MONOCHROMATOR UTILIZING THE ROTARY POWER OF QUARTZ*

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Abstract

Plane polarized light moving parallel to the *c* axis of quartz has the plane of polarization rotated various amounts depending on the wave length; the shorter the wave length, the greater the rotation. This rotary dispersion is the basis of the monochromator.

Four basal sections of quartz are used with the thicknesses in the ratios of 1:2:4:8 and so arranged that light passes successively from the thickest to the thinnest. When the polarized beam emerges from the far side of the thickest quartz, it passes through another polarizer which blocks the wave lengths vibrating at right angles to the polarization axis of this second polarizer but transmits the wave lengths vibrating parallel to that direction. In a similar way, each following stage can be thought of as eliminating half of the light entering it until finally a single band of about 150 Å width emerges. By means of mechanical gearing, the turning of a single knob rotates the polarizers so that this narrow pass band can be made to move continuously from one end of the spectrum to the other.

Because of the large aperture, adequate illumination can be obtained for microscopic work by using an incandescent tungsten filament lamp.

The Emmons method of double variation is a powerful means of accurately determining the refractive index of small crystal fragments. The weakest link in the chain of apparatus that must be assembled is the monochromator. Even with using the carbon arc as a light source, the intensity of light issuing from the average monochromator is so low that prolonged work is a strain on the eyes. The development of the quartz monochromator here described was undertaken in the hope of obtaining an instrument that would give more adequate illumination for the Emmons method. The limited use to which it has already been put has given most satisfactory results and indicates that it may have a wider application than that for which it was designed originally.

Within recent years considerable attention has been given to the development of *linear birefringent filters*. Their use and construction is described by Billings (1947) and Evans (1949). Such filters are based on the interference of polarized light produced by plates of birefringent crystals. Plates are cut to give maximum birefringence, that is, parallel to the plane of the optic axes of biaxial crystals and parallel to the optic axis of uniaxial crystals. The superposition of several crystal plates of

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proper thickness interlaminated with parallel polarizers permits the passage of a single narrow pass band of light. Such a filter can be made to pass any predetermined wave length, or may be tuned by the insertion of quarter wave plates and rotation of the polarizers. The quartz monochromator discussed here can be described as a tunable filter utilizing the rotary power of quartz and the large rotary dispersion. Although the pass band can not be made as narrow as that of a linear birefringent filter without using a very great thickness of quartz, it has certain advantages of construction. The quarter wave plates are unnecessary and even the thinnest of the quartz plates is sufficiently thick to be easily handled by the optical worker. A quartz plate giving the same broad band by interference is exceedingly thin.

TABLE 1. ROTATION OF PLANE OF POLARIZATION BY QUARTZ

λ in Å	Rotation in degrees	
	1 mm. thick	53 mm. thick
7600	12.67	671.51
6708	16.54	876.62
6563	17.32	917.96
5890	21.68	1,149.04
5461	25.70	1,362.10
5270	27.54	1,459.62
5086	29.72	1,575.16
4861	32.77	1,736.81
4340	42.60	2,257.80
4047	48.93	2,593.29
3934	52.15	2,763.95

APPROXIMATE LIMITS OF VISIBILITY

λ in Å	Rotation in degrees	
	1 mm.	53 mm.
4000	49.0	2,597
7000	15.3	811
Difference in rotation between extremes	33.7	1,786

That the plane of polarization of light moving parallel to the *c* axis of quartz is rotated is common knowledge; the magnitude of this rotation is less well known. In Table 1 the angular rotation for the plane of polarization in quartz is given for various wave lengths in the visible spectrum. Figure 2 shows graphically the relation of wave length to rotation. It will be noted that the difference in angular rotation between the extreme wave lengths (4000 Å—49°, 7000 Å—15° per millimeter of thickness) is 33.7° for a one-millimeter plate and approximately 1800° for a 53 millimeter plate. The 53-millimeter plate is considered since it was used in the construction of the monochromator.

