_1 + \theta_2 = \alpha$$

$$\tan \delta = \pm \frac{\sqrt{K} - 1}{\sqrt{K} + 1} \tan \frac{\alpha}{2} \tag{3}$$

where $K = \frac{A_2}{A_1}$ and δ is the angular difference, for any value of a, between the positions of EE' for a match when $A_2 = A_1$ and when $A_2 = A_1 \cos^2 a$. It is thus evident if a be varied by rotating OB' about the point O, that to obtain a match EE' must be rotated in the same direction as OB' and by an amount such that the normal to EE' always makes an angle δ with OH the bisector of BOB'.

It would seem a difficult task to build a mechanism that would maintain EE' in the proper position to satisfy the theoretical value of δ given by (3). If such a mechanism were obtained the observer could detect no difference in the intensities of the two halves of the field, once the instrument was adjusted, no matter what value a might be given. The limits of accuracy in ordinary polarimetry are such as to make such a mechanism unnecessary. If EE' should always be maintained at right angles to OH, the fixed zero point of the instrument would be in error by the amount δ for any value of a, provided the instrument had been previously adjusted for $a = O$. If the zero of the instrument be adjusted to read correctly for any particular value of a and then a be changed, the zero will be in error by the difference between the values of δ corresponding to the two values of a. The curve in figure 2 shows the value of δ, obtained by solving (3), corresponding to any value of a between 0° and 15°. From this curve it is at once evident that with an instrument equipped with a Lippich polarizing system, in adjustment for a polarization angle $a = 10°$, a may be varied between the limits of 4° and 12°.4 without introducing an error due to a change in the zero point greater than 0°.1 S (sugar degrees), provided EE' be constantly maintained at right angles to OH. If the zero point be adjusted for $a = 8°.5$, a may be varied from 0° to 11°.5 with a maximum error of 0°.1 S; or from 5°.6 to 10°.3 with a maximum error of 0°.05 S.

The instrument shown in figure 3 was built[1] for the Bureau of Standards to fulfill the theoretical conditions mentioned above. It is a double quartz wedge compensation instrument with a Lippich polarizing system. The analyzing nicol and the large nicol of the polarizing system are mounted in bearings and are joined by gears with a connecting rod. The milled head of this rod is shown half way between the base of the instrument and the observing telescope. When the milled head is rotated the two nicols are rotated, and the design of the gears is such that the analyzing nicol always receives one-half the angular displacement

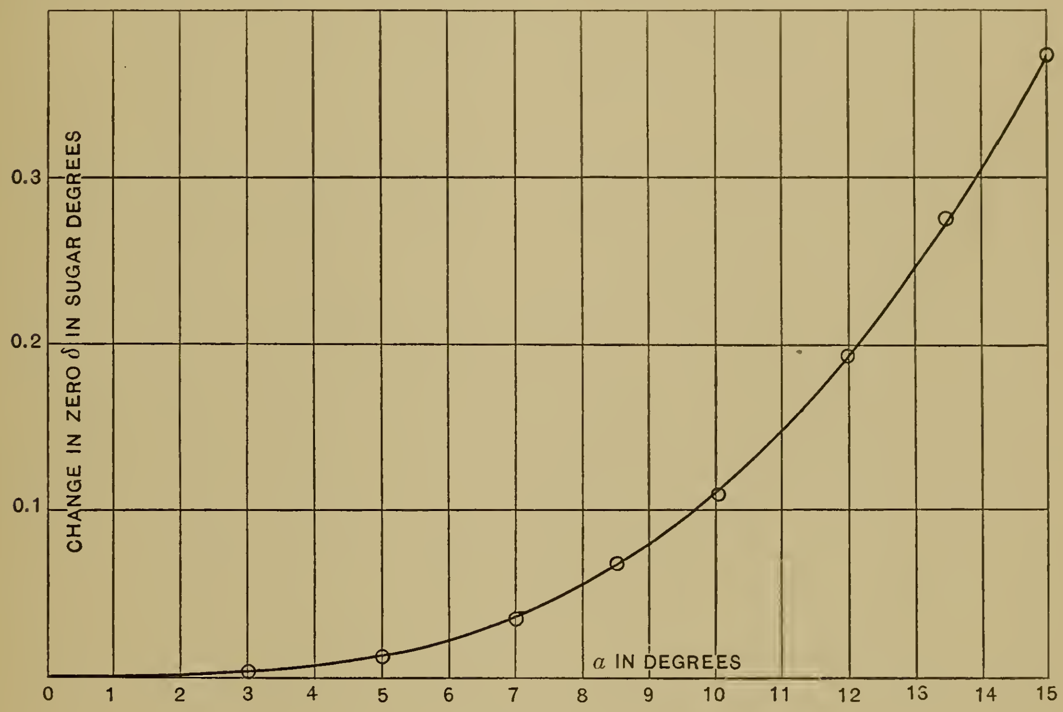

Fig. 2.

of the large nicol of the polarizing system. Around the milled head is a circular scale which shows the polarizing angle for any position of the nicols. The milled heads on the right and left hand sides of the instrument drive the quartz wedges of the compensator, and their position is such as to permit the arm of the observer to rest free from strain while making a setting. The wedges can instantly be clamped rigid for any part of the scale. The scales on the quartz wedges are the type used on regular Frič saccharimeters. Being of glass and read by transmitted light, the scale divisions are exceedingly clear and there is no

[1] The builders were Messrs. Josef and Jan Frič. Prag, Kral. Vinohrady, 233, Austria.

black dividing line between a scale and its vernier. In all research work where small temperature corrections are to be made it is necessary to know accurately the temperature of the quartz wedges. Polariscope builders seem to have ignored this fact. A thermometer (10°–40° C., in one-fifth degrees), with a horizontal scale and with its bulb between the quartz wedges, has accordingly been mounted in a brass case on top of the metal box containing the compensator.

For all ordinary sugar testing, where the temperature of the room changes slowly, the reading of this thermometer is practically the temperature of the room. The observer is thus able to take the temperature with the same facility that he reads the scale on his wedge, since the thermometer scale is in a similar position and is illuminated by the same light source. The base of the instrument has been made exceptionally heavy and is mounted on rubber tips to insure against accidental change of position relative to the light source.

The improvements are equally advantageous for all uses to which the polariscope may be put. However, it is in the testing of sugars the new instrument should find its broadest application. With the instrument in adjustment for a polarization angle of 10° the observer can instantaneously adjust the sensibility so as to have sufficient light to polarize the darkest sugars, or he can with equal facility have an instrument far more sensitive than any ordinary saccharimeter. In measuring rotations with the greatest possible accuracy, or when it is desired to make the settings with the least possible strain on the eye, the observer has only to change the polarization angle until he has just sufficient light to bring the two halves of the field to the same intensity. He then has for his eye an instrument so adjusted as to give the maximum sensibility for making the setting, no matter what the character of the substance whose rotation is being measured. With the instrument adjusted for $a=O$ the observer soon learns the exact change in the zero point of the scale for all values of a, and instantly makes the slight correction mentally for each value of a used. He is thus able to determine the polarization of the better grades of sugar to an accuracy of ±.01° S.

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