

OR 2,742,818

33K
X 4550T

April 24, 1956

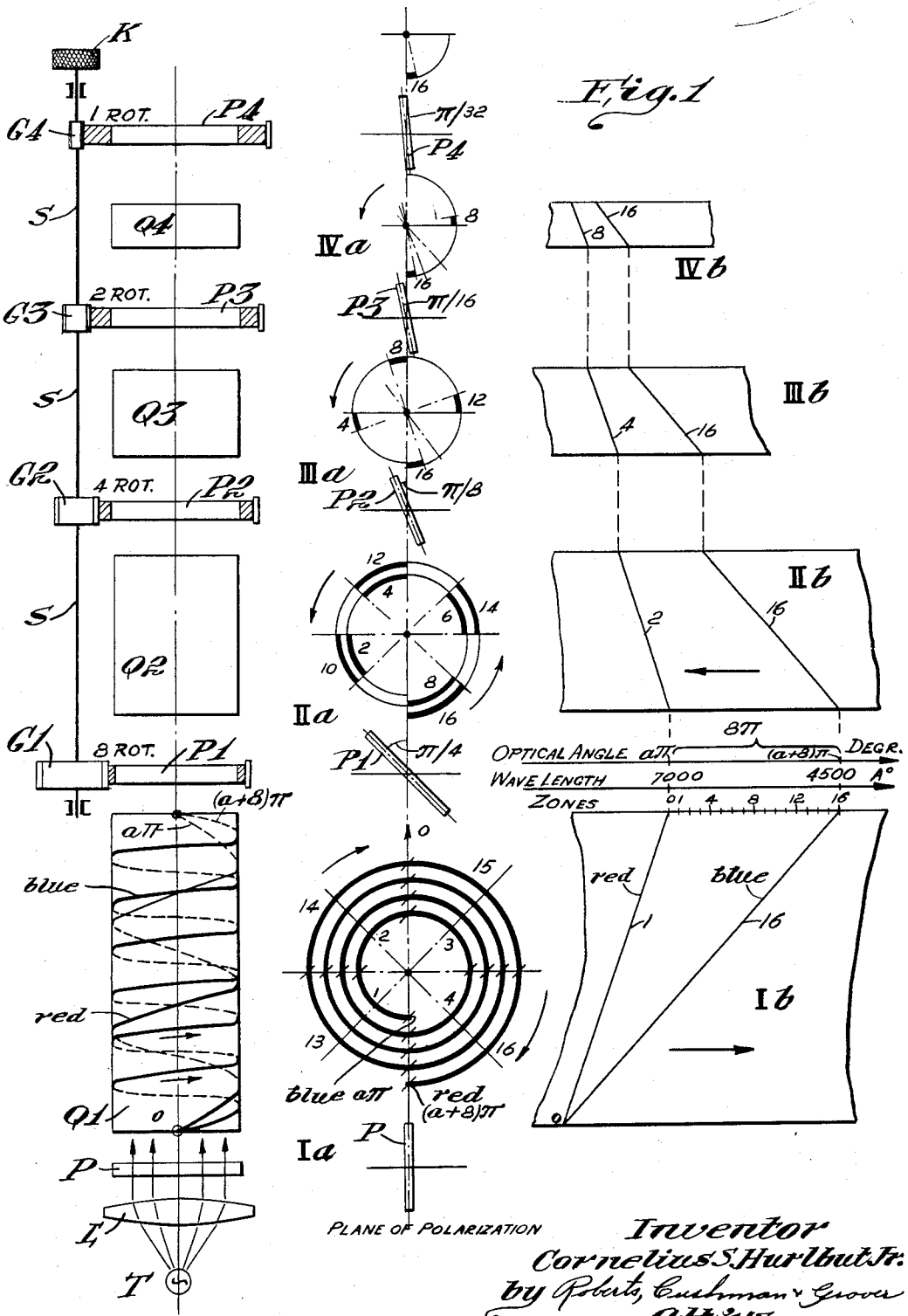
C. S. HURLBUT, JR
RADIATION BAND SELECTOR

