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By

AUGUSTUS N. HILL

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

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APPROVED BY:

C. Fremont Harris
Chairman, Thesis Committee

A. F. Pershing
Member of the Thesis Committee

Sherman W. Eager
Head of the Department

D. C. McIntosh
Dean of the Graduate School

## PREFACE

The idea for this paper was a direct result of the writer's skepticism of the glowing advertisements of the various manufacturers of color films. Also, if color film could be used for direct application of scientific research, especially that in the realm of color, considerable effort could be saved. Letters to manufacturers got very little information as to the limitations of color films for such uses.

The writer wishes to acknowledge the assistance given him by Dr. S. W. Eager on photographic problems, Mr. C. Fremont Harris on problems of optics and lighting, and Mr. J. R. Wells, Tipton, Oklahoma, for the use of his Harrison Color Corrector Set and the many helpful suggestions he offered during the experiment.

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# Chapter I

## The Problem

For many years, man has sought ways and means to reproduce that which he has seen. Early stages of his development along this line are reflected in the ancient hieroglyphics left as memorials to the great men of times gone by. Attempts to use colors in addition of the hieroglyphics are evident in faint colorative stains still discernible.

Following this have been many means of expression and reproduction. Oil painting, early lithography, black and white photography, each has had, and still has, its place in the process of reproducing what man has seen and experienced about him. Added to this list now is color photography.

While color photography is not a new science, it has been only during the past fifteen or twenty years that it has enjoyed any marked degree of popularity among amateur photographers. In this time great advances have been made in the manufacture and processing of color film for the amateur. No longer is it necessary to own expensive equipment to enjoy this fascinating means of artistic reproduction. Indeed, if one is to believe the claims made either directly or by implication in the various and numerous advertising lay-outs of manufacturers, it would seem one needs only his eyes and "This Blah-Blah" film for artistic results to rival those of the great masters of painting. All colors will come out as pure as colors in dew-kissed roses. Exactly as it is in nature. Of course, such extravagant claims take on airs of wishful thinking to the man who uses his inquiring faculties at all. To the man with a scientific background, such claims are not well founded.

As an instrument of scientific endeavor, color photography has been widely advertised. Claims are made that the exact color of any object can be recorded for all time by use of certain color films. This has been advocated in the field of the biological sciences, especially. After having read much advertising on the subject, one is immediately faced by several questions. If there is any deviation of color rendition, is it constant, or does it vary with wavelength? Does the color shift vary with the color temperature of the source being used? Is the color shift characteristic of a certain basic type, i.e., subtractive or additive, processes? How will exposure time affect the fidelity of a particular color film?

All these questions must be answered before one can make any conclusive statements as to the adaptability of color film to precise uses. An effort will be made to answer them in this paper.

# Chapter II

## A Brief Historical Background of Color Photography

As previously mentioned, the desire to reproduce in color has existed in mankind for many centuries. In fact, early Japanese manuscripts have been found describing a process of reproduction which is very similar to modern lithography and color-printing.[1] This process involved transfer of color by superimposing many color screens on a marble slab or silk. No mention was made of how colors for each screen was determined.

Significant advances in the realm of color reproduction were not made until the period beginning with the early 17th century and continuing to the present. As far back as 1611, Antonius de Dominis postulated in a published work that all colors were formed by the absorption of white light by objects.[2] Indeed, he carried his theory farther by postulating that the fundamental colors were red, green, and violet and that all other colors were the result of differential absorption of white light by these fundamental colors. This theory is in striking agreement with present theories along this same line.

Shortly after Antonius de Dominis propounded this theory, Aquilonius (1613) advanced the theory that red, yellow, and blue were the primary colors.[3] To support his theory, Aquilonius set up a method of color synthesis using half-circles of light of the three colors.

Nearly fifty years later, Sir Isaac Newton (1666) discovered the solar

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1 E. J. Wall, History of Three-Color Photography, p. 2.

2 Ibid., p. 5.

3 Ibid., p. 6

spectrum by use of a prism.[4] With the discovery of the solar spectrum, which was continuous throughout the entire spectrum from the reds to the violets, there was positive proof that white light was the summation of many colors and not only three. This discovery did much to spur interest in color research.

Early in 1700, J. C. Le Blon, a French printer, introduced to Europe a color-printing process which is the very essence of modern color-printing techniques.[5] Le Blon first made use of copper plates to print with Newton's seven colors by superposition on a white background. As his colors were transparent, he got credible works. The process was tedious and time consuming, but it certainly was an advancement. The process, when used by others, resulted in a great deal of variation in results due to the fact that each operator used his own inks and there was no standardization of color between them. This lack of standardization in inks, however, was not the greatest source of variation. Le Blon had proposed no method for determining the composition of each color, so the actual rendition of color was entirely dependent upon the conception of the operator as to what colors and intensities composed another color. This, of course, presented a great limitation. In 1722, Le Blon changed his printing process to include only four keys (plates), one each for red, yellow, blue, and black to be printed upon "pure white". Here was modern color-printing in its infancy.

About 90 years later (1812), the world was introduced to the first practical mechanical method of reproducing colored pictures, lithography.[6] A Bavarian by the name of Senefelder began working colored pictures on marble

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4 <u>Ibid</u>., p. 6.

5 <u>Ibid</u>., p. 7.

6 <u>Ibid</u>., p. 15.

"stones" by using an etching through a grease coating. The grease would repel water in the regions in which it was left, but at the same time would be receptive to colored inks. In the regions where there was no grease, the water would cling and repel the ink. This work had to be done entirely by hand and was extremely laborious. Men spent years in apprenticeship before they were permitted to work their own "stones", and even then they were ultra-specialists in certain types of work.

While so much work was going on in the field of color-printing and reproduction, efforts were being redoubled to explain just why combinations of three colors could give the necessary impressions of all colors. It remained for Thomas Young to suggest a plausible explanation.[7] Young's theory of color vision explained, and still does, for that matter, many of the questions which had been raised. Young assumed that each normal eye contains three types of color-sensitive receiving areas. Each type shows a marked preference of one of the three primary colors: red, green, and blue-violet. Following Young's theory, as one looks at the spectrum, the impression of gradual color changes is caused by the change in the relative stimulation of these color-sensitive areas, or receptors. On the violet end of the spectrum, the blue-violet receptors are stimulated strongly and transmit this stimulation to what Young called the "sensorium" part of the brain. As the eye views successive portions of the spectrum, the various receptors are stimulated. In the case of the yellow, for instance, it was presumed that the red and green receptors are equally activated. For white light, all three types of receptors are activated equally. This theory of Young's fell into disuse, and it remained for Helmholtz to popularize it by performing a series of experiments and building up eye-color-sensitive curves.[8] Consequently, this theory is most frequently

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7 D. A. Spencer, Color Photography in Practice, p. 15.

8 R. A. Houstoun, A Treatise on Light, p. 344.

referred to as the Young-Helmholtz theory of color vision, today.

Shortly after Young published his theory of color-vision, Clerk Maxwell was the first man on record to propose the possibility of reproduction of scenes by color photography.[9,10] Maxwell pointed out that if the filtering out process were done by glass-filters in front of a camera instead of by the color receptors of the eye, identical end results could be possible. Here is an effort to build up what one thinks he sees rather than to reproduce actually the spectral wavelengths. A red flower appears red because it absorbs all but the red rays from white light, and these in turn stimulate the red-sensitive receptors of the eye. If this same red flower were to be viewed through a red filter, only the red rays from the petals would be permitted to pass through it. Following this line of reasoning, Maxwell proposed that successive pictures be made of the same object using the ordinary sensitive emulsions and red, green, and violet filters. This process would give what is known today as "separation negatives". It was then necessary to make a "positive" of each of these negatives. In order to integrate them into a single picture, Maxwell proposed that each of these separation positives be projected from a projector using the corresponding filter. If all three were projected simultaneously on a common screen, a color picture should result from the addition of the three colored lights. One of Maxwell's best friends, Thomas Sutton,[11] carried out Maxwell's instructions in a demonstration for the Royal Academy of Sciences in 1855. For some unexplained reason, Maxwell and Sutton chose to use four filters and projectors: red, green, yellow, and blue. A contemporary reported "that a sort of photograph....was produced in the natural colors."

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9 Wall, Op. Cit., p. 18.

10 Spencer, Op. Cit., p. 18.

11 Wall, Op. Cit., p. 31.

In France, there was a young and wealthy nobleman who not only was a patron of the sciences but who also worked diligently in his own small way. He had several friends who were members of the Academie des Sciences, but he was not himself a member. In 1862, Ducos du Hauron[12] sent his "Solution physique due probleme de la reproduction des coleurs par le photographie" to his friend. This friend read the paper and was greatly impressed with it. All his efforts to present this paper to the Academie were blocked by the prejudice of the members to a nobleman in science and also by the lack of proof of many of the things that du Hauron postulated in his paper. Du Hauron published his paper privately in 1868; it received a great deal of attention abroad, and was red in the Academie des Sciences shortly afterward. In his paper, du Hauron <u>predicted</u>, without designing or building models, nearly all of our present methods and processes in color photography. Most notable was his postulation of the "subtractive" color-printing process. Here the color-printing would be done in colors complimentary to those used in the actual photographing.

From the preceding paragraphs, it will be deduced that the trends for the perfection of a natural color process were aimed toward means of reproducing what a normal eye sees. A few of these processes developed in later years, such as the Lumiere process, Dufaycolor, Kodachrome, and Ansco Color will be discussed in later paragraphs. One process which was aimed to reproduce the actual wavelength was invented by Gabriel Lippmann in 1891.[13]

It is well known that standing waves may be set up by light waves as well as by sound and other wave motions. If light is incident normal to the first surface of a glass plate, a phase change of half a wavelength takes place. If

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[12] <u>Ibid</u>., p. 33.

[13] Houstoun, <u>op</u>. <u>cit</u>., p. 151.

it then is reflected perfectly from a second medium so that both the incident and reflected wave are traversing the same direct path, standing waves will be set up with nodes at the second surface and at distances of integral multiples of the half-wavelength from it. Between the nodes will be antinodes. Lippmann used this principle in his color reproduction. He backed a glass plate with a sensitive emulsion with a reflecting layer of mercury behind the emulsion. The light will enter the glass, pass through the film, be reflected by the mercury surface, pass through the film again, and then through the glass. Nodes and antinodes will be set up in the film by the principles of standing waves mentioned above. The sensitive emulsion will not be affected at the nodal points, but it will be affected a maximum amount at the antinodes. Thus, when the film is developed and fixed, there will be a great number of reflecting planes of silver at half-wavelength distances from the back surface and half-wavelength distances between each other. The thicknesses of the silver layers will be very thin and practically transparent. Now, then, if this plate is viewed with white light normal to the surface, the individual layers of silver will each reflect its own waves. All the constituent rays will be reflected, but only those whose wavelengths are such that they will reinforce themselves will be seen on reflection. All others will be destroyed by destructive interference. By this action, the natural colors originally incident upon a certain area of the film will be seen upon reflection. It can be seen readily seen that this process would result in only the spectral wavelengths incident. It has one very serious drawback, namely: the film must have a very fine grain emulsion. Present day emulsions give good results, but the care which must be exercised in developing and handling makes this process very difficult to use.

In the following discussions, the term additive color process shall apply to those processes in which the positive permits passage of the color with which the negative was made in the parts of the image where this color is present. A subtractive process removes from white light those primary colors with which the negative was taken, in the parts of the image where those colors were absent.