If light is passed through a basal section of quartz, placed between polarizers, those wave lengths whose planes of polarization have been

FIG. 1. Quartz monochromator.

rotated so that they are parallel to the vibration direction of the upper polarizer will be transmitted. Wave lengths whose planes of vibration have been rotated so that they are at right angles to the vibration direction of the upper polarizer will be eliminated. In a spectroscope the spectrum will be found to be crossed by a number of dark bands, "channel spectra"; these bands correspond to the wave lengths rejected by the upper polarizer. In Fig. 3 is shown diagrammaticaly a band that is passed (*a*) and a band that is rejected (*b*).

In construction of the instrument, four basal sections of quartz are used and arranged in tandem, each section being half as thick as the one preceding. If the thickest section, #1, has unit thickness, section #2 has a thickness of $\frac{1}{2}$, #3 a thickness of $\frac{1}{4}$, and #4 a thickness of $\frac{1}{8}$. Five polarizers are used. One is to polarize the light before entering section #1 and one for each of the four quartz sections to select given wave lengths as the light emerges.

When the bands which are transmitted by the polarizer of section #1 pass through section #2, they are rotated just half as much as in the first

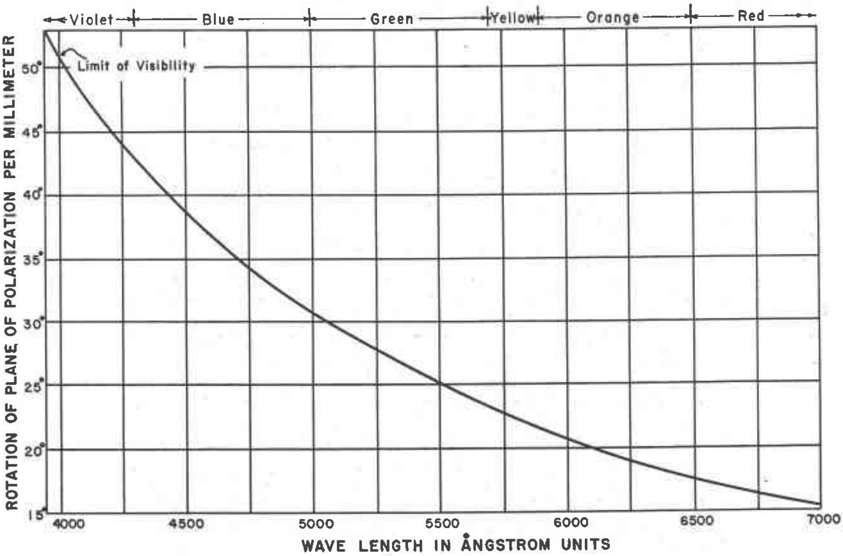

FIG. 2. Rotary dispersion in quartz.

section. Therefore, if the polarizer of section #2 is oriented properly, it will transmit alternate light bands passed by the first polarizer. For example, if two wave lengths are rotated 1200° and 1380° respectively by the first quartz section, the #1 polarizer can be set to pass both. However, on entering section #2 each is rotated half as much as previously or 600° and 690°, respectively. Consequently, when #2 polarizer is set to pass one of these, it will elminate the other. Ideally, then, the first quartz section should be just thick enough to give a difference in rotation between the extreme wave lengths of visible light of 1440°. Thus eight bands, one every 180° of rotation, would be transmitted, whereas those 90° removed would be eliminated. In this way, with correct orientation of the polarizers, four bands would pass polarizer #2, two would pass polarizer #3, and one would pass polarizer #4. Figure 4 shows transmis-

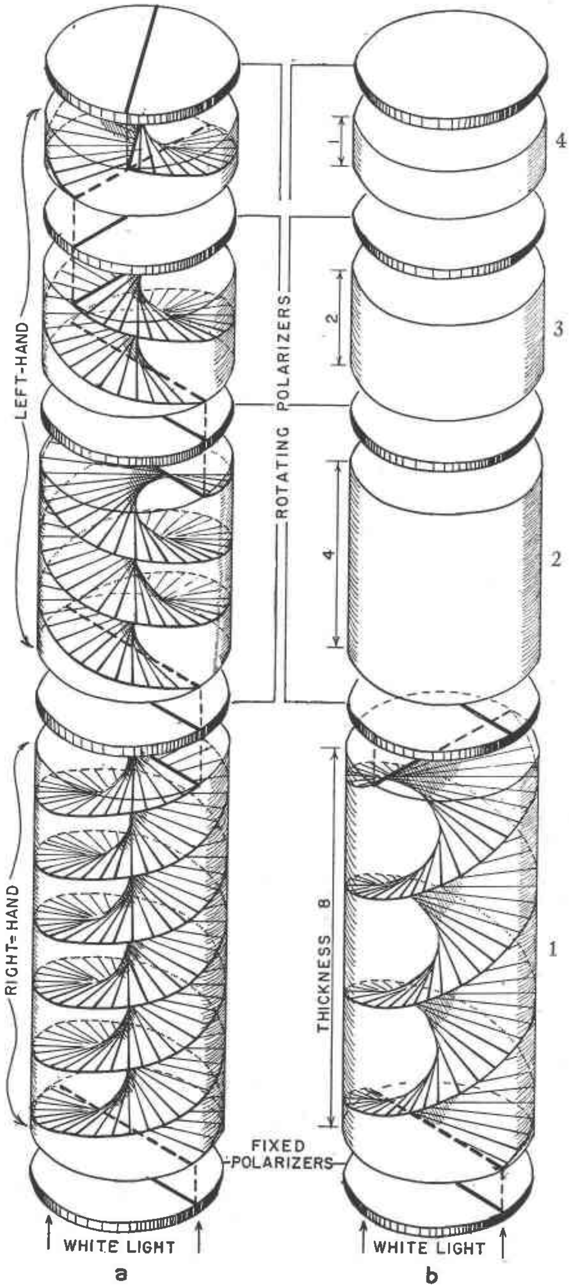

FIG. 3. Arrangement of quartz and polarizers. (a) Diagrammatic representation of the rotation of a single wave length with polarizers set to permit it to pass through the instrument. (b) Diagrammatic representation of a wave length blocked after passing through the thickest quartz section.

sion curves for four such basal sections. This arrangement is very much like a linear birefringent filter with a setting arranged to transmit a single narrow band.

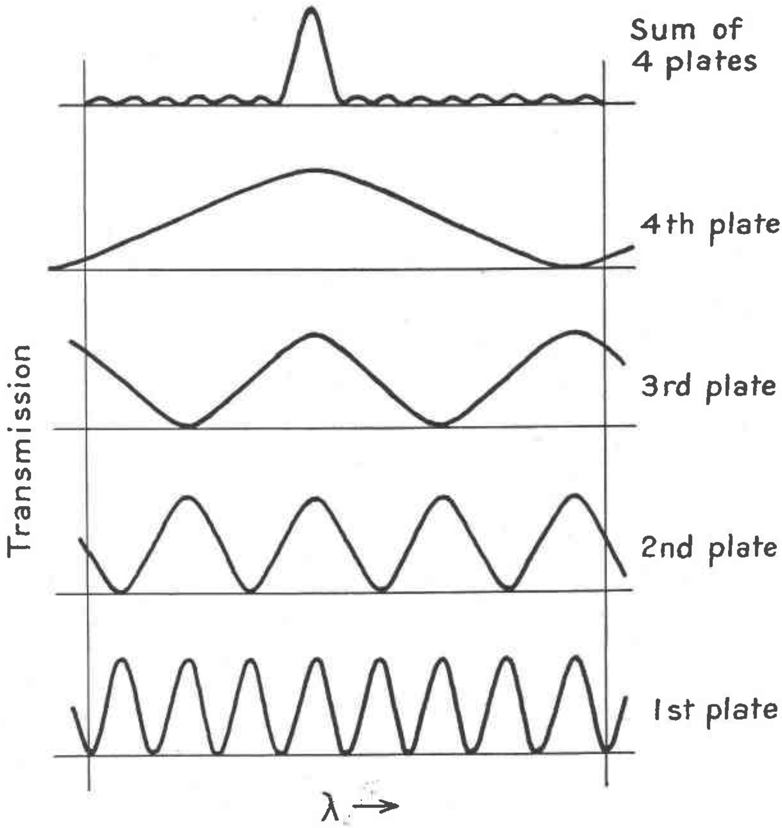

FIG. 4. Transmission curves of four quartz sections between polarizers showing the coincidence of the transmission maxima at a given wave length.

The quartz monochromator is tunable and can be set to pass a single band anywhere in the visible spectrum if the polarizers are simultaneously rotated appropriate amounts. The rotation of each polarizer is directly proportional to the thickness of the quartz plate with which it is associated. Since the thickest quartz section, #1, is twice as thick as section #2, four times as thick as section #3, and eight times as thick as section #4, the relative rotations of the polarizers are 8, 4, 2, and 1, respectively. It is possible to construct the instrument using all right-hand or all left-hand quartz by having light move from the fixed polarizer into the thinnest section.

If several instruments are to be made, it is difficult to standardize on either hand of quartz, for in nature, or in any purchased lot of crystals, about 50 per cent is right-hand and 50 per cent is left-hand. It is possible to utilize about equal amounts of both types if the thickest quartz section is of one hand and the other quartz sections of the opposite hand. This arrangement is satisfactory if light passes from the fixed polarizer into the thickest quartz section. The monochromator was constructed with the thickest section of right-hand quartz and the others of left-hand quartz (Fig. 3*a*).

When the instrument is assembled all the polarizers are set in parallel position. Mechanical gearing to a single shaft maintains the proper rotation ratios and permits the polarizers to be rotated simultaneously by turning a single knob. For example, consider a given wave length that is rotated to the right 1000° by quartz plate #1. Polarizer #1 is rotated 1000° to the right to be in a position to let it pass. On passing through quartz plate #2 this wave length would be rotated 500° to the left; polarizer #2 is rotated 500° to the right and is in a position to let it pass. Quartz section #3 will rotate the same wave length 250° to the left and polarizer #3, rotated 250° to the right, is in a position to let it pass. Finally, on passing through quartz #4, the light will be rotated 125° to the left, giving a total left-hand rotation by 2, 3, and 4 of 875°. Thus if polarizer #4 is rotated 125° to the right, it will pass the desired wave length and other wave lengths will have been effectively eliminated.

If one wishes to shift to a slightly shorter wave length, for example, one which is rotated 1020° by quartz #1, it would be accomplished by a further 20° rotation of polarizer #1 and proportionate rotations of the other polarizers. In such a way, one can move the pass band continuously from one end of the visible spectrum to the other and the wave length can be read directly on a dial.

In the preceding paragraphs the rotation of the polarizers alone has been considered. It has been found, however, that it is more practical to cement a polarizer directly to each quartz section and rotate the sections. In this way half the number of air-to-quartz and air-to-glass surfaces are eliminated and internal reflections are reduced.

Spectral distribution curves taken at seven settings show the transmission throughout the visible spectrum to be essentially uniform with between $2\frac{1}{2}$ and 3 per cent of any wave length passing the monochromator. This transmission compares favorably with the 5 per cent theoretically possible. The difference between the theoretical and measured transmission is due largely to internal reflections. Those reflections could be eliminated and the efficiency improved by immersing in oil. The average pass band width as determined by the spectral distribution curves is about 150 Å, which appears to be narrow enough for most microscopic work. With the addition of a fifth quartz section the average band width could be reduced to about 75 Å.

For the most efficient use of the monochromator the white light must be collimated. This can be effected by an external lens system, but for most purposes sufficient collimation is obtained by moving the light source several inches away from the instrument.

In using the monochromator as a light source for a polarizing microscope, it is necessary that the vibration direction of light leaving the instrument be parallel to the vibration direction of the lower nicol. For this reason the instrument is constructed so that light emerges through the fixed polarizer whose vibration direction is vertical.

The quartz monochromator has definite advantages over the conventional prism monochromator. The chief advantage is that, even with the apparent low efficiency, it can be used with an incandescent tungsten lamp as a light source and yield adequate illumination. The reason for this is that the large aperture, determined by the diameter of the quartz sections, of the quartz monochromator can be completely and effectively used. In the instruments constructed, the diameter of the quartz is one inch, but, by increasing the diameter to 1.41 inches, the amount of monochromatic light obtained from the instrument could be doubled.

References

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