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# THE CHRISTIANSEN LIGHT FILTER: ITS ADVANTAGES AND LIMITATIONS

(WITH TWO PLATES)

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## INTRODUCTION

Since the Christiansen light filter is little known in this country, it is believed that a brief description of the filter and a discussion of its possibilities may be useful. The object of the present paper is threefold: 1, to report an improvement in the construction of the filter, which allows its use in an intense beam of light; 2, to discuss the advantages and limitations of these filters for general usage; and 3, to give some "practical suggestions" concerning the construction of these filters. The improvement mentioned has arisen from a need (in our laboratory) for an extensive beam of reasonably monochromatic light intense enough to produce an easily measured amount of photosynthesis in a higher plant. The second and third purposes of the paper are to answer numerous inquiries the writer has received during the past year.

## REVIEW OF LITERATURE

In 1884 C. Christiansen discovered that a mass of glass particles immersed in a liquid transmitted freely that color for which the liquid and glass particles had the same refractive index. He pointed out in two papers (1884, 1885) that any desired color could be obtained and that a color complementary to the one directly transmitted was seen at oblique angles. He also showed that the wave length of the transmitted ray decreased rapidly with an increase in temperature. After a paper with comments and improvements by Lord Rayleigh in 1885, the subject lay dormant for nearly 50 years with the exception of a descriptive paragraph in all editions of R. W. Wood's "Physical Optics." In a series of three papers F. Weigert and collaborators (1927, 1929, 1930) show the necessity of accurately controlling the temperature of the filters and the advantage of a refined optical system, and also describe a single filter that transmits red light when at 18° C.

and blue light when at 50° C. Konrad von Fragstein, in 1932 and 1933, describes a filter for the near ultraviolet. One filter covers the range from 3000 Å to 3700 Å by temperature variation. E. Knudsen, in 1934, discusses all the various ways of making these filters and points out the possibility of making a filter of particles of low-dispersion glass in combination with particles of high-dispersion glass fused together, both having the same index of refraction for the desired wave length. He has made such a filter but gives no details of its performance.

#### DESCRIPTION OF THE FILTER AND DISCUSSION OF ITS ACTION

In their commonest form these filters are made up of a solid pack of optical glass particles (0.5 to 2 mm in size) in a glass cell, with the spaces between filled with a liquid having the same index of refraction as the glass for the wave length desired. (The present paper is not concerned with the various emulsions and colloidal preparations exhibiting "Christiansen colors." Readers interested in these are referred to Knudsen, 1934.) Figure 1 gives the curves—index of refraction plotted against wave length—for a low-dispersion (borosilicate) crown glass and a suitable liquid—10 percent (by volume) carbon disulphide in benzene at 20° C. (both anhydrous). Remembering the laws of refraction and reflection at an interface, we see that for the wave length where both liquid and glass have the same index of refraction, the filter acts as a solid plate, and the rays of this wave length are transmitted without deviation or reflection loss within the filter. All other rays of shorter and longer wave lengths are deviated and reflected in an amount dependent upon the difference in the indices at the interfaces—glass to liquid and liquid to glass. Examining these curves in figure 1 more closely, we see that they depart from each other more rapidly on the blue side of the crossing than they do on the red side. This is typical of most suitable glasses and liquids. This shows that the filters will have a sharper blue "cut-off" than the red. Also a filter made for blue light will transmit purer colors than one made for longer wave lengths. These two characteristics are evident in the curves shown in figures 2 and 3. Obviously, it is desirable to use a glass of the lowest possible dispersion in combination with a liquid having the highest possible dispersion.

The refractive index of a liquid changes rapidly with its temperature in comparison with that of the glass. Hence the color transmitted by the filter will vary with its temperature. Thus to maintain a given color, the temperature of the filter must be held constant. For use

with light of low intensity, such as in visual work, a carefully thermostated water bath is sufficient. For use with intense light, such as direct sunlight, other more direct means of cooling (discussed below) are necessary. Weigert (1929), making use of this temperature co-