The first commercially successful additive color process was the Lumiere Autochrome plate.[14] This plate has since been introduced as a roll film. In Autochrome an irregular mosaic screen is used as the needed filters. This mosaic screen is prepared by taking three portions of potato starch grains and dyeing them red, green, and blue-violet, respectively. After dyeing, these grains are mixed as thoroughly as possible and then sprinkled on a sticky surface. Any surplus grains are brushed off lightly. Regions not filled by starch grains are filled in with pulverized lamp-black. This entire plate is then pressed under high pressure, and the starch grains thus are flattened into irregularly spaced red, green, and blue-violet filters. Upon this mosaic screen surface, a panchromatic emulsion is deposited. In development, the exposed film is developed once, reversed, and redeveloped so that there are areas behind the mosaic screen which will transmit light in varying intensities according to the intensity of the light incident upon it <u>after</u> passing through the screen. So, upon projection, the taking mosaic serves as a projection screen for color addition.[15]

Another additive process which enjoyed considerable use by amateur photographers in this country before World War II was Dufaycolor. Dufaycolor film was a mosaic screen type of film as was the Autochrome.[16] Its distinguishing

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[14] Spencer, *op. cit.*, p. 136.

[15] J. E. Mack and M. J. Martin, *The Photographic Process*, p. 183.

[16] *Ibid.*, p. 383.

feature being a regular geometric screen rather than an irregular mosaic screen. This screen is built up by "cross-hatching" the face of the film with alternate rows of red and a combination of blue and green squares. This is achieved by successive inkings and rulings. In the completed product, the little squares formed are about 0.002 sq. mm. While this is approximately three times as large as the average potato starch grain, it still cannot be detected by the eye on normal projection and is further rendered less undesirable by the geometric pattern.

Of particular interest to the amateur photographer are two relatively new types of films. These are Kodachrome and Ansco Color. Both of these films are of the subtractive color process type, both are "integral tripacks", and both are "dye-coupled" emulsions. The meaning of subtractive color process has already been dealt with. By "integral tripacks" is meant the building up of the film on one base with the three color sensitive layers on this one film base. The implications of "dye-coupled" will be treated with individually as the dye-coupler process is the distinguishing difference between Kodachrome and Ansco Color.

Kodachrome film, introduced in 1935, is the first integral tripack type of color film to be introduced.[17] As the case in all tripacks, it has three emulsion layers, each specially sensitized, built up on a single gelatine or cellulose base. The first emulsion next to the base is one which is of the panchromatic type and more especially sensitive to red. The second layer from the base is an orthochromatic emulsion and sensitive to green. The top layer, and third from the base, is a non-color sensitized emulsion which will respond only to the blue or violet rays. Between the red-sensitized and green-sensitized layers is a very thin gelatine layer dyed a light red color. The green-

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17 Spencer, op. cit., p. 136.

sensitive and blue-sensitive layers are separated by a thin yellow gelatine layer. As to filter action, the blue layer needs no filter since it will react only to the blue light. The yellow filter just before the green-sensitive layer will pass both green and red light. The red filter will pass only the remaining red rays to affect that layer of emulsion. Upon developement, the entire film is developed and then the image is reversed and dissolved. Following this, it is redeveloped through a series of operations:

1. All three of the reversal positive images are developed in a dye-coupler developer. Here a certain component of the developer reacts chemically with silver halides of the image to give a blue-green (minus red) image in all three layers.

2. The two top layers are then bleached out by a very carefully controlled diffusion process, leaving the minus-red image on the third layer. After bleaching, the two top layers are again redeveloped to produce a magenta (minus-green) image.

3. The outermost layer then is bleached and redeveloped to produce the yellow (minus-blue) image.

4. The silver image which is left now is removed, and the final "transparency" is ready for projection as a series of three colored-layers: blue-green (cyan), magenta, and yellow.

It is apparent from the above process that this film requires precision control during development, and it is because of this that the manufacturer recommends its return for development. In fact, the original cost of the film is a price figured on that procedure.

Since it is known from Planck's radiation law that the color distribution of the light from the same source operating at differing temperatures, or from fixed temperatures of different sources, is not the same, Kodachrome is "balanced" for a particular type of light. Daylight has a much larger portion of blues and violets and is approximately equalled by a black-body radiating at a temperature of 5900°K. Ordinary tungsten filament lamps operate with a "color temperature" of approximately 3200°K. A certain type of tungsten filament lamps designed to operate on 70 volts are actually operated at 110 volts. These lamps, called photoflood lamps, are brilliant and have a color temperature of approximately 3400°K. To allow for these three basic types of lighting, Kodachrome is issued in types balanced to each. If a certain type of film is used with a type of lighting for which it is not balanced without a compensating filter, the results will be a "cold" or "hot" according to whether or not the film is balanced for red or blue predominance in the source. For example, if Kodachrome Type A (tungsten, 3400°K.) is used outdoors without a peach-colored compensating filter, the results will be "cold", or predominantly blue, transparency because the film was originally manufactured so as to filter out some of the excessive red found in the lower temperature source. So, in daylight, the same reds would be filtered out and leave the blue portions of the spectrum.

The color film now known as Ansco Color was first introduced in America as Agfacolor in 1937.[18] Ansco Color is also an integral tripack, dye-coupler film. Its distinguishing feature is that a single, specialized developer which contains one essential element of a series of dye-stuffs reacts with the other constituents which are incorporated in the emulsion at the time of manufacture to produce an insoluble dye wherever a silver image is formed on development of the exposed film. The color produced, of course, is dependent upon the second constituent contained in the film. The constituent needed to produce red in one layer, that for yellow in a second, and that for blue-green in a third.

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18 Ibid., p. 138.

After exposure, the Ansco Color film is developed and reversed as is Kodachrome, but, from this point on, the processes differ widely. In Ansco Color, the reversal positive is developed only one time in the special developer so the colors are formed in one processing. Then the silver image is dissolved, leaving a subtractive color image. The end result is the same as in Kodachrome, but the process is simple enough to be carried out by the advanced amateur in his own dark-room with little special equipment.

One interesting aspect of a dye-coupler film is that the image is actually almost grainless,[19] and the objectionable mosaic screen is not present to be seen upon extreme enlargement. It must, of course, be pointed out that this apparent grainlessness is no better than the grain of the emulsion used. This defect is largely overcome in Kodachrome due to the fact that the dyes formed in this process diffuse between grains a great deal. Both Ansco Color and Kodachrome permit of greater sharpness in the image than is possible using a mosaic screen.

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19 Mack and Martin, op. cit., p. 388.

## Chapter III

### Conditions and Procedures Followed

Since the object of this paper was to investigate the color fidelity of some commercial color films, it was decided to use the two brands of color films most readily available to the amateur and the laboratory worker. Of these, the types of each which were color balanced for use specifically to daylight and tungsten sources were used. From here on, these films will be referred to as follows:

Film "A": A film balanced for use with 3400°K. sources and should be processed by the manufacturer.

Film "B": A film balanced for use with 5900°K. sources and should be processed by the manufacturer.

Film "C": A film balanced for use with 5900°K. sources and may be processed by advanced amateurs or commercial firms other than the manufacturer.

Film "D": A film balanced for use with 3200°K. sources and may be processed by advanced amateurs or commercial firms other than the manufacturer.

It would be very difficult, indeed, to make any measurements of spectral color shift unless the actual wavelength to the light used is known. In order to achieve this end, monochromatic light sources were set up. Sources with bright-line spectra, such as the mercury arc, sodium arc, helium and hydrogen spectrum tubes, were used. A great number of combinations of filters were tried before it was possible to get what appeared to be monochromatic light as observed through a Gaertner wavelength spectrometer. The lines finally used were (with their sources):

7065 AU--Helium gas spectrum tube.

6563 AU--Hydrogen gas spectrum tube.

6158 AU--Sodium vapor lamp (actually the mean of the 6154 AU and 6161 AU lines).

5893 AU--Sodium vapor lamp (actually the mean of the 5890 AU and 5896 AU lines).

5780 AU--Mercury vapor lamp (actually the mean of the 5770 AU and 5791 AU lines).

5461 AU--Mercury vapor lamp.

4916 AU--Mercury vapor lamp.

4471 AU--Helium spectrum lamp.

4358 AU--Mercury vapor lamp.

These sources, then, would give monochromatic light over a fairly well proportioned span of the visible spectrum. While it is realized that more sources may have lead to more conclusive results, the economic factor had to be considered.

Original plans called for these monochromatic sources to shine upon a reflectance plate, and the exposures to be made with the reflected light. A large sheet (14" x 16") of ¼" aluminum plate was polished and then coated with an even coating of magnesium oxide (MnO). Magnesium oxide smoke, obtained by combustion of magnesium ribbon in air, was used because it has very high and uniform reflectance for the entire range of the visible spectrum. When the reflected light from this plate was measured, it was found that many of the intensities would be so low that undesirably long exposures would be necessary. This made it necessary to use an exposure from the direct light.

First efforts at determining the exposure for the direct light indicated that these exposures, also, would be very long. In order to overcome some of this long exposure, a photosphere was designed about the spectrum tubes so that a larger portion of the emitted light could be directed into the lens of the camera. Various schemes were used, but the one which seemed to give the best results involved two parabolic mirrors (see Fig. 1).

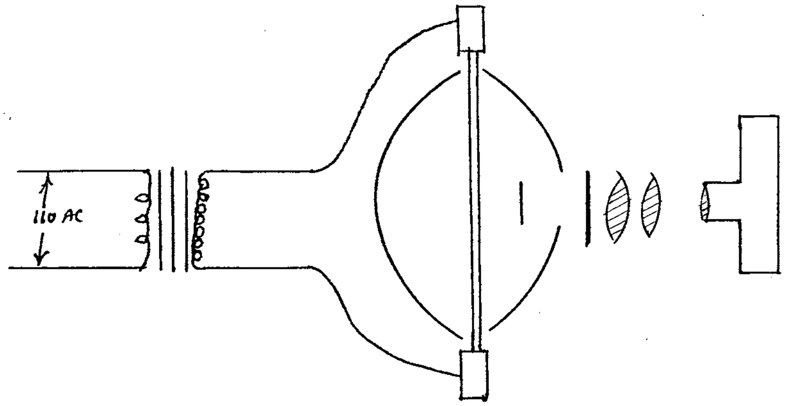


Fig. 1

A parabolic mirror (actually the reflector from an automobile headlight) was cut to accomodate a spectrum tube along a vertical axis through the focus of the parabola. This mirror was suitably mounted on a base with strap-iron legs. Immediately in front of this mirror and facing it, was another parabola mirror of the same dimensions as the first. At the focus of this parabolic mirror, was placed a small spherical mirror. With this arrangement, it was possible for rays of light from the spectrum tube to rendered parallel by the first mirror. These parallel rays, upon striking the second mirror, would then be reflected through its focus, at which point was the spherical mirror. This spherical mirror reflected these rays out through a hole cut in the second parabolic mirror. After passing from the photosphere, the light was passed through the necessary filters and lens to the camera.

Considerable difficulty was experienced in locating the small mirror at the proper position, but worthwhile results were achieved. The amount of light incident upon the exposure meter used was increased by about 20%. When the spherical mirror was replaced by a small plane mirror, an additional gain of 5% was achieved.

There was still the probability that an image of the spectrum tube would be formed in the camera even after the light was rendered parallel by use of a lens system and a very short focussing distance on the camera were used. To reduce this chance to the minimum, the mirror surfaces of the parabolic reflectors were coated with magnesium oxide smoke. This coating of magnesium oxide seemed to reduce the amount of the light from the photosphere but very slightly, while the image of the spectrum tube was eliminated entirely.

Although monochromatic light was to be used, there was some question as to whether or not there was any necessity to correct the exposures for color balance of the film to the color temperature of the source. By theory, this color correction would render the light from a particular source in balance with a black-body radiating at the temperature at which the film was balanced. However, by reasoning, the aim was not to arrive at a balance of all colors in this experiment, but to expose to monochromatic light only. If only one wavelength were in the light, then a balance should not be necessary. It was finally decided that exposures would be made both with and without color correction for the color temperatures of the bare sources. The color correction was achieved by using filters taken from a Harrison Color Correction Set, Series VI, and exposures corrected according to the filter factors furnished by the manufacturer.