2,742,818

Filed Sept. 11, 1951

2 Sheets-Sheet 1

72553



April 24, 1956

C. S. HURLBUT, JR
RADIATION BAND SELECTOR

2,742,818

Filed Sept. 11, 1951

2 Sheets-Sheet 2

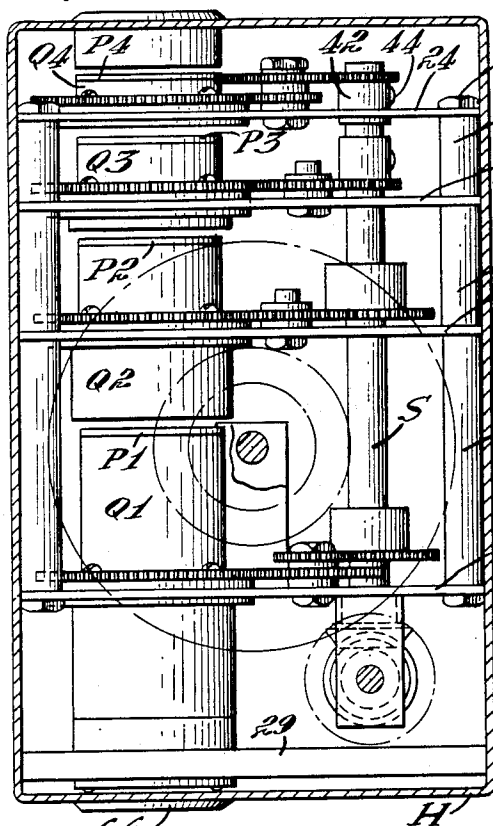


Fig. 2

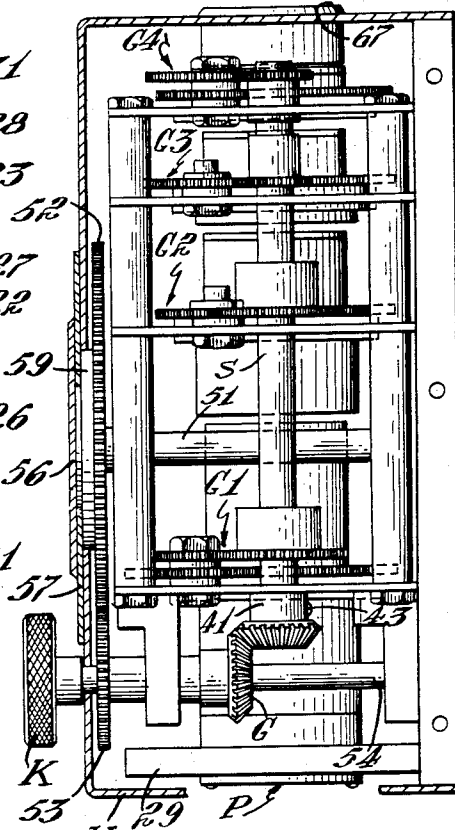


Fig. 3

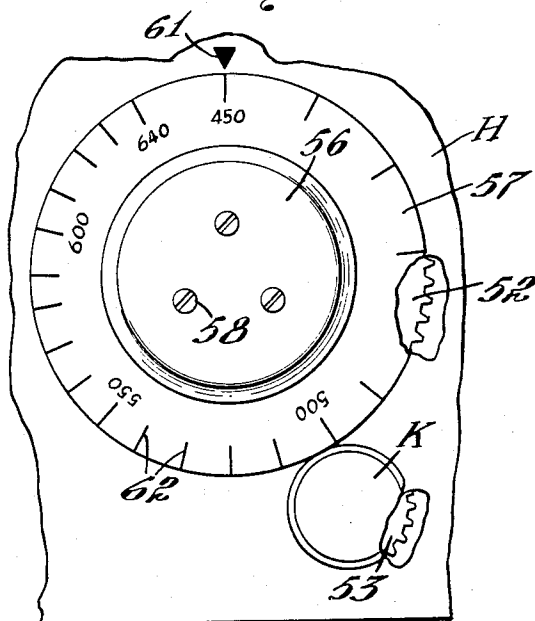


Fig. 4

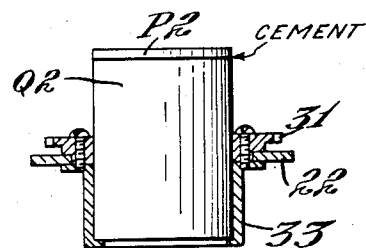


Fig. 5

Inventor
Cornelius S. Hurlbut Jr.
by Robert, Cushman & Groves
Att'ys.

1

2,742,818

RADIATION BAND SELECTOR

Cornelius S. Hurlbut, Jr., Belmont, Mass., assignor to
Cambridge Thermionic Corporation, Cambridge,
Mass., a corporation of Massachusetts

Application September 11, 1951, Serial No. 246,067

14 Claims. (Cl. 88—65)

The present invention relates to instruments providing radiation, such as light, of essentially a single wave length, called monochromators if applied to the visible spectrum.

Monochromators of the conventional type using prisms and arc lamps are not only cumbersome or costly but do not provide a linear relation between wave length and adjusting movement. It has been proposed to obtain monochromatic light by way of circular polarization of light in quartz or other substances, but such devices permit neither separation of an essentially single wave length, with band widths predeterminable to any desired degree, nor fine adjustment to a desired wave length, nor continuous selection of a wave length on a linear scale.

It is the object of the present invention to provide a device which avoids the above mentioned disadvantages of prior art devices by permitting selection of an essentially single frequency band from a spectrum of radiant energy; to provide, as applied to the visible spectrum, a source of monochromatic light originating from an incandescent source such as a tungsten lamp, permitting variation of wave length continuously through the spectrum and selection with comparatively simple means of a band of the average width of 150 angstrom units, which which band however can be narrowed to any desired degree; and to provide a source of monochromatic light for spectroscopy, microscopy, for investigations of the type such as the determination of refractive index according to the Emmons method of double variation of refractometry by the method of minimum deviation, for lecture demonstrations on color and color vision, for biological and psychological experimental procedures, and for many other purposes where color filters do not offer the flexibility or color control that is desirable in such situations. Other objects are to provide such a device which has a comparatively very large aperture furnishing adequate light of all wave lengths derived from a tungsten filament lamp or other incandescent light source; and to provide an instrument of this type which fits a wide variety of needs in all fields of activity where a strong and reliable light source of essentially pure color is required which is at least as effective but less cumbersome and costly than previous monochromators.

Additional objects are to provide an instrument of the above outlined type which can be manufactured with fairly inexpensive and uncomplicated mechanical elements, which can be operated by unskilled persons and which generally advances this art.

In one of its main aspects, the invention accomplishes its object by polarizing a beam of radiation of a plurality of wave lengths, rotating with rotary dispersion means the planes of polarization of the polarized beam through arcs which are functions of the wave lengths so that difference of arcs causes effective coincidence of at least two of the rotated planes, selecting from the beam radiation of different wave length which is polarized in substantially coinciding planes, and rotating the selected planes with further rotary dispersion means through arcs which are functions of the wave lengths corresponding to

2

the coinciding planes but differ numerically from the first mentioned arcs, thus breaking said coincidence. After the second rotation radiation of one of the previously coinciding planes can be selected by polarizing means, thus obtaining a band which is narrower than that of the initially used radiation of a plurality of wave lengths. As applied to light, the invention contemplates considerable rotary dispersion of white collimated and polarized light in a column of quartz or other crystal through several full angles, and the segregation of several stages of coincident light of different wave length by polarizing means, and repeated rotary dispersion, each stage having a crystal and a polarizing selector, the crystals being so stepped as to thickness and hence degree of optical rotation, and the selectors being interconnected for simultaneous mechanical rotation at given gear ratios, that a narrow band of any desired wave length can be segregated from any region of the initially supplied spectral range.

In another aspect, apparatus according to the invention comprises means for plane polarization of light of a plurality of wave lengths, an optically active body having a face for receiving and a face for discharging the polarized light, this body being optically aligned to rotate the planes of polarization to different amounts depending on wave length, means at the discharging face for selecting light polarized in a given direction, and a second optically active body with a receiving face juxtaposed to the selecting means, the second body being optically dimensioned in relation to the first body to rotate the polarized light reaching it at its receiving face through amounts which are at its discharging face numerically different from the amounts of rotation in the first body, whereby light bands of different wave lengths which are superimposed at the discharging face of the first body are separated by the second body.

Other objects, aspects and features will appear, in addition to those contained in the above statement of the nature and substance including some of the objects of the invention, from the herein presented exposition of its basic theoretical principles and from the following description of several typical practical embodiments thereof illustrating its novel characteristics. This description refers to drawings in which:

Fig. 1 is a diagram illustrating the construction and function of monochromators according to the present invention;

Fig. 2 is a front elevation in general corresponding to Fig. 1;

Fig. 3 is a side elevation corresponding to Fig. 2;

Fig. 4 is a front elevation of the monochromator according to Figs. 2 and 3 showing the continuous adjustment and scale provisions; and

Fig. 5 is a detail section showing the mounting of a quartz column.

Fig. 1 incorporates and indicates diagrammatically the principal optical elements shown in detail in Figs. 2 and 3, which elements are in these figures marked with identical symbols. These optical elements are quartz or other crystal columns Q1, Q2, Q3 and Q4, polarizing plate or prism P, and polarizing selector plates or prisms P1, P2, P3 and P4, herein also referred to as analyzers. These are shown at the left hand side of Fig. 1. On the right hand side of Fig. 1 are developments Ib, IIb, IIIb and IVb of co-axial multi-shave cylindrical surfaces within the respective quartz columns, with the horizontal dimensions (representing angles and corresponding wave length respectively) considerably compressed. These developments are used to plot in rectangular coordinates the angular deviation or rotary dispersion of polarization within the quartz columns or blocks. In the center of Fig. 1 are diagrammatic top views of columns, represent-

ing polar scales corresponding to the developments and likewise indicating the rotary dispersion of polarized collimated light of various wave lengths, within the quartz columns; in addition these polar diagrams indicate the selective effect of plates P1, P2, P3 and P4. They are marked Ia, IIa, IIIa and IVa.

A light source for example a tungsten filament lamp emitting light which is collimated by lens L, is indicated at T of Fig. 1. It will be understood that the actual instrument, such as shown in Figs. 2 to 4, will usually not include lamp T and collimator L, these being part of standard optical laboratory equipment with which monochromators according to the invention are mainly used.

The faces of the quartz sections or columns are cut perpendicular to the optical or Z axis such that the plane of polarization of polarized light entering parallel to this axis will be rotated. The planes of light of different wave lengths are rotated different amounts, long wave lengths (red) being rotated less than short wave lengths (blue). If polarized white light enters a quartz section of sufficient length, the angles of rotation will exceed 360° (2π), so that the end or exit face of the quartz column discharges light of two or more superimposed wave lengths. If a polarizing plate is put into this emerging light, it will select the wave lengths in its plane of polarization. Thus, the rotary dispersion can be used to stretch the spectrum to any desired degree depending on the length of the quartz column, but this does not permit the segregation of any essentially single wave length band from the widely expanded spectrum. Such segregation is accomplished in accordance with the invention as will now be explained in detail.

The dimensions indicated in Fig. 1 are derived from a practical embodiment wherein quartz section Q3 is twice as thick as section Q4, section Q2 is twice as thick as section Q3 and section Q1 is twice as thick as section Q2. Section Q1 is right handed, whereas sections Q2, Q3 and Q4 are left handed. The selector plates P1, P2, P3, P4 are mechanically coupled as schematically indicated in Fig. 1 by gears G1, G2, G3, G4 on shaft S which can be rotated by means of knob K. For purposes of the diagram Fig. 1 it is assumed that plates P1, P2, P3, P4 are mounted on gear rings of equal pitch, meshing with toothed wheels fast on shaft S and having diameters stepped in the ratio 1 to 2 to 4 to 8 for gears G4, G3, G2, G1, respectively. Thus, while P4 rotates once, P3 rotates twice, P2 four times, and P1 eight times, as indicated in Fig. 1. Plate P is fixed relatively to the frame of the instrument. The quartz columns can likewise be fixed, as assumed in Fig. 1, or they can rotate with plates P1, P2, P3, P4 as shown in Figs. 2 and 3. The number, thicknesses and sense of rotation of the quartz sections and the movement of the selector plates or prisms can be different so long as they conform to the general principles of the invention, as will become apparent below.

The light from lamp T, collimated at L, and plane polarized at P, is rotated as indicated in Fig. 1 by helical traces in the elevation of quartz section Q1, further indicated by the polar diagram at Ia and still further by the Cartesian diagram at Ib.

Starting with angle zero for the white light polarized by plate P, the plane of the red light is rotated through an angle of a π and the thickness or blue light through an angle of a $\pi+8\pi$, it being assumed for purposes of explanation that the length of section Q1 is such that the utilized spectral region is rotated through an angle of 8π or sixteen right angles. Likewise for purposes of explanation, this region is subdivided into sixteen bands accordingly numbered at Ia and Ib.

Ignoring for the time being selector plate P1, we find that the spectral region stretched through 8π in column Q1, is rotated in opposite sense in column Q2 and hence shortened as indicated at IIb. A similar rotation takes place in columns IIIb and IVb, the angles being one half of the preceding ones, here for example a $\pi/2$ in Q2, a

$\pi/4$ in Q3 and a $\pi/8$ in Q4, for the blue light. The sixteen zones, an approximate wave length scale and an angle scale are applied to diagram Ib of Fig. 1. The straight lines in diagrams Ib to IVb indicate the rotation, through the respective columns, of the planes of polarization of the light of extreme wave lengths, called for short red and blue respectively; they correspond of course to the helixes of Q1. In diagrams Ia to IVa, the section numbers are applied to spirals extending through the appropriate angles with appropriate sense of rotation; the compression of the band width is likewise indicated at Ia to IVa.

Coming now to the function of the selecting polarizers P1, P2, P3, P4, it is assumed that these plates are oriented at angles $\pi/4$, $\pi/8$, $\pi/16$ and $\pi/32$ to the zero axis defined by the initial polarizer P. These angles are indicated in Fig. 1 between the polar diagrams Ia to IVa. We note that these angles correspond to the gear ratio 8:4:2:1. We note further that plate P1 passes the even numbered sections, that P2 passes sections 4, 8, 12 and 16, that P3 passes sections 8 and 16, and that finally plate P4 passes the single section 16.

A single section is thus segregated, and it will be evident from diagrams Ia to IVa, that any wave length can be selected simply by rotating knob K. If all five polarizers are effectively parallel in zero position, the emerging light is polarized in the plane defined by plate P.

Due to the properties of the polarizing material, the intensity distribution has for each selected zone a peak within an approximately sinusoidal distribution curve having two maxima and two minima for a rotary dispersion through 2π . Thus the selectivity is sharper than indicated by the mere width of a zone.

In order to permit mechanical rotation of all selector plates in the same sense (which is preferable for mechanical reasons) the first or thickest column (Q1) has to rotate the planes in the sense opposite to that of those following Q2, Q3, Q4. It will however be understood that all right-hand or all left-hand quartz can be used if the analyzer plates following the thickest and remaining columns respectively, are mechanically rotated in opposite sense, with the ratios of thickness and mechanical rotation the same, in accordance with the above explained principles of the invention.

It will be further understood that the complete optical rotation corresponding to the utilized spectral range is not necessarily a multiple of $\pi/2$, that the amount of optical rotation and hence the column lengths may vary with the width of the pass band depending on the thickness of the first column, and that the necessary number of quartz columns depends on the thickness of the first column; the thicker the first column, the more elements required and the narrower the final band.

It will now be evident that, in accordance with well known optical principles, the direction of the light can be reversed, with the polarized beam of white light incident at the thinnest quartz section.

It will be further evident that the principle of the invention can be applied to other than visible radiation, such as in the ultra violet and infrared ranges and beyond. The rotary dispersion can be carried out by any suitable means including those effective for this purpose in the Roentgen and gamma ray regions on the one, and ultra high frequency regions on the other side of the visible spectrum and the same holds for plane selection.

Generally speaking devices according to the invention provide for selection from a radiant energy spectrum with a frequency range a , of a band or zone of length a/n with a peak of intensity substantially at its center by polarizing in an initial plane a beam of radiation including frequencies within the range a , by progressively rotating this plane through angles which are functions of the frequencies such that the difference between the rotation of the lowest and highest frequencies within the frequency range of the spectrum is $qb\pi$, this rotation being carried out with a series of q rotary dispersion

5

means (q being the number, equal to 2 or a higher integer, of the dispersion means of the series, and b being a real number greater than $\frac{1}{2}$) which are axially aligned with the beam so that the series has two outer and at least two adjacent inner radiation transmitting faces, one of the outer faces being adjacent the means which determines the initial polarizing plane to receive the beam therefrom, by selecting radiation of given planes of polarization with rotatable polarization analyzers mounted between the inner faces and at the second outer face which analyzers are coupled to orient the analyzing planes at angles with the above initial plane in the ratio

$$c + m\pi, c + \frac{m\pi}{2}, \dots, c + \frac{m\pi}{2q-1}$$

(wherein c is a number including zero and m is a number exclusive of zero), and by rotating the analyzers relatively to the initial polarizing plane while maintaining their above ratio of orientation.

The mechanical construction of a practical embodiment of the invention will now be described with reference to Figs. 2 to 5. It will be noted that this embodiment differs from that of Fig. 1 in that the selector plates are fastened to and rotate with the quartz columns.

Figs. 2 and 3 show a supporting frame consisting of metal sheets 21, 22, 23, 24 distanced by tubes 26, 27, 28 and held together by bolts 31. The lengths of the tubes correspond to the thicknesses of quartz columns Q1, Q2, Q3, Q4. These and the polarizers P, P1, P2, P3, P4 are indicated in these figures in correspondence with the diagrammatic showing of Fig. 1. Plate P is mounted on a frame plate 29. The polarizing elements P, P1, P2, P3, P4 can be of the commercially available sheet or film type, with or without protecting glass covers.

The shaft S can be rotated with the aid of knob K and bevel gear G. Gears G1, G2, G3, G4 drivingly connect shaft S to the four quartz columns and selectors, by means of toothed wheels 31 fixed to the column mounts as indicated in Fig. 5 which also indicates sockets 33 for supporting the quartz sections on frame sheets 21, 22, 23, 24. The selector plates are cemented to the quartz, as likewise shown in Fig. 5.

The shaft S with its gears is axially secured by collars 41, 42 appropriately fixed thereto as by means of set screws 43, 44. The gears are conventional and need no further description; the proper gear ratio as at length discussed with reference to Fig. 1 and must of course be strictly maintained.

A housing H supports an indicator shaft 51 with gear wheel 52 that meshes with gear wheel 53 on control knob shaft 54, as also indicated in Fig. 4. A circular plate 56 with scale disk 57 is at 58 screwed to a smaller plate 59 fast on shaft 51 and turning within a circular window of housing H which carries a mark 61 for reading scale 62 on plate 57.

It will now be evident that manipulation of knob K rotates the plates P1, P2, P3, P4 and permits selection of an essentially nonochromatic band whose wave length can be read directly on the appropriately calibrated scale 57.

In order to protect the outer quartz faces, glass windows 66, 67 can be inserted in corresponding openings of the housing.

In the practical embodiment according to Figs. 2 to 5, the thicknesses of the columns are for Q1—60 mm., Q2—30 mm., Q3—15 mm. and Q4—7.5 mm., and the complete spectrum is in the first column expanded through 2,000 degrees. The average width of the emerging band is approximately 150 angstrom.

It will now be evident that, in the above embodiment, the number of zones n is 16, that the number q of rotary dispersion means (quartz columns in this embodiment) is 4; that b equals 2, and that m equals $\frac{1}{4}$.

It should be understood that the present disclosure is for the purpose of illustration only and that this inven-

6

tion includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. Apparatus for selecting radiation of given wave length from a radiation spectrum, which comprises means for plane polarizing collimated radiation of a plurality of wave lengths; a rotary dispersion body arranged for transmitting said radiation substantially parallel to its optic axis, from an entrant face adjacent said polarizing means to an exit face thereof, to rotate the planes of polarization of said radiation to different amounts depending on said wave lengths, said body having a thickness sufficient to rotate said planes relative to each other to an amount greater than substantially 180 degrees, causing coincidence of the planes of polarization of two different wave lengths of the radiation spectrum; polarization means at said exit face for selecting radiation polarized in a given direction; and a second rotary dispersion body with its entrant face juxtaposed to said polarization means and likewise transmitting said radiation parallel to its optic axis to its exit face, said second body being optically dimensioned in relation to said first body to rotate the polarized radiation reaching it through its entrant face, through angles the amounts of which are at its exit face numerically different from said amounts of rotation in said first body; whereby bands of different wave lengths whose planes of polarization coincide at the exit face of said first body are separated at the exit face of said second body.

2. Apparatus for selecting radiation of given wave length from a plane polarized radiation spectrum, which comprises a rotary dispersion body arranged for transmitting said plane polarized radiation substantially parallel to its optic axis, from an entrant face adjacent said polarizing means to an exit face thereof, to rotate the planes of polarization of said radiation to different amounts depending on said wave lengths, said body having a thickness sufficient to rotate said planes relative to each other to an amount greater than substantially 180 degrees, causing coincidence of the planes of polarization of two different wave lengths of the radiation spectrum; polarization means at said exit face for selecting radiation polarized in a given direction; and a second rotary dispersion body with its entrant face juxtaposed to said polarization means and likewise transmitting said radiation parallel to its optic axis to its exit face, said second body being optically dimensioned in relation to said first body to rotate the polarized radiation reaching it through its entrant face, through angles the amounts of which are at its exit face numerically different from said amounts of rotation in said first body; whereby bands of different wave lengths whose planes of polarization coincide at the exit face of said first body are separated at the exit face of said second body.

3. Apparatus according to claim 2 wherein said bodies are of substantially the same material and one body has substantially one-half the length of the other body.

4. Apparatus according to claim 2 wherein said dispersion bodies are of quartz cut perpendicular to the optic axis.

5. Apparatus according to claim 2 further comprising a second polarization means arranged at the discharging face of said second body.

6. Apparatus according to claim 5 wherein said polarization means is rotatable and coupled to rotate proportionate to said amounts of rotation provided by the dispersion bodies preceding the respective selecting means.

7. Apparatus according to claim 5 wherein said dispersion bodies are of substantially the same material and of different length, and the polarizing planes of said polarization means are oriented at angles which are proportionate to said lengths of said bodies.

8. Apparatus for the selection, from a plane polarized wave energy spectrum of frequencies within a given range, of a band or zone narrower than said range, comprising a

series of at least two wave energy transmitting rotary dispersion means essentially transparent for said range in paths on a given axis, each dispersion means of said series being adapted to rotate on said axis the planes of polarization of energy within said range, through angles which are functions of said frequencies and of the lengths of said paths in the respective dispersion means, the thickness of the entrant dispersion means of said series, on said axis, being such as relatively to rotate the planes of polarization for the highest and lowest frequencies of said range through angles the difference of which is $qb\pi$ with q the number, equal to 2 or a higher integer, of said dispersion means and with b a real number greater than $\frac{1}{2}$ ($qb\pi$ being thus greater than π), and the thickness on said axis of the other dispersion means of the series being such as relatively to rotate said planes of polarization through angles the difference of which is an integer fraction of $qb\pi$; a series of polarization means mechanically rotatable on said axis, one polarization means being placed at the outside of the last dispersion means of said series opposite to said entrant dispersion means, and the other polarization means being placed between each pair of dispersion means; and means for coupling said polarization means to rotate them simultaneously through angles in the ratio, counted in said axis from said entrant dispersion means towards said outside polarization means, of

$$(c+m\pi), \left(c+\frac{m\pi}{2}\right), \left(c+\frac{m\pi}{3}\right) \cdots \left(c+\frac{m\pi}{q-1}\right)$$

wherein c is a number including zero and m is a number exclusive of zero; whereby planes of polarization corresponding to frequencies of polarized energy entering the entrant dispersion means are spread by relative rotation therein through angles that are greater than π so that at least two frequencies have coinciding planes of polarization, whereby the consecutive dispersion means change the angles between the planes of polarization, and whereby each polarization means selects a plane of polarization to segregate frequency maxima with coinciding planes of polarization passed by the preceding polarization means, so that a single frequency maximum emerges through the outside polarization means.

9. Apparatus according to claim 8 wherein the dispersion means and the polarization means are fixed to each other and rotate together.

10. Apparatus according to claim 8 wherein the rotating effect of all dispersion means is in the same sense, and said coupling means rotates the polarization means fol-

lowing next to said entrant dispersion means in the sense opposite to the sense of rotation of the other polarization means.

11. Apparatus according to claim 8 wherein the rotating effect of said entrant dispersion means is in the sense opposite to the rotating effect of the other dispersion means, and said coupling means rotates all polarization means in the same sense.

12. Apparatus according to claim 8 wherein $q=4$, $n=16$, $m=\frac{1}{4}$, and $b=2$.

13. Apparatus according to claim 8 wherein said dispersion means are crystal columns cut perpendicular to the optical axis.

14. Apparatus for selecting zones of given wave lengths from a spectrum, which comprises a polarizer; a first quartz column cut with its faces perpendicular to its optic axis and at a distance adapted to rotate the plane of polarization of the blue light through an angle which is 8π greater than the angle of rotation of the red light, and arranged with one face adjacent said polarizer; second, third and fourth quartz columns optically aligned with said first column and cut similarly thereto so as to rotate the plane of polarization of the blue light through angles which are 4π , 2π , and π , respectively, greater than the angles of rotation, respectively, of the red light; four analyzers one following each column; and coupling means for rotating said analyzers such that the rate of rotation of the first analyzer to that of the following ones is in the ratio of eight to four to two to one; whereby each consecutive analyzer eliminates alternate wave length zones which have coinciding planes of polarization before they enter the column preceding the respective analyzer, so that a single zone with a wave length of maximum intensity emerges from the fourth analyzer.

References Cited in the file of this patent

UNITED STATES PATENTS

2,163,530	Thieme	June 20, 1939
2,184,999	Land	Dec. 26, 1939
2,527,593	Stadler	Oct. 31, 1950
2,531,823	Murray	Nov. 28, 1950
2,600,962	Billings	June 17, 1952

OTHER REFERENCES

J. O. S. A., Evans, vol. 39, March 1949, pages 229, 230, 237-239.