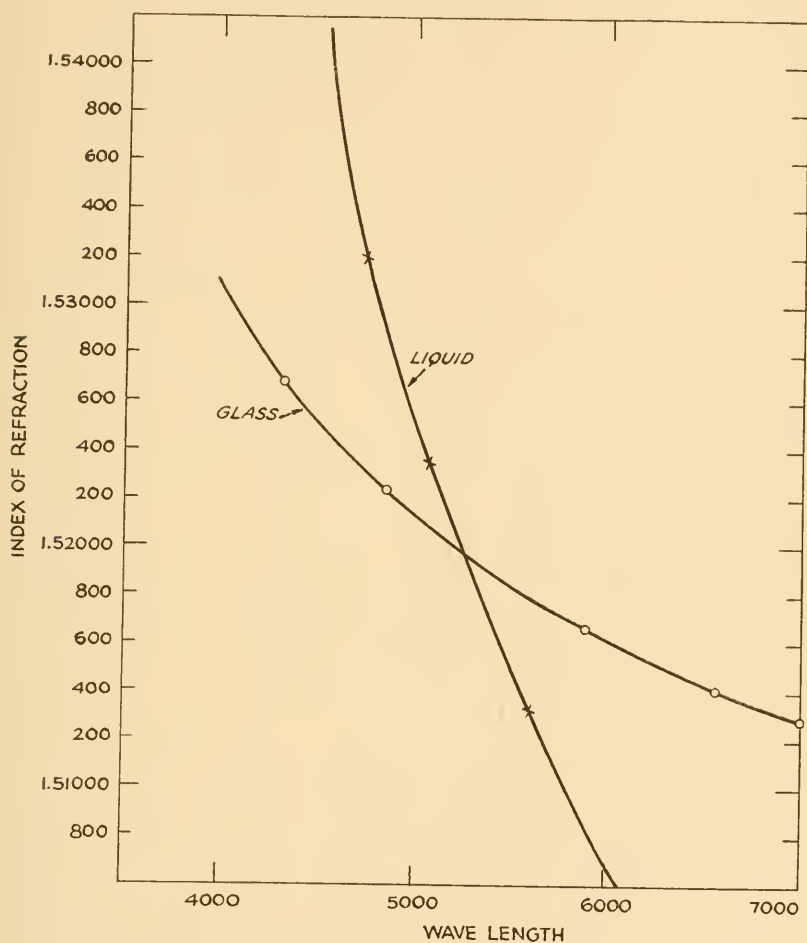


FIG. 1.—Index of refraction curves of the components of a filter.

efficient, constructed an ingenious filter using methyl benzoate with crown glass particles. This filter transmits red light when at 18° C. and blue at 50° C.

These filters are not used like the ordinary colored-glass ones. The "undesired" colors are not absorbed as in the case of colored glass, but are scattered symmetrically in a halo about the center line through

the filter. The angular position of a given "undesired" color about the axis of the filter depends upon two factors: 1, the difference in the indices of the liquid and glass for that wave length; and 2, the

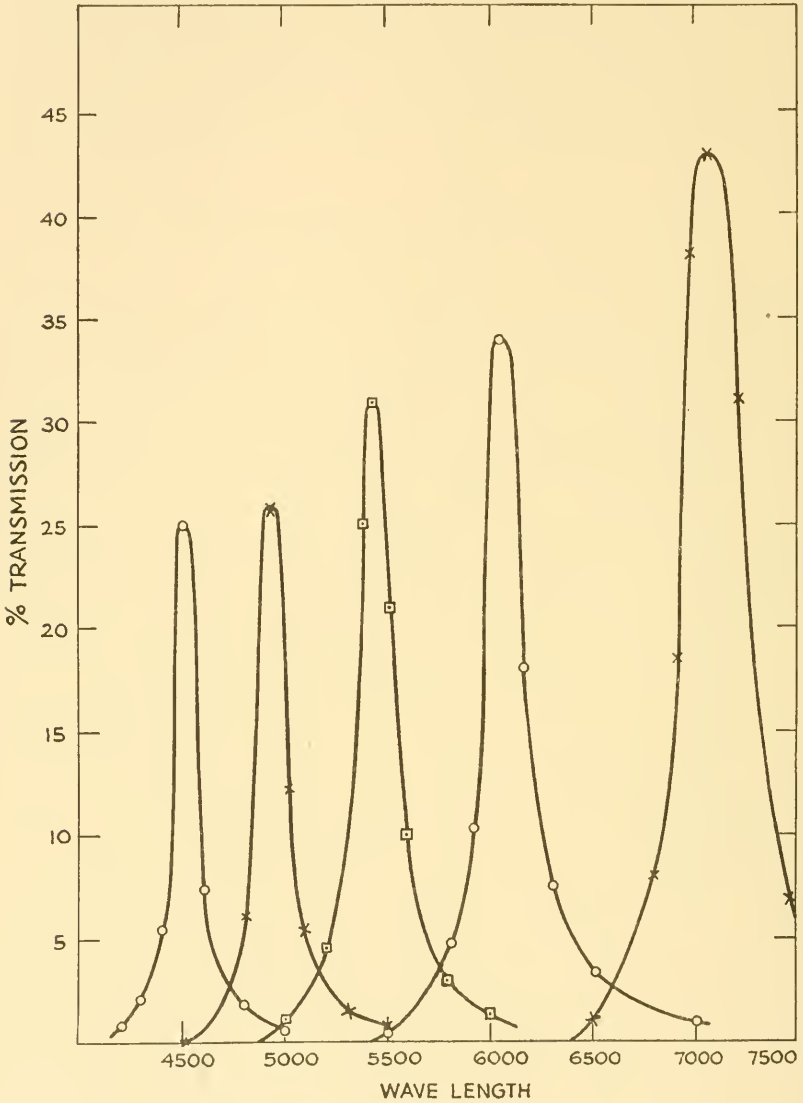


FIG. 2.—Transmission curves of a set of five filters at 20° C.

number of interfaces through which the beam passes (i. e., particle size and thickness of the filter). Also, since the interfaces are oriented in a random or probability manner, there exists only a "most proba-

ble" angle for a given "undesired" color and this color is in evidence in varying amounts at all angular positions about the axis of the filter. Some means of intercepting these "undesired" wave lengths is necessary. The simplest means is to use an optical system consisting of two lenses with the filter placed between them in parallel light. In this case the "undesired" wave lengths are cut out by a diaphragm placed at the image of the source of light. It is imperative that the opening in this diaphragm should conform with the shape of the source of light. If a filament is the source, the opening in the diaphragm should be cut to conform to the shape and size of the image of the filament. If this is not done, the maximum purity of color is not attained. Obviously, the purity of the color obtained increases with an increase in focal length or a decrease in numerical aperture of the optical system used. (See, for instance, von Fragstein, 1933, pp. 33 and 34.) Thus it is necessary to measure the transmission of the filter with the particular optical set-up to be used. Another way of using the filter is in parallel light—direct sunlight, for instance—employing a series of diaphragms to intercept the halo of "undesired" wave lengths. In this case it is necessary to place the filter at a considerable distance from the observer, since the purity of color obtained increases with distance from the filter.

Owing to the fact that the "undesired" colors are not absorbed but are scattered at various angles about its axis, the Christiansen filter cannot be used in any optical system where sharp images are desired. For instance, it cannot be used before the lens of a camera in photography. The only way it could be used in this respect is with its own optical system to illuminate the object (necessarily a small one) to be photographed.

Figure 2 shows the transmission characteristics of a set of five filters at 20° C. They are all made of borosilicate crown glass particles (1 to 2 mm in size) immersed in mixtures of carbon disulphide and benzene. The blue filter has about 4 percent (by volume) carbon disulphide, the red one 20 percent, and the others have percentages between these limits. These filters are 50 mm in diameter, 18 mm thick, and the windows are fused on optical flats. Two of them are shown in plate I. The transmission curves (fig. 2) were measured with the filters in parallel light between two 20-cm focal length lenses. A double monochromator and vacuum thermocouple were used to make the measurements. This purity of color is obtained only in the image of the filament used as a source.

A battery of 10 such filters ranging from ultraviolet to infrared, each selecting a spectral region about 150 Å wide (at half maximum),

was used by Messrs. Abbot, Stebbins, and Aldrich on Mount Wilson in 1934 to measure the distribution of radiation in the spectra of stars at the Conde focus of the 100-inch reflector. The filters were mounted within a constant-temperature box upon a squirrel-cage device, so as to be successively introduced into a collimated beam. The selected ray was brought to focus with a 19-cm focus lens. All this part of the experiment worked well, and owing to the short-focus objective lens

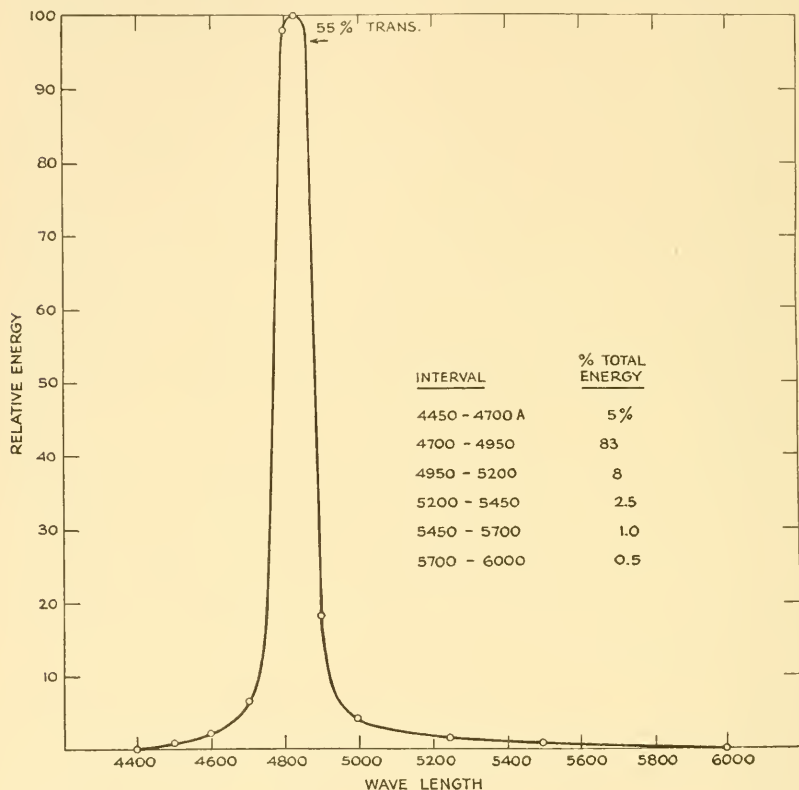
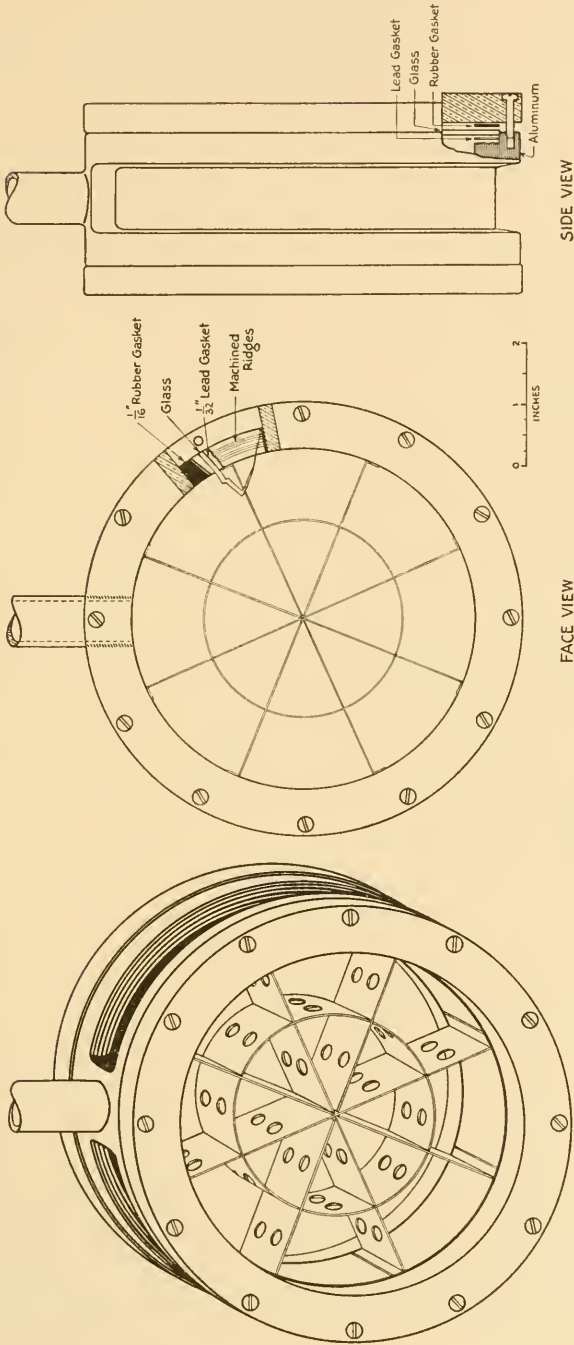


FIG. 3.—Energy transmission curve for a 6-inch diameter filter equipped with vanes.

the quality of the atmospheric seeing was immaterial. Unfortunately, the sharp peak of the photoelectric cell sensitivity proved fatal to the success of the observations. Small traces of stray light of bluish color were so disproportionately effective as to mask real values in the ultraviolet and the red. Dr. Abbot hopes to develop a sufficiently sensitive black receiver as a substitute for the photoelectric cell in future stellar work.

Figure 3 shows the energy transmitted by a 6-inch diameter filter (described below and detailed in fig. 4), using the parallel rays of





SIDE VIEW

FACE VIEW

FIG. 4—Diagrams showing detailed construction of a 6-inch filter with vanes.

direct sunlight. The observations were made 66 feet from the filter with the filter temperature held at 20° C. This purity of color is obtained over a 6-inch circular area at that distance.

#### AN IMPROVEMENT THAT PERMITS THE USE OF AN INTENSE BEAM OF LIGHT

The necessity of an optical system and the disadvantage of the temperature coefficient have been pointed out in detail in previous publications. However, for any exacting use of the filter where much light energy is used there is still another trouble which proves to be very serious: when a strong beam of light is forced through the filter, some energy is absorbed, and the center reaches a higher temperature than the edges, owing to poor heat conduction. The color transmitted is no longer pure, even when the filter is in a water bath. The writer has finally overcome this difficulty by inserting aluminum vanes through the body of the filter so as to cut off the least amount of light and carry off as much heat as possible. Details of a satisfactory filter equipped with these vanes are shown in figure 4. The body of the filter is cast aluminum, machined as shown, to take the glass windows and the necessary gaskets. No cement is known to the writer that will satisfactorily withstand the benzene and carbon disulphide mixture on the inside and the water on the outside. For this reason the windows were clamped on, as shown, with a soft lead gasket ( $\frac{1}{8}$  inch thick) underneath the glass. Ridges were machined on the aluminum face to press into the lead gasket and improve the seal. A  $\frac{1}{16}$ -inch rubber gasket is placed between the glass window and the brass clamping ring. The vanes are of  $\frac{3}{32}$ -inch aluminum assembled so that their extremities press firmly against the inner wall of the aluminum case, thus providing a path of good heat conduction from the inside of the filter to the surrounding water bath. The holes shown in the vanes allow the cell to be filled with the glass particles after it is assembled. Without these vanes, the center of this filter rose 9° C. above the temperature of the water bath when the rays from a 1,000-watt lamp were concentrated on the filter. With the vanes installed, the temperature at the center of the filter rose only 0.25° C. above that of the water bath under the same conditions.

Plate 2 figure 1, is a photograph of this filter in its water bath. The filter is filled with glass particles and a liquid (about 9 percent carbon disulphide in benzene), and gave the transmission curve shown in figure 3 under the conditions previously mentioned. Plate 2, figure 2, is a photograph of a 12 × 14-inch filter (not filled) with its water bath. When in use the water of the bath is thermostated and stirred.

Aluminum was chosen as the metal for the cell and vanes because it is least attacked by the various liquids used. The outside of the aluminum case must be carefully covered with several coats of waterproof paint.

#### PRACTICAL CONSIDERATIONS IN THE CONSTRUCTION AND USE OF THESE FILTERS

The Christiansen filter is little known in this country. For this reason the writer believes it will not be amiss to pass on to those interested some practical points concerning the construction of these filters and their uses. In this connection the writer is drawing on the literature cited and his own experience with these filters.

The type of cell chosen to hold the components depends upon the use to be made of the filter. For visual work and other uses where only moderate intensities are necessary, a glass cell with parallel windows fused on is suitable. If a permanent filter is desired, a small expansion chamber should be provided on the filling "neck," and after filling, the cell should be sealed off above the expansion chamber in a flame. To do this safely the expansion chamber should be packed in carbon dioxide snow. When high intensities of light are used, such as direct sunlight, the cell needs to be of the type detailed in figure 4. To be sure, a thin glass cell may be used for high intensity work, but the purity of color will be very inferior to that obtained with a metal-cased filter equipped with vanes.

The glass particles for the filter should be of the best optical quality obtainable—preferably low-dispersion borosilicate crown glass. Fused quartz is also suitable and of course necessary for ultraviolet work. However, the quartz should be free of bubbles and inclusions, as these lower the transmission of the filter and give it a muddy appearance. In preparing the glass particles, the writer has used the following procedure. If the glass or fused quartz is in large fragments, it is ground up with an iron mortar and pestle until the larger particles are 2 or 3 mm in size. This should be done with a minimum of grinding. A damp towel should be wrapped about the top of the pestle and draped over the top of the mortar to prevent the "dust" from flying. The operator should use some protection over his nostrils to avoid breathing the dust. The glass particles are graded by running them through several sizes of sieves. Before using, the particles must be carefully cleaned. This is best accomplished by boiling in chromic acid cleaning solution. The particles are then washed many times in clear water, then in distilled water, and finally dried completely. The particle size found suitable by previous workers and the writer ranges from 0.5

to 2 mm (usually graded closer—i. e., 0.5 to 1 mm, or 1 to 2 mm). A cell 15-mm thick using the 0.5 to 1 mm particles gives approximately the same results as a 30-mm cell using the 1 to 2 mm particles. With a given optical system, reducing the particle size or increasing the cell thickness gives a narrower transmission curve with lower percentage transmission at the "peak." In an "ideal" filter the glass particles would be perfectly homogeneous as to refractive index, and these particles and the liquid surrounding them would be all at exactly the same temperature. It is because these two conditions can never be realized that the percentage transmission at the "peak" decreases as the number of interfaces in the filter is increased.

In filling the cell it is best to put the liquid in first—enough to fill the cell about half full. The glass particles are then poured in slowly so that air bubbles are not carried down. It is difficult to free the cell of air bubbles after it is packed solid with the glass particles. The liquid or liquids used must be anhydrous and of the highest purity. The mixing of carbon disulphide and benzene—originally suggested by Christiansen in 1884—to obtain a liquid of any desired index of refraction (between that of pure benzene and pure carbon disulphide, of course) has been found very satisfactory by the writer in spite of its relatively high temperature coefficient. Methyl benzoate, used by Weigert (1929, 1930), in combination with crown glass particles makes a remarkably variable filter. Von Fragstein (1932, 1933) uses a mixture of 44 per cent alcohol (ethyl) and benzene with fused quartz particles for an ultraviolet filter. This filter, with suitable optics, transmits a narrow band of wave lengths in any desired part of the region 3000 Å to 3700 Å. The wave length of maximum transmission is shifted as desired in this region by temperature variation, just as in Weigert's methyl benzoate cell.

Various optical systems have been described in the literature. Weigert's (1929) autocollimator is of considerable interest as it passes the rays twice through the filter. The writer has shown that the filter can be used successfully without an optical system (other than plane mirrors and diaphragms) in direct sunlight, or, of course, in any beam of similar parallelism of rays. In using an optical system it is again emphasized that the diaphragm at the image of the source of light must conform in size and shape to this image. Any change in this diaphragm will change the transmission characteristics of the set-up. This is shown clearly by Weigert (1929, fig. 13, p. 159).

In the use of the filter for studying the wave-length effect of some photochemical phenomena it is necessary to allow for or take into account the effect of the "undesired" colors—i. e., those wave lengths

shorter and longer than the wave length of maximum transmission. In any case care must be exercised in determining the combined effect of the shape of the transmission curve of the filter, the wave length versus sensitivity curve of the phenomena under investigation, and, in the case where the energy content of the beam from the filter is measured with a photocell, the sensitivity versus wave-length response of the detector. For instance, if the energy in the beam from an ultra-violet filter is measured with a photocell that has its maximum sensitivity in the blue, considerable error may come into the final result owing to the long-wave-length "tail" on the transmission curve of these filters. (See von Fragstein, 1933, fig. 8, p. 33.)

The writer believes that these filters will be found of considerable value as a source of monochromatic light for rough visual measurements of refractive index, rotation of plane of polarization, etc., because one can set cross hairs on the wave length of maximum transmission within  $\pm 10$  angstroms. With a sealed filter and accurate temperature control this wave length of maximum transmission is sharp and reproducible.

The large filter shown in plate 2, figure 2, will be used with sunlight to irradiate a growing plant in an experiment to determine the wave-length effect of photosynthesis. At great distance it will yield a transmission curve comparable to that shown in figure 3. Two filters are to be used—one to cover the range 4000 A to 6000 A, the other from 5500 A to 8000 A. The wave length of maximum transmission is moved through these ranges by temperature variation.

The possibility of substituting a high-dispersion glass for the liquid—i. e., making the filter of a high-dispersion glass flowed around the particles of low-dispersion glass—is interesting. Knudsen (1934) has accomplished this, but gives no details. The resultant filter will have only a very small temperature coefficient, which will considerably enhance its usefulness. The writer has in his possession two suitable glasses, but has not yet had an opportunity to complete the filter.

The writer is grateful to A. N. Finn, of the United States Bureau of Standards, who has kindly furnished the borosilicate crown glass, and to L. B. Clark, of the Division of Radiation and Organisms of the Smithsonian Institution, who constructed the glass cells with fused-on optical windows.

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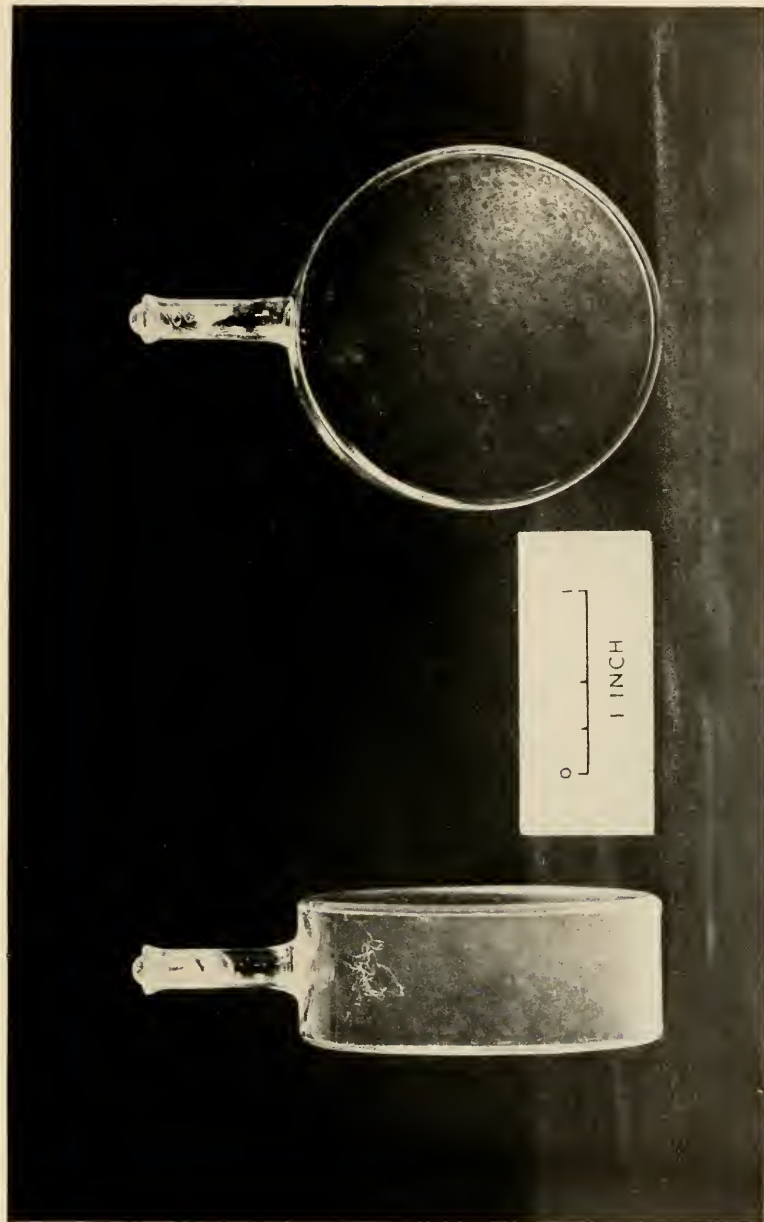
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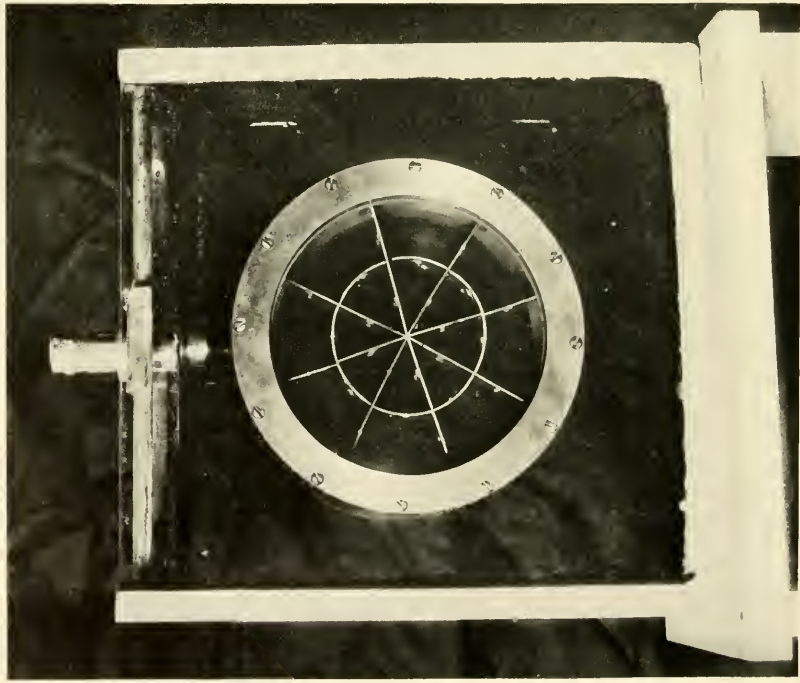
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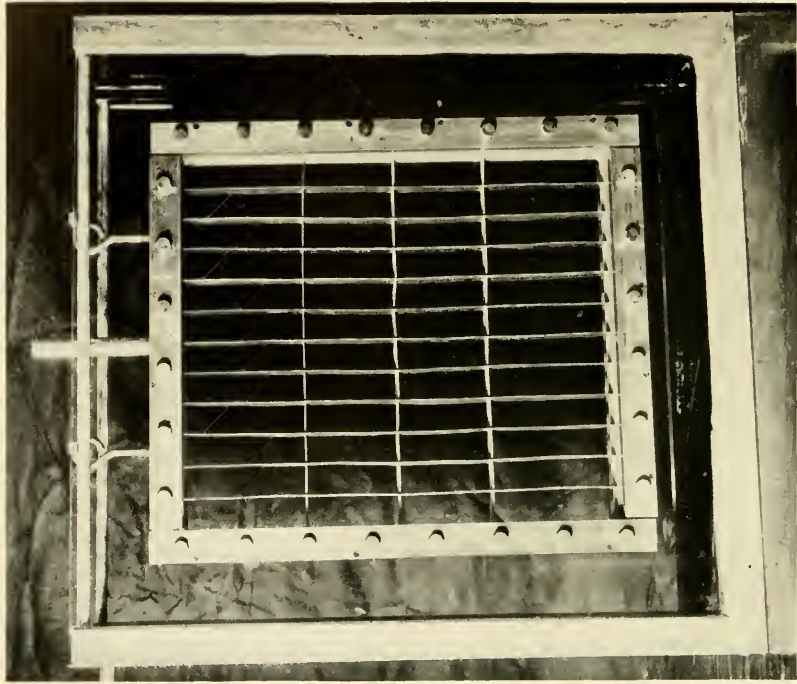
- Christiansen's experiment. In all editions of Wood's *Physical Optics*.



TWO-INCH FILTERS IN GLASS CELLS



1. A 6-INCH CHRISTIANSEN LIGHT FILTER WITH WATER BATH



2. A 12X14-INCH CHRISTIANSEN LIGHT FILTER WITH WATER BATH