The color temperature of the various sources used were:

Helium spectrum tube--4300°K.

Hydrogen spectrum tube--6500°K.

Sodium vapor lamp--2800°K.

Mercury vapor lamp--5900°K.

The color temperature of the mercury arc lamp was such as to make it not necessary to correct to achieve color balance when using a film rated as a daylight type.

The exposures necessary were determined by use of three exposure meters: a Sixtus, German-made and reputedly very sensitive in low intensities; a Weston II, a very popular and sensitive meter; and a DeJur 5B. Upon taking readings, if the three meters agreed upon the same exposure, it was taken to be reliable. If only two agreed, the exposure was taken with misgivings. However, if no two agreed, it was necessary to estimate which *might* be right. It was these latter exposures which had the greatest number of retakes necessary. (On the whole, the Sixtus did show a reliability in the low readings.)

Since a basic intent of the experiment was to observe the effect of exposure on the color rendition, three exposures were determined: first, fifty per cent over the *indicated* exposure (+ 50%); second, the same as the indicated exposure (± 0%); and third, fifty per cent less than the indicated exposure (- 50%). Color correction filters made it necessary to multiply these exposures by the proper filter factors.

In order that the fidelity of the transparencies resultant to the exposures determined above could be checked in some manner, a means had to be devised. If the color film were capable of reproducing only the spectral wavelength to which it was exposed, the comparison would have been a simple case of using a wavelength spectrometer to determine this one wavelength produced. However, since color film of the types used in this experiment are "tripacks" and depend upon three-color reproduction to simulate what the eye sees, it would be incorrect to make such an assumption. If, on the other hand, the film actually recorded other colors besides the one, as does happen, it would be reasonable to expect a maximum transmission of the subject wavelength when the transparency is illuminated with white light. It was on this latter premise that all further checking was done.

Comparison of the transmission of the transparencies formed by exposing the film to the various monochromatic lights as outlined above was done by using a Gaertner Polarizing Spectrophotometer. The Gaertner Polarizing Spectrophotometer consists of three essential parts: 1) a wavelength spectrometer; 2) a Martens polarizing photometer; and 3) photosphere and holders to illuminate the samples.[1]

Light from the lamps of the photosphere is reflected from a magnesium oxide-coated disc out of the photosphere to a pair of rhombs made of soft crown glass. These rhombs split this single beam into two equal beams. One of these, the upper one in practice, is directed through the sample of unknown transmission, and the second beam is passed through a standard sample, or no sample at all--a "blank beam". This latter case is the condition used in this experiment. From the sample holders the light proceeds to another pair of rhombs which reunite the beams into another beam, composed of two sharply divided half-circles of light, one from each sample holder. This beam is then directed upon a Wollaston biprism which serves as the polarizing element of the Martens photometer.

While this beam is said to be reunited, actually it is still of two parts, upper and lower. As they pass through the Wollaston biprism each is separated into two plane-polarized beams.[2] The ordinary polarized beam is lost, leaving the extraordinary beams which are polarized in planes at right angles to each other. Upon emergence from the Wollaston biprism, they are directed through the Nicol prism which is used as an analyzer. Rotation of the Nicol prism will result in an increase in intensity of one of the beams. The angle of rotation $\theta$ is a measure of their relative intensities in that the amplitudes of each beam varies with the angle $\theta$: one beam as the $\sin \theta$, and the other as the $\cos \theta$. The ratio of intensities varies as the $\cot^2\theta$, if the sample is in the upper

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[1] Bulletin 126, Optical Instruments of Recent Design, Gaertner Scientific Corp., p. 12.

[2] Ibid., p. 15.

beam and the standard in the lower beam. From the analyzer the beam is directed into the entrance slit of the wavelength spectrometer which uses a constant deviation prism to disperse the beams into their respective spectra, one above the other. It is the job of the operator to adjust the analyzer prism so that the two fields are of equal intensities; this "match point" is obtained when the dividing line between the two half-circles is no longer visible.

The procedures outlined above were followed through, and exposures made for each of the wavelengths chosen for all four types of film used, for +50% and -50% as well as for the basic indicated exposure, and corrected and uncorrected for color temperature balance. Some two hundred fifty exposures were made and analyzed.

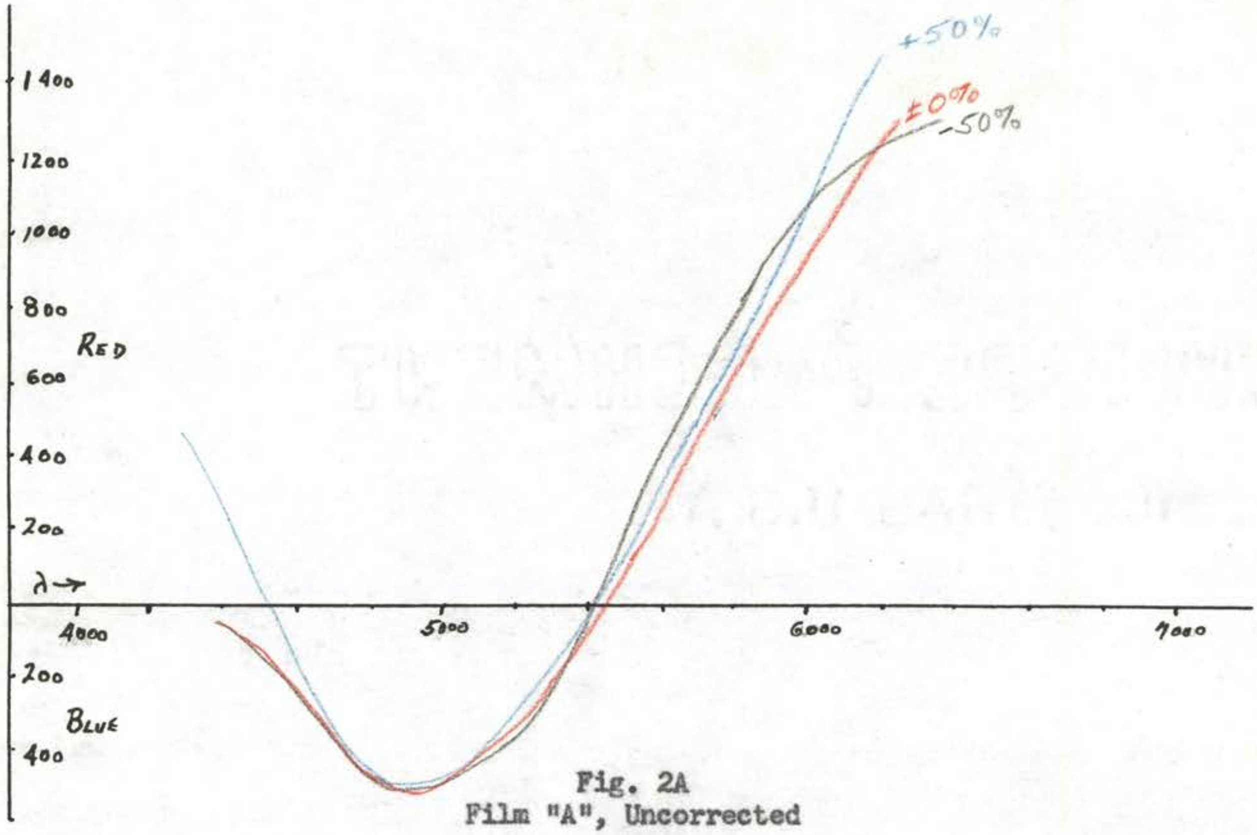


**Fig. 2A**
**Film "A", Uncorrected**

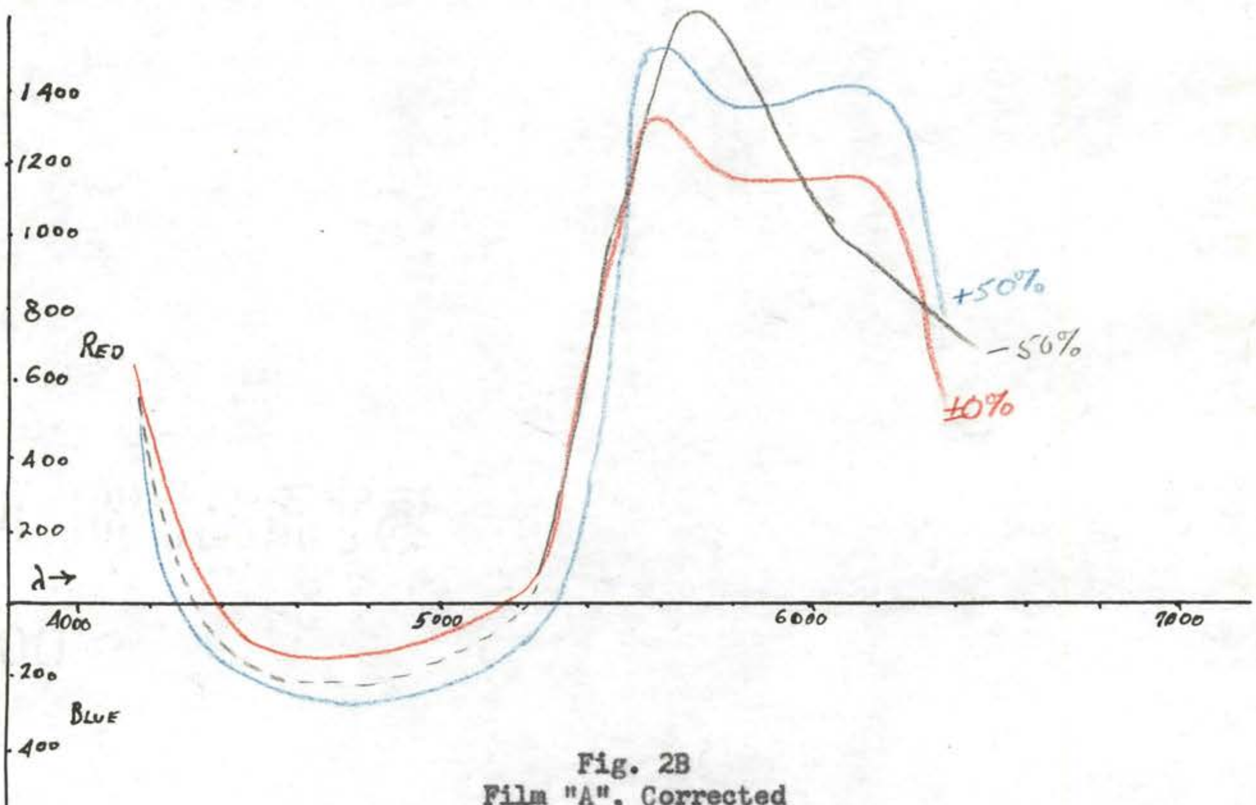


**Fig. 2B**
**Film "A", Corrected**

# Chapter IV

## Analysis and Conclusions

### A. Analysis

The data contained in the tables included with this paper were plotted in ordinary Cartesian coordinates. When this was done, the three curves for each wavelength, uncorrected for color temperature, were plotted separately from those for temperature corrected exposures. It was from these graphs that the spectral shifts were determined. Upon determining the spectral shift from the subtraction of the monochromatic wavelength from the wavelength of maximum transmission through the transparencies, the spectral shift was plotted against the wavelength of the monochromatic light used for the source.

Film "A" there was a very large spectral shift noted in the yellow region toward red, or longer wavelengths. This shift was so very pronounced that the yellow-doublet from sodium was a definite orange color. This was true of both exposures corrected and uncorrected for color temperature. A shift toward short wavelengths was found to take place between 4300 AU and 5400 AU, but this shift was only about one-sixth as great, in the maximum, as took place above 5400 AU. Zero shift was indicated by all three exposures at approximately 4400 AU and 5400 AU. The shift for the 6563 AU light could not be determined due to the fact that the transparency made for this wavelength indicated increasing transmission in the long wavelengths; it is possible that the maximum shift was reached beyond the visual range of the observer. Film "A" had the maximum shift about 5900 AU (corrected) and at an estimated 6500 AU (uncorrected). In general, the spectral shift for the +50%, ±0%, and -50% exposures gave very closely parallel curves. The exposures for ±0% showed the least shift throughout the spectrum. The -50% exposures had less shift in the red and more shift in the green and blue regions than did the +50% exposures.

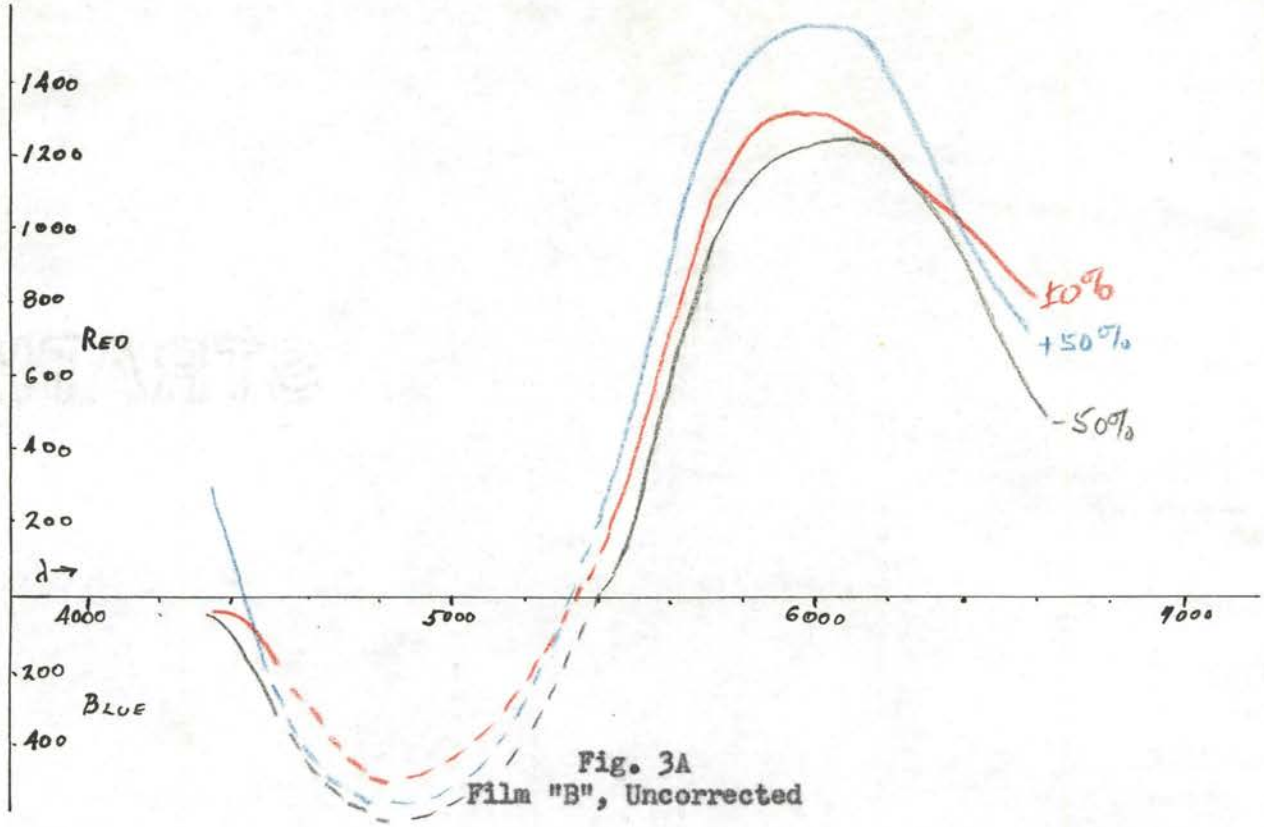


Fig. 3A
Film "B", Uncorrected

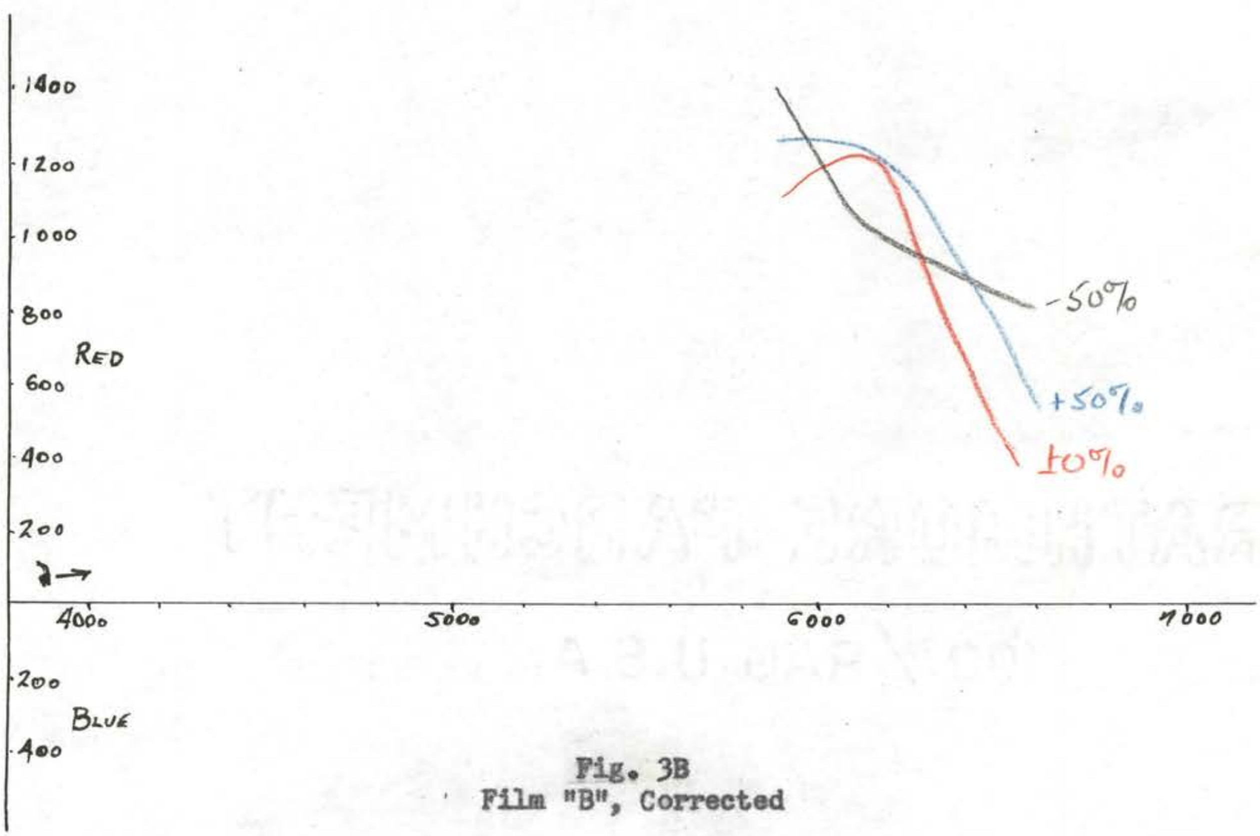


Fig. 3B
Film "B", Corrected

Film "B" showed the same general characteristics as Film "A" except that the maximum shift in Film "B" occurred at about 6000 AU (uncorrected) and was slightly less in magnitude. In general, there is a shift towards the longer wavelengths above 5200 AU (approximately) and shift toward short wavelengths between 4400 AU and 5200 AU. The shift toward blue was not as great with Film "B" as with Film "A" when corresponding types of exposures are considered. The graphs for the corrected exposures for Film "B" indicated an increasing shift to the blue but did not exhibit a maximum from which to compute the spectral shift. In general, the spectral shift for the +50%, ±0%, and -50% exposures resulted in parallel graphs with the -50% exposures exhibiting the least shift in the green and blue regions. What happens through much of the spectrum for the transparencies made with exposures corrected for color temperature correction annot be inferred since these graphs, as a whole, indicated the possibility of a maximum outside the visual range of the observer.

Film "C", in the uncorrected series, exhibits a maximum shift at approximately 5900 AU. This shift is in the order of 1500 AU toward the red, enough to make the 5893 AU yellow-doublet appear a very definite red. The shift is toward redness from approximately 5200 AU upward and below 4400 AU. If one should extrapolate the portions of the curves that are definitely known, a shift to the blue of approximately 700 AU at 4800 AU can be inferred. The ±0% transparency exhibits the greatest shift above 5200 AU and below 4400 AU. The zero spectral shift for Film "C", uncorrected, is found at approximately 5300 AU and 4400 AU. The data for Film "C", corrected, is so very meager that no conclusions could be deduced from it.

Film "D", uncorrected, exhibits a maximum shift toward the red of about 1300 AU in the neighborhood of 5900 AU. The uncorrected series, by extrapolation, indicates a maximum shift toward the blue of approximately 500 AU in the vicinity of 4800 AU. The +50% and ±0% exposures, uncorrected, are roughly

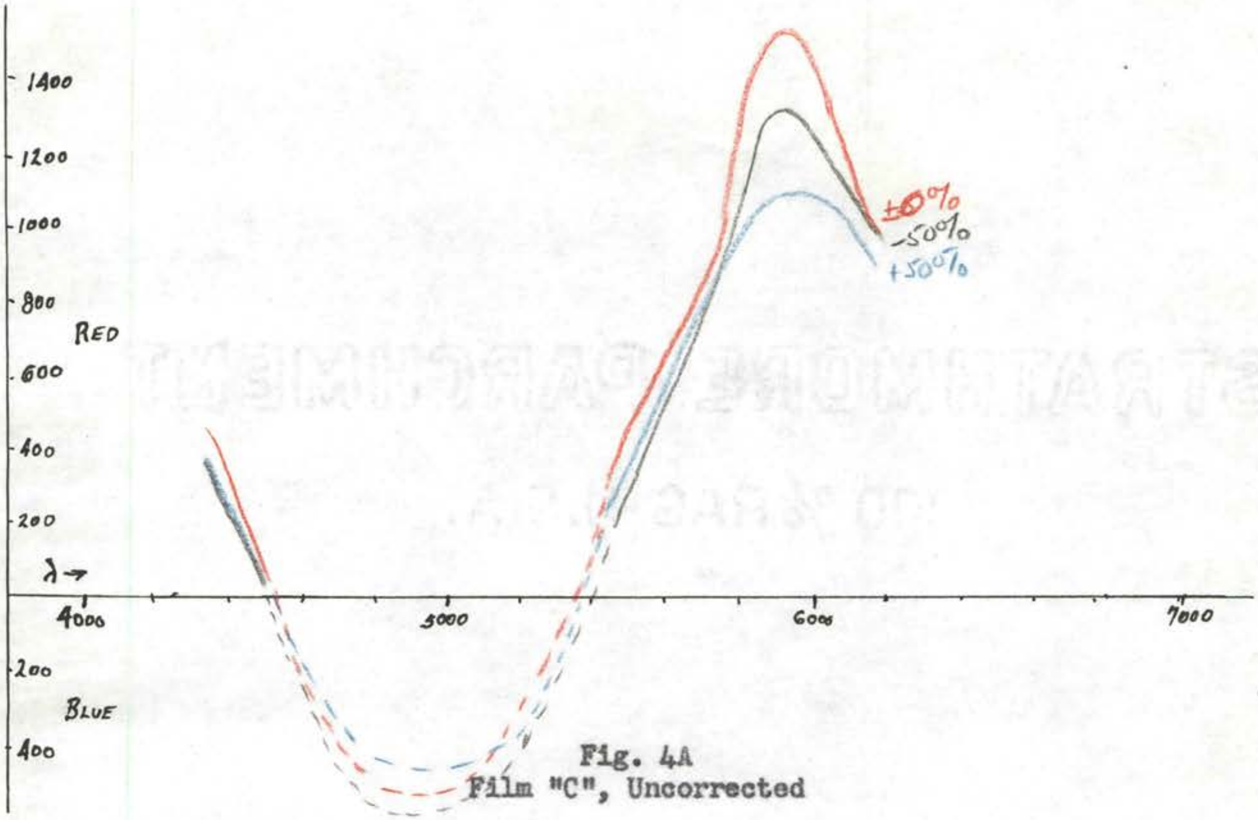


**Fig. 4A**
**Film "C", Uncorrected**

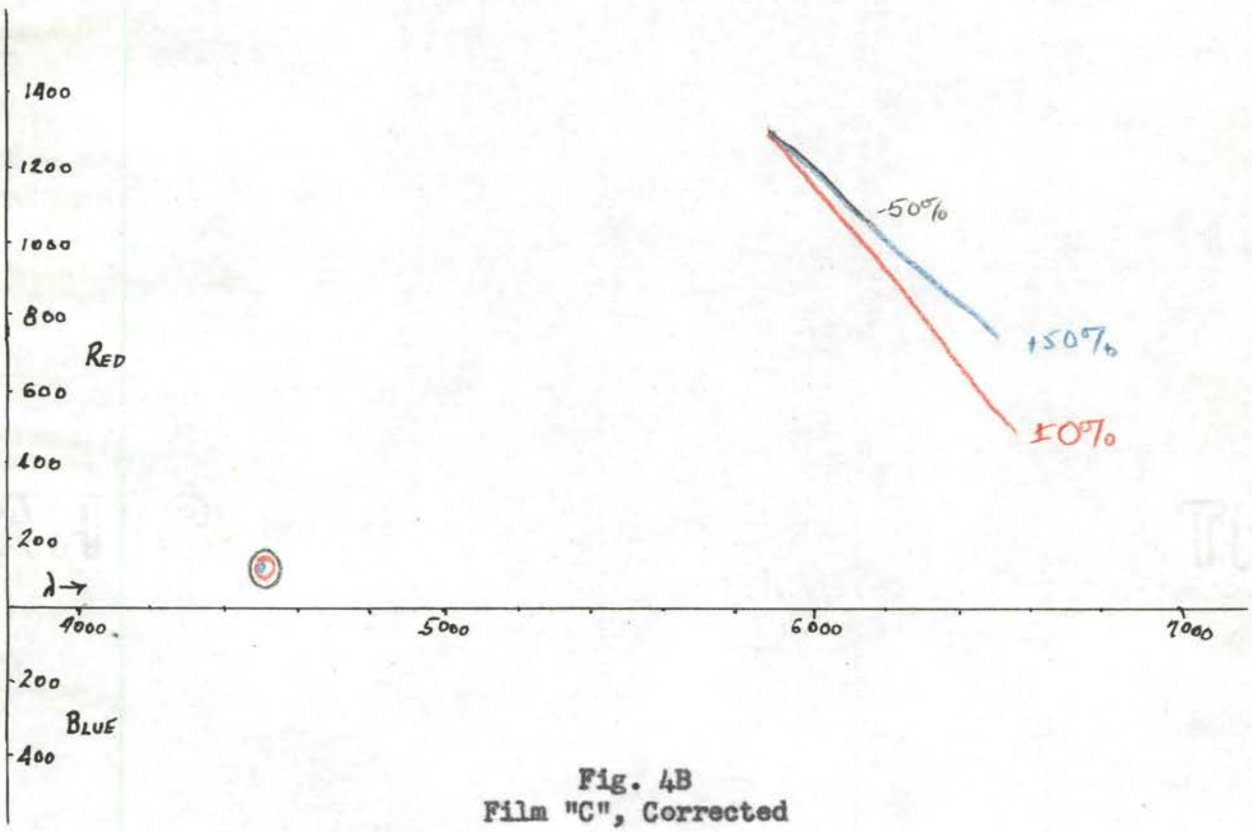


**Fig. 4B**
**Film "C", Corrected**

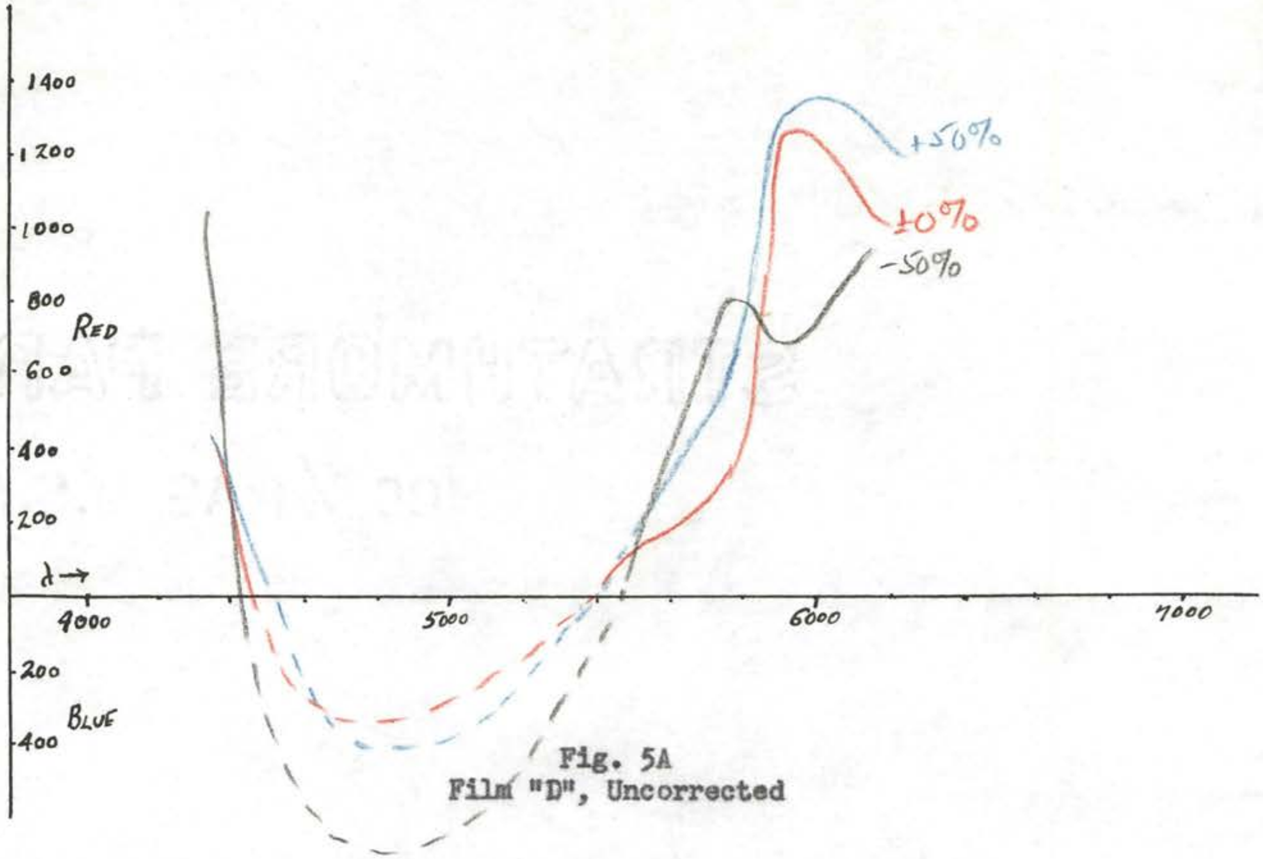


Fig. 5A
Film "D", Uncorrected

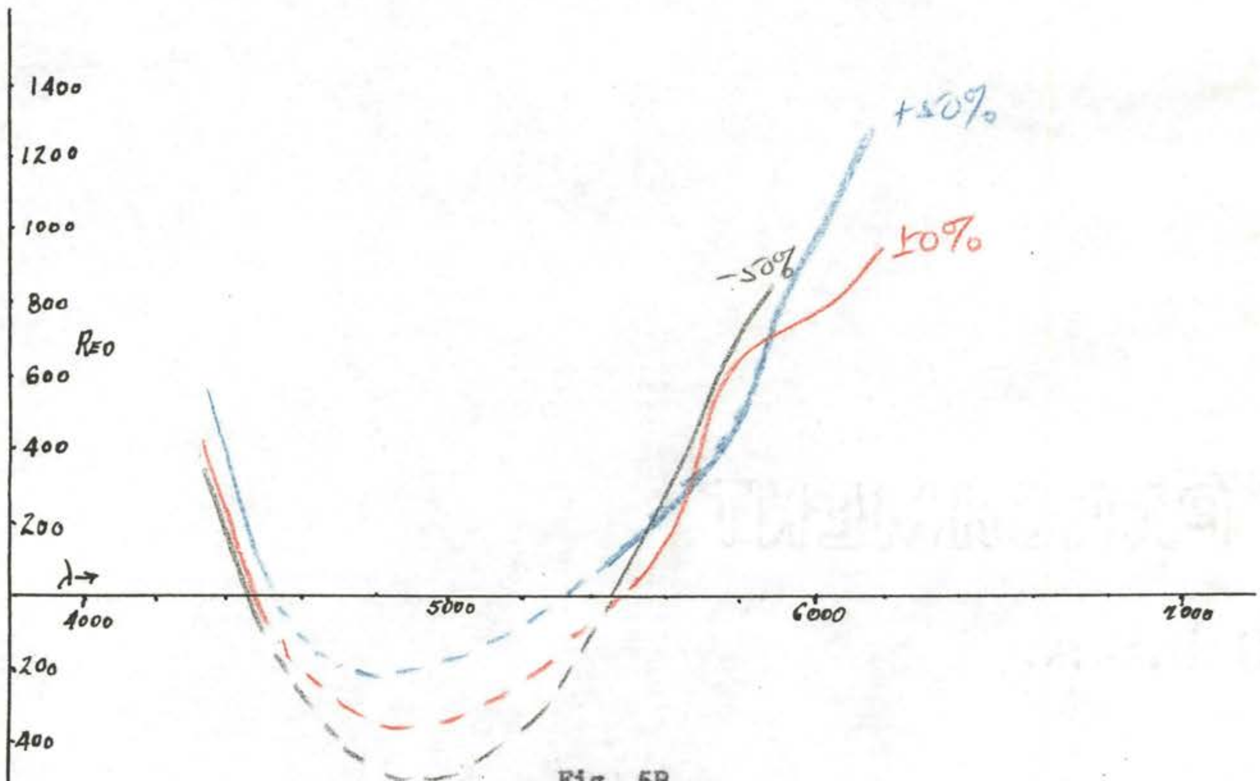


Fig. 5B
Film "D", Corrected

parallel in their shifts, but the -50% behaves somewhat irregularly. Using the method of extrapolation, the +50% exposures would be expected to maintain a shift toward the red throughout. Similarly, the ±0% exposures would appear to shift slightly toward the blue only from 4500 AU to 5100 AU. In the corrected series for this film, the maximum shift toward the reds is not determined since the spectral shift curve is still increasing at the longest wavelength exposures successfully made. In this series, i.e., corrected, the 5893 AU transparency was a cherry red. This corrected series shows the -50% and ±0% exposure curves almost coinciding throughout, at least to 5900 AU. the ±0% and -50% curves, by extrapolation, show shifts of about 250 AU toward the blue at the neighborhood of 5000 AU. The +50% curve has a blue shift only between 4500 AU and 5100 AU. The range of the blue shift for the ±0% and -50% curves appears to be between 4600 AU and 5500 AU.

B. Conclusions

An examination of the spectral shift curves shows that the variation of exposure time in both color corrected and color uncorrected cases does not affect the shift very greatly. The principal effect observed in both cases seemed to point out that the under-exposure tends to increase the blue content of the resultant transparency slightly and the over-exposure tends to increase the red content slightly. This means that if a transparency appears to be too dark, under-exposed within the range of this experiment, a more intense lighting would tend to offset this darkness without sacrificing color rendition. Similarly, film over-exposed within the range tested in this experiment, could be improved by a decreased intensity of lighting.

The shapes of the transmission curves for the transparencies made with monochromatic light were very closely similar whether the source was corrected for color temperature or not. The curves showed the same maxima and minima; these were, in most cases, displaced only in per cent of transmission but not in actual color rendition. Likewise, the spectral shift curves are very similar for both color temperature correction and uncorrection. From these indications, it may be deduced that the rendition of a particular spectral wavelength is neither enhanced or harmed, materially, by color temperature correction. So in general, if any of these films were to be used to make any picture in which several colors were to appear together, the color temperature correction would be desirable to properly apportion the color intensities to some standard. If monochromatic light were to be used, color temperature correction would be unnecessary. If color film were to be used for making a spectrogram, the intensities of the colors would be in proper proportion by color temperature correction, but the color fidelity would be none the better.

Film "A" and Film "B" were manufactured by the same company. In both cases the characteristics, as evidenced by the spectral shift curves, are generally similar. There is a variation of intensity between the two films without any color correction. Both Film "A" and Film "B" have similar shifts toward the shorter blue and greens in those regions and a shift toward the longer reds in the yellow and red regions. In amateur photography this combination may seem very desirable to many since it would add to color contrast. To the researcher this variation would be detrimental.

Film "C" and Film "D" were manufactured by the same company. The general conclusions comparing Film "A" and "B" may apply also to Film "C" and Film "D". The main difference being that with the latter two films there is not as great a tendency to have a region which shifts toward the shorter blues. Instead, as far as color fidelity is concerned, the fidelity of Film "C" and Film "D" is slightly better in the green and blue regions. Here, it should be pointed out that there is a tendency for these two films to shift all colors toward the longer wavelengths, hence giving results which are consistently too red.

Throughout this experiment, effort was made to use the 7065 AU line of the helium spectrum tube. First efforts failed to get it to record on any type of film used with the indicated exposures. Second efforts, using four times as great exposure, also failed. From this, it has been deduced that the films are not sensitive to light of this wavelength, or, if at all, very slightly.

The net results of this experiment may be summarized as being:

1. Reaffirmation that color film at its present stage of development is not applicable to those uses in which a high degree of color fidelity is desired.

2. Color film is a medium for getting pleasing color pictures whose color rendition failures are probably not readily discernible by the normal eye except in the most gross cases.

3. Exposure time, within the limits of these tests, affects the color intensity but not the fidelity.

4. Color temperature correction is not necessary for monochromatic light.

5. Films made by the same manufacturer and then balanced for different color temperatures at the time of manufacture can be relied upon to give closely similar results.

## TABLE I

### Transmission for Film "A"

### 6563 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.340 | | |
| 7400 | 0.320 | 0.420 | 0.180 |
| 7200 | 0.310 | 0.270 | 0.170 |
| 7000 | 0.270 | 0.240 | 0.150 |
| 6800 | 0.270 | 0.220 | 0.125 |
| 6600 | 0.220 | 0.180 | 0.110 |
| 6400 | 0.165 | 0.130 | 0.085 |
| 6200 | 0.102 | 0.095 | 0.060 |
| 6000 | (NM) | (NM) | (NM) |
| 5800 | 0.020 | (NM) | (NM) |
| 5600 | 0.010 | 0.009 | 0.007 |
| 5400 | 0.005 | 0.004 | 0.003 |
| 5200 | 0.003 | 0.002 | 0.002 |
| 5000 | 0.001 | 0.001 | 0.002 |
| 4800 | | | |
| 4600 | | | |
| 4400 | | | |
| 4200 | | | |

### 6563 AU, Corrected

| | | | |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.330 | 0.360 | 0.320 |
| 7400 | 0.340 | 0.320 | 0.280 |
| 7200 | 0.330 | 0.330 | 0.280 |
| 7000 | 0.280 | 0.270 | 0.250 |
| 6800 | 0.260 | 0.255 | 0.220 |
| 6600 | 0.230 | 0.230 | 0.190 |
| 6400 | 0.170 | 0.160 | 0.150 |
| 6200 | 0.130 | 0.130 | 0.110 |
| 6000 | 0.075 | (NM) | (NM) |
| 5800 | (NM) | (NM) | (NM) |
| 5600 | 0.016 | 0.014 | 0.015 |
| 5400 | 0.007 | 0.007 | 0.006 |
| 5200 | 0.004 | 0.004 | 0.004 |
| 5000 | 0.002 | 0.002 | 0.002 |
| 4800 | 0.001 | | |
| 4600 | | | |
| 4400 | | | |
| 4200 | | | |

TABLE II

Transmission for Film "A"

6158 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.330 | 0.180 | 0.200 |
| 7600 | 0.370 | 0.350 | 0.310 |
| 7400 | 0.350 | 0.365 | 0.305 |
| 7200 | 0.330 | 0.350 | 0.310 |
| 7000 | 0.305 | 0.300 | 0.270 |
| 6800 | 0.280 | 0.290 | 0.250 |
| 6600 | 0.220 | 0.240 | 0.220 |
| 6400 | 0.180 | 0.190 | 0.170 |
| 6200 | 0.140 | 0.130 | 0.120 |
| 6000 | (NM) | (NM) | (NM) |
| 5800 | (NM) | (NM) | (NM) |
| 5600 | 0.018 | 0.028 | 0.015 |
| 5400 | 0.007 | 0.007 | 0.006 |
| 5200 | 0.004 | 0.004 | 0.003 |
| 5000 | 0.002 | 0.003 | 0.001 |
| 4800 | 0.002 | 0.002 | 0.001 |
| 4600 | | | |
| 4400 | | | |
| 4200 | | | |

6158 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.280 | 0.230 | 0.180 |
| 7600 | 0.380 | 0.280 | 0.200 |
| 7400 | 0.300 | 0.310 | 0.240 |
| 7200 | 0.290 | 0.310 | 0.250 |
| 7000 | 0.310 | 0.290 | 0.250 |
| 6800 | 0.280 | 0.260 | 0.220 |
| 6600 | 0.240 | 0.220 | 0.185 |
| 6400 | 0.180 | 0.170 | 0.135 |
| 6200 | 0.130 | 0.130 | 0.100 |
| 6000 | (NM) | (NM) | (NM) |
| 5800 | (NM) | (NM) | (NM) |
| 5600 | 0.013 | 0.013 | 0.014 |
| 5400 | 0.007 | 0.006 | 0.005 |
| 5200 | 0.004 | 0.004 | 0.003 |
| 5000 | 0.003 | 0.003 | 0.002 |
| 4800 | 0.001 | 0.001 | 0.001 |
| 4600 | | | |
| 4400 | | | |
| 4200 | | | |

# TABLE III

## Transmission for Film "A"

### 5893 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.170 | 0.100 | 0.080 |
| 7200 | 0.160 | 0.085 | 0.070 |
| 7000 | 0.130 | 0.075 | 0.060 |
| 6800 | 0.120 | 0.070 | 0.052 |
| 6600 | 0.115 | 0.070 | 0.048 |
| 6400 | 0.110 | 0.065 | 0.045 |
| 6200 | 0.105 | 0.060 | 0.040 |
| 6000 | 0.085 | 0.050 | 0.035 |
| 5800 | (NM) | 0.034 | 0.022 |
| 5600 | 0.040 | 0.020 | 0.014 |
| 5400 | 0.025 | 0.013 | 0.008 |
| 5200 | 0.015 | 0.008 | 0.005 |
| 5000 | 0.008 | 0.005 | 0.004 |
| 4800 | 0.005 | 0.004 | 0.003 |
| 4600 | 0.004 | 0.003 | |
| 4400 | | | |
| 4200 | | | |

### 5893 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.280 | | 0.150 |
| 7400 | 0.310 | 0.210 | 0.150 |
| 7200 | 0.310 | 0.220 | 0.130 |
| 7000 | 0.280 | 0.210 | 0.113 |
| 6800 | 0.280 | 0.220 | 0.120 |
| 6600 | 0.270 | 0.200 | 0.110 |
| 6400 | 0.265 | 0.200 | 0.110 |
| 6200 | 0.230 | 0.170 | 0.100 |
| 6000 | 0.190 | 0.140 | 0.008 |
| 5800 | 0.130 | 0.095 | 0.005 |
| 5600 | 0.080 | 0.060 | 0.030 |
| 5400 | 0.050 | 0.035 | 0.020 |
| 5200 | 0.035 | 0.022 | 0.012 |
| 5000 | 0.020 | 0.012 | 0.007 |
| 4800 | 0.075 | 0.005 | 0.004 |
| 4600 | 0.005 | | |
| 4400 | | | |
| 4200 | | | |

# TABLE IV

## Transmission for Film "A"

### 5780 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | 0.500 |
| 7600 | 0.150 | | 0.500 |
| 7400 | 0.170 | 0.140 | 0.550 |
| 7200 | 0.165 | 0.130 | 0.580 |
| 7000 | 0.160 | 0.120 | 0.580 |
| 6800 | 0.150 | 0.120 | 0.590 |
| 6600 | 0.140 | 0.110 | 0.590 |
| 6400 | 0.140 | 0.115 | 0.575 |
| 6200 | 0.130 | 0.115 | 0.560 |
| 6000 | 0.100 | 0.100 | 0.550 |
| 5800 | 0.085 | 0.085 | 0.500 |
| 5600 | 0.055 | 0.060 | 0.480 |
| 5400 | 0.035 | 0.035 | 0.420 |
| 5200 | 0.020 | 0.025 | 0.300 |
| 5000 | 0.010 | 0.015 | 0.220 |
| 4800 | 0.005 | 0.005 | 0.140 |
| 4600 | 0.003 | 0.003 | 0.095 |
| 4400 | | | 0.090 |
| 4200 | | | 0.090 |

### 5780 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.400 | | |
| 7600 | 0.620 | 0.470 | 0.420 |
| 7400 | 0.580 | 0.450 | 0.460 |
| 7200 | 0.580 | 0.480 | 0.490 |
| 7000 | 0.550 | 0.490 | 0.470 |
| 6800 | 0.550 | 0.480 | 0.470 |
| 6600 | 0.580 | 0.470 | 0.470 |
| 6400 | 0.560 | 0.480 | 0.470 |
| 6200 | 0.560 | 0.460 | 0.470 |
| 6000 | 0.510 | 0.420 | 0.420 |
| 5800 | 0.440 | 0.380 | 0.360 |
| 5600 | 0.410 | 0.300 | 0.300 |
| 5400 | 0.310 | 0.220 | 0.220 |
| 5200 | 0.240 | 0.150 | 0.130 |
| 5000 | 0.180 | 0.055 | 0.060 |
| 4800 | 0.055 | 0.020 | 0.020 |
| 4600 | 0.045 | 0.007 | 0.007 |
| 4400 | 0.050 | 0.007 | 0.007 |
| 4200 | 0.050 | 0.007 | |

# TABLE V

## Transmission for Film "A"

### 5461 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.300 | 0.290 | 0.250 |
| 7200 | 0.315 | 0.250 | 0.210 |
| 7000 | 0.325 | 0.250 | 0.210 |
| 6800 | 0.280 | 0.240 | 0.200 |
| 6600 | 0.290 | 0.250 | 0.210 |
| 6400 | 0.310 | 0.270 | 0.220 |
| 6200 | 0.340 | 0.285 | 0.240 |
| 6000 | 0.380 | 0.320 | 0.265 |
| 5800 | 0.400 | 0.350 | 0.315 |
| 5600 | 0.440 | 0.370 | 0.340 |
| 5400 | 0.440 | 0.345 | 0.330 |
| 5200 | 0.370 | 0.310 | 0.285 |
| 5000 | 0.310 | 0.200 | 0.180 |
| 4800 | 0.210 | 0.110 | 0.105 |
| 4600 | 0.150 | 0.075 | 0.006 |
| 4400 | 0.150 | 0.055 | 0.007 |
| 4200 | 0.140 | 0.065 | 0.007 |

### 5461 AU, Corrected

| | | | |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.310 | 0.225 | 0.150 |
| 7200 | 0.280 | 0.205 | 0.170 |
| 7000 | 0.260 | 0.205 | 0.150 |
| 6800 | 0.300 | 0.200 | 0.140 |
| 6600 | 0.300 | 0.205 | 0.140 |
| 6400 | 0.290 | 0.220 | 0.160 |
| 6200 | 0.320 | 0.220 | 0.165 |
| 6000 | 0.320 | 0.290 | 0.220 |
| 5800 | 0.360 | 0.305 | 0.265 |
| 5600 | 0.380 | 0.280 | 0.280 |
| 5400 | 0.390 | 0.330 | 0.285 |
| 5200 | 0.325 | 0.290 | 0.230 |
| 5000 | 0.230 | 0.180 | 0.160 |
| 4800 | 0.150 | 0.090 | 0.074 |
| 4600 | 0.100 | 0.065 | 0.040 |
| 4400 | 0.110 | 0.050 | 0.030 |
| 4200 | 0.110 | 0.075 | 0.040 |

## TABLE VI

### Transmission for Film "A"

### 4916 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | | |
| 6200 | | | |
| 6000 | | | |
| 5800 | 0.001 | | 0.002 |
| 5600 | 0.004 | | 0.003 |
| 5400 | 0.004 | | 0.004 |
| 5200 | 0.005 | | 0.004 |
| 5000 | 0.008 | 0.002 | 0.006 |
| 4800 | 0.015 | 0.004 | 0.007 |
| 4600 | 0.018 | 0.004 | 0.0075 |
| 4400 | 0.024 | 0.006 | 0.010 |
| 4200 | 0.021 | 0.003 | |

### 4916 AU, Corrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | | |
| 6200 | | | |
| 6000 | 0.001 | | |
| 5800 | 0.003 | 0.002 | |
| 5600 | 0.004 | 0.004 | |
| 5400 | 0.005 | 0.004 | |
| 5200 | 0.007 | 0.004 | |
| 5000 | 0.009 | 0.007 | |
| 4800 | 0.014 | 0.010 | |
| 4600 | 0.015 | 0.008 | |
| 4400 | 0.012 | 0.008 | |
| 4200 | | | |

TABLE VII

Transmission for Film "A"

4471 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | 0.001 | |
| 6200 | 0.001 | 0.001 | 0.001 |
| 6000 | 0.002 | 0.002 | 0.002 |
| 5800 | 0.003 | 0.003 | 0.003 |
| 5600 | 0.005 | 0.004 | 0.004 |
| 5400 | 0.006 | 0.006 | 0.005 |
| 5200 | 0.010 | 0.008 | 0.007 |
| 5000 | 0.018 | 0.015 | 0.014 |
| 4800 | 0.035 | 0.025 | 0.030 |
| 4600 | 0.050 | 0.050 | 0.050 |
| 4400 | 0.055 | 0.055 | 0.058 |
| 4200 | 0.055 | 0.070 | 0.060 |

4471 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | | |
| 6200 | 0.001 | 0.001 | |
| 6000 | 0.002 | 0.002 | 0.002 |
| 5800 | 0.003 | 0.003 | 0.003 |
| 5600 | 0.003 | 0.004 | 0.003 |
| 5400 | 0.005 | 0.004 | 0.003 |
| 5200 | 0.006 | 0.006 | 0.004 |
| 5000 | 0.013 | 0.012 | 0.008 |
| 4800 | 0.020 | 0.023 | 0.018 |
| 4600 | 0.040 | 0.034 | 0.027 |
| 4400 | 0.062 | 0.048 | 0.035 |
| 4200 | 0.055 | 0.047 | 0.049 |

TABLE VIII

Transmission for Film "A"

4358 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | 0.110 | 0.090 | |
| 6800 | 0.110 | 0.080 | 0.015 |
| 6600 | 0.100 | 0.075 | 0.015 |
| 6400 | 0.120 | 0.085 | 0.020 |
| 6200 | 0.140 | 0.110 | 0.030 |
| 6000 | 0.195 | 0.140 | 0.050 |
| 5800 | 0.270 | 0.200 | 0.080 |
| 5600 | 0.330 | 0.280 | 0.140 |
| 5400 | 0.400 | 0.350 | 0.200 |
| 5200 | 0.440 | 0.400 | 0.245 |
| 5000 | 0.450 | 0.420 | 0.290 |
| 4800 | 0.450 | 0.380 | 0.280 |
| 4600 | 0.390 | 0.370 | 0.245 |
| 4400 | 0.375 | 0.350 | 0.220 |
| 4200 | 0.340 | 0.340 | |

4358 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | 0.080 | 0.045 | 0.007 |
| 6600 | 0.080 | 0.048 | 0.008 |
| 6400 | 0.095 | 0.055 | 0.010 |
| 6200 | 0.120 | 0.075 | 0.018 |
| 6000 | 0.180 | 0.115 | 0.029 |
| 5800 | 0.230 | 0.175 | 0.007 |
| 5600 | 0.300 | 0.230 | 0.095 |
| 5400 | 0.380 | 0.300 | 0.135 |
| 5200 | 0.410 | 0.360 | 0.190 |
| 5000 | 0.460 | 0.380 | 0.220 |
| 4800 | 0.420 | 0.365 | 0.225 |
| 4600 | 0.380 | 0.340 | 0.210 |
| 4400 | 0.380 | 0.290 | 0.210 |
| 4200 | 0.315 | 0.280 | |

# TABLE IX

## Transmission for Film "B"

### 6563 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.330 | 0.320 | 0.290 |
| 7400 | 0.390 | 0.350 | 0.250 |
| 7200 | 0.390 | 0.320 | 0.260 |
| 7000 | 0.370 | 0.320 | 0.250 |
| 6800 | 0.345 | 0.285 | 0.230 |
| 6600 | 0.300 | 0.250 | 0.190 |
| 6400 | 0.230 | 0.210 | 0.160 |
| 6200 | 0.165 | 0.150 | 0.125 |
| 6000 | 0.110 | 0.090 | 0.080 |
| 5800 | (NM) | 0.045 | 0.050 |
| 5600 | 0.022 | 0.020 | 0.020 |
| 5400 | 0.010 | 0.009 | 0.008 |
| 5200 | 0.005 | 0.005 | 0.005 |
| 5000 | 0.0035 | 0.004 | 0.004 |
| 4800 | 0.0035 | 0.004 | 0.0035 |
| 4600 | 0.003 | 0.004 | 0.004 |
| 4400 | | | |
| 4200 | | | |

### 6563 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.420 | 0.425 | 0.190 |
| 7400 | 0.410 | 0.360 | 0.220 |
| 7200 | 0.410 | 0.340 | 0.205 |
| 7000 | 0.390 | 0.365 | 0.205 |
| 6800 | 0.340 | 0.340 | 0.190 |
| 6600 | 0.320 | 0.285 | 0.175 |
| 6400 | 0.245 | 0.225 | 0.150 |
| 6200 | 0.190 | 0.180 | 0.095 |
| 6000 | 0.120 | 0.130 | 0.070 |
| 5800 | 0.052 | 0.055 | 0.035 |
| 5600 | 0.026 | 0.021 | 0.017 |
| 5400 | 0.010 | 0.010 | 0.007 |
| 5200 | 0.006 | 0.006 | 0.005 |
| 5000 | 0.0045 | 0.0045 | 0.004 |
| 4800 | 0.004 | 0.0045 | 0.004 |
| 4600 | 0.004 | 0.004 | 0.004 |
| 4400 | | 0.007 | 0.0045 |
| 4200 | | | |

TABLE X

Transmission for Film "B"

6158 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.430 | 0.330 | |
| 7600 | 0.460 | 0.360 | 0.380 |
| 7400 | 0.430 | 0.440 | 0.425 |
| 7200 | 0.425 | 0.400 | 0.400 |
| 7000 | 0.400 | 0.380 | 0.375 |
| 6800 | 0.380 | 0.350 | 0.360 |
| 6600 | 0.320 | 0.310 | 0.300 |
| 6400 | 0.260 | 0.255 | 0.230 |
| 6200 | 0.170 | 0.170 | 0.170 |
| 6000 | 0.110 | 0.100 | 0.090 |
| 5800 | 0.060 | 0.050 | 0.050 |
| 5600 | 0.020 | 0.020 | 0.020 |
| 5400 | 0.009 | 0.008 | 0.008 |
| 5200 | 0.005 | 0.005 | 0.005 |
| 5000 | 0.004 | 0.0045 | 0.004 |
| 4800 | 0.004 | 0.004 | 0.004 |
| 4600 | 0.004 | 0.004 | 0.004 |
| 4400 | | | |
| 4200 | | | |

6158 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.380 | 0.310 | 0.350 |
| 7400 | 0.420 | 0.340 | 0.360 |
| 7200 | 0.400 | 0.350 | 0.350 |
| 7000 | 0.360 | 0.340 | 0.340 |
| 6800 | 0.340 | 0.315 | 0.330 |
| 6600 | 0.300 | 0.280 | 0.280 |
| 6400 | 0.240 | 0.210 | 0.245 |
| 6200 | 0.160 | 0.165 | 0.155 |
| 6000 | 0.090 | 0.100 | 0.095 |
| 5800 | 0.040 | 0.040 | 0.043 |
| 5600 | 0.015 | 0.016 | 0.016 |
| 5400 | 0.006 | 0.0055 | 0.006 |
| 5200 | 0.004 | 0.004 | 0.004 |
| 5000 | 0.0025 | 0.0035 | 0.003 |
| 4800 | | | |
| 4600 | | | |
| 4400 | | | |
| 4200 | | | |

# TABLE XI

## Transmission for Film "B"

### 5893 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) +50% | ± 0% | -50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | 0.130 |
| 7400 | 0.125 | 0.095 | 0.080 |
| 7200 | 0.105 | 0.085 | 0.075 |
| 7000 | 0.100 | 0.080 | 0.060 |
| 6800 | 0.080 | 0.070 | 0.050 |
| 6600 | 0.080 | 0.065 | 0.045 |
| 6400 | 0.080 | 0.058 | 0.045 |
| 6200 | 0.065 | 0.050 | 0.040 |
| 6000 | 0.050 | 0.042 | 0.030 |
| 5800 | 0.035 | 0.026 | 0.020 |
| 5600 | 0.020 | 0.015 | 0.010 |
| 5400 | 0.010 | 0.008 | 0.006 |
| 5200 | 0.008 | 0.006 | 0.005 |
| 5000 | 0.005 | 0.005 | 0.004 |
| 4800 | 0.005 | 0.005 | 0.004 |
| 4600 | 0.005 | 0.005 | 0.004 |
| 4400 | | | |
| 4200 | | | |

### 5893 AU, Corrected

| | | | |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.260 | 0.280 | 0.250 |
| 7400 | 0.270 | 0.280 | 0.260 |
| 7200 | 0.305 | 0.290 | 0.260 |
| 7000 | 0.300 | 0.300 | 0.250 |
| 6800 | 0.280 | 0.290 | 0.240 |
| 6600 | 0.280 | 0.285 | 0.230 |
| 6400 | 0.260 | 0.265 | 0.210 |
| 6200 | 0.240 | 0.250 | 0.180 |
| 6000 | 0.180 | 0.190 | 0.135 |
| 5800 | 0.100 | 0.120 | 0.008 |
| 5600 | 0.070 | 0.075 | 0.045 |
| 5400 | 0.040 | 0.050 | 0.026 |
| 5200 | 0.028 | 0.035 | 0.020 |
| 5000 | 0.019 | 0.030 | 0.015 |
| 4800 | 0.010 | 0.020 | 0.011 |
| 4600 | | 0.018 | 0.010 |
| 4400 | | | |
| 4200 | | | |

TABLE XII

Transmission for Film "B"

5780 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) | | |
|---|---|---|---|
| | + 50% | ± 0% | - 50% |
| 8000 | | | |
| 7800 | 0.680 | 0.690 | 0.550 |
| 7600 | 0.625 | 0.640 | 0.530 |
| 7400 | 0.650 | 0.625 | 0.580 |
| 7200 | 0.670 | 0.630 | 0.560 |
| 7000 | 0.650 | 0.650 | 0.580 |
| 6800 | 0.640 | 0.620 | 0.620 |
| 6600 | 0.625 | 0.620 | 0.600 |
| 6400 | 0.630 | 0.600 | 0.580 |
| 6200 | 0.620 | 0.600 | 0.560 |
| 6000 | 0.580 | 0.580 | 0.550 |
| 5800 | 0.490 | 0.500 | 0.470 |
| 5600 | 0.420 | 0.420 | 0.420 |
| 5400 | 0.330 | 0.320 | 0.320 |
| 5200 | 0.220 | 0.230 | 0.225 |
| 5000 | 0.113 | 0.120 | 0.125 |
| 4800 | 0.055 | 0.050 | 0.050 |
| 4600 | 0.025 | 0.025 | 0.022 |
| 4400 | 0.032 | 0.025 | 0.025 |
| 4200 | 0.050 | 0.050 | 0.040 |

TABLE XIII

Transmission for Film "B"

5461 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.450 | 0.330 | 0.220 |
| 7400 | 0.370 | 0.290 | 0.220 |
| 7200 | 0.350 | 0.290 | 0.200 |
| 7000 | 0.335 | 0.280 | 0.200 |
| 6800 | 0.340 | 0.265 | 0.200 |
| 6600 | 0.340 | 0.270 | 0.200 |
| 6400 | 0.330 | 0.300 | 0.205 |
| 6200 | 0.350 | 0.310 | 0.220 |
| 6000 | 0.360 | 0.315 | 0.250 |
| 5800 | 0.360 | 0.330 | 0.260 |
| 5600 | 0.320 | 0.300 | 0.270 |
| 5400 | 0.260 | 0.280 | 0.250 |
| 5200 | 0.195 | 0.190 | 0.180 |
| 5000 | 0.110 | 0.100 | 0.100 |
| 4800 | 0.045 | 0.042 | 0.040 |
| 4600 | 0.020 | 0.019 | 0.020 |
| 4400 | 0.020 | 0.020 | 0.020 |
| 4200 | 0.052 | 0.030 | 0.030 |

TABLE XIV

Transmission for Film "B"

4472 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | | |
| 6200 | | | |
| 6000 | 0.001 | 0.0005 | 0.0005 |
| 5800 | 0.001 | 0.001 | 0.001 |
| 5600 | 0.0015 | 0.0015 | 0.001 |
| 5400 | 0.0015 | 0.0015 | 0.0015 |
| 5200 | 0.002 | 0.002 | 0.002 |
| 5000 | 0.004 | 0.0045 | 0.003 |
| 4800 | 0.009 | 0.012 | 0.006 |
| 4600 | 0.030 | 0.018 | 0.011 |
| 4400 | 0.032 | 0.030 | 0.017 |
| 4200 | 0.026 | | 0.022 |

4472 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | | | |
| 6200 | | | |
| 6000 | 0.0005 | 0.0005 | 0.0005 |
| 5800 | 0.001 | 0.001 | 0.001 |
| 5600 | 0.0015 | 0.0015 | 0.001 |
| 5400 | 0.0015 | 0.0015 | 0.001 |
| 5200 | 0.002 | 0.002 | 0.0015 |
| 5000 | 0.004 | 0.0035 | 0.003 |
| 4800 | 0.010 | 0.009 | 0.007 |
| 4600 | 0.024 | 0.022 | 0.017 |
| 4400 | 0.035 | 0.030 | 0.020 |
| 4200 | 0.050 | 0.045 | 0.040 |

TABLE XV

Transmission for Film "B"

4358 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | 0.004 | 0.002 | 0.0005 |
| 6400 | 0.005 | 0.003 | 0.001 |
| 6200 | 0.0075 | 0.004 | 0.0015 |
| 6000 | 0.014 | 0.010 | 0.004 |
| 5800 | 0.025 | 0.018 | 0.005 |
| 5600 | 0.045 | 0.028 | 0.010 |
| 5400 | 0.072 | 0.040 | 0.015 |
| 5200 | 0.100 | 0.060 | 0.025 |
| 5000 | 0.118 | 0.090 | 0.040 |
| 4800 | 0.150 | 0.110 | 0.060 |
| 4600 | 0.150 | 0.125 | 0.070 |
| 4400 | 0.130 | 0.138 | 0.070 |
| 4200 | 0.135 | 0.100 | 0.080 |

TABLE XVI

Transmission for Film "C"

6563 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | -50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.270 | 0.240 | |
| 7600 | 0.260 | 0.200 | |
| 7400 | 0.260 | 0.195 | |
| 7200 | 0.245 | 0.185 | 0.060 |
| 7000 | 0.235 | 0.175 | 0.065 |
| 6800 | 0.230 | 0.160 | 0.066 |
| 6600 | 0.215 | 0.150 | 0.066 |
| 6400 | 0.180 | 0.135 | 0.065 |
| 6200 | 0.130 | 0.105 | 0.062 |
| 6000 | 0.086 | 0.070 | 0.060 |
| 5800 | 0.050 | 0.039 | 0.045 |
| 5600 | 0.012 | 0.012 | 0.018 |
| 5400 | 0.004 | 0.004 | 0.008 |
| 5200 | 0.0035 | 0.003 | 0.004 |
| 5000 | 0.004 | 0.0035 | 0.003 |
| 4800 | 0.005 | 0.0045 | 0.0035 |
| 4600 | 0.0035 | 0.004 | 0.0045 |
| 4400 | | | 0.004 |
| 4200 | | | |

6563 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | -50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.260 | | 0.135 |
| 7400 | 0.270 | 0.140 | 0.095 |
| 7200 | 0.270 | 0.150 | 0.075 |
| 7000 | 0.250 | 0.150 | 0.068 |
| 6800 | 0.240 | 0.145 | 0.068 |
| 6600 | 0.215 | 0.138 | 0.064 |
| 6400 | 0.180 | 0.120 | 0.065 |
| 6200 | 0.140 | 0.100 | 0.055 |
| 6000 | 0.085 | 0.065 | 0.040 |
| 5800 | 0.040 | 0.031 | 0.024 |
| 5600 | 0.012 | 0.010 | 0.010 |
| 5400 | 0.004 | 0.004 | 0.004 |
| 5200 | 0.003 | 0.0035 | 0.0025 |
| 5000 | 0.0035 | 0.004 | 0.004 |
| 4800 | 0.004 | 0.0045 | 0.0045 |
| 4600 | 0.0045 | 0.004 | 0.0035 |
| 4400 | | | |
| 4200 | | | |

# TABLE XVII

## Transmission for Film "C"

### 6158 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.390 | | |
| 7600 | 0.460 | | 0.340 |
| 7400 | 0.460 | 0.410 | 0.310 |
| 7200 | 0.490 | 0.450 | 0.340 |
| 7000 | 0.490 | 0.430 | 0.330 |
| 6800 | 0.440 | 0.400 | 0.310 |
| 6600 | 0.345 | 0.340 | 0.280 |
| 6400 | 0.270 | 0.280 | 0.215 |
| 6200 | 0.190 | 0.200 | 0.160 |
| 6000 | 0.120 | 0.140 | 0.100 |
| 5800 | 0.055 | 0.055 | 0.045 |
| 5600 | 0.015 | 0.010 | 0.012 |
| 5400 | 0.004 | 0.0045 | 0.004 |
| 5200 | 0.003 | 0.003 | 0.003 |
| 5000 | 0.0035 | 0.004 | 0.0035 |
| 4800 | 0.0045 | 0.005 | 0.004 |
| 4600 | 0.0025 | | 0.004 |
| 4400 | | | |
| 4200 | | | |

### 6158 AU, Corrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.430 | 0.445 | 0.305 |
| 7400 | 0.450 | 0.440 | 0.330 |
| 7200 | 0.475 | 0.465 | 0.370 |
| 7000 | 0.460 | 0.460 | 0.350 |
| 6800 | 0.430 | 0.400 | 0.325 |
| 6600 | 0.360 | 0.340 | 0.280 |
| 6400 | 0.300 | 0.275 | 0.220 |
| 6200 | 0.180 | 0.190 | 0.175 |
| 6000 | 0.120 | 0.125 | 0.120 |
| 5800 | 0.043 | 0.050 | 0.049 |
| 5600 | 0.010 | 0.014 | 0.013 |
| 5400 | 0.0045 | 0.004 | 0.004 |
| 5200 | 0.0035 | 0.003 | 0.0035 |
| 5000 | 0.004 | 0.004 | 0.004 |
| 4800 | 0.0045 | 0.005 | 0.005 |
| 4600 | 0.0035 | 0.0035 | 0.0035 |
| 4400 | | | |
| 4200 | | | |

TABLE XVIII

Transmission for Film "C"

5893 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.140 | | 0.140 |
| 7400 | 0.150 | 0.110 | 0.115 |
| 7200 | 0.150 | 0.095 | 0.100 |
| 7000 | 0.138 | 0.100 | 0.085 |
| 6800 | 0.140 | 0.105 | 0.090 |
| 6600 | 0.135 | 0.105 | 0.090 |
| 6400 | 0.130 | 0.105 | 0.085 |
| 6200 | 0.115 | 0.095 | 0.078 |
| 6000 | 0.088 | 0.070 | 0.060 |
| 5800 | 0.060 | 0.045 | 0.038 |
| 5600 | 0.020 | 0.019 | 0.015 |
| 5400 | 0.009 | 0.007 | 0.0055 |
| 5200 | 0.006 | 0.005 | 0.0045 |
| 5000 | 0.0075 | 0.005 | 0.0045 |
| 4800 | 0.008 | 0.008 | 0.0055 |
| 4600 | 0.003 | 0.003 | 0.004 |
| 4400 | | | |
| 4200 | | | |

5893 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.115 | 0.120 | 0.060 |
| 7200 | 0.115 | 0.110 | 0.060 |
| 7000 | 0.110 | 0.100 | 0.059 |
| 6800 | 0.115 | 0.092 | 0.059 |
| 6600 | 0.120 | 0.100 | 0.060 |
| 6400 | 0.120 | 0.095 | 0.062 |
| 6200 | 0.110 | 0.090 | 0.060 |
| 6000 | 0.090 | 0.075 | 0.050 |
| 5800 | 0.055 | 0.043 | 0.030 |
| 5600 | 0.025 | 0.020 | 0.015 |
| 5400 | 0.011 | 0.009 | 0.005 |
| 5200 | 0.009 | 0.006 | 0.0045 |
| 5000 | 0.010 | 0.007 | 0.005 |
| 4800 | 0.007 | 0.007 | 0.006 |
| 4600 | 0.004 | 0.003 | 0.003 |
| 4400 | | | |
| 4200 | | | |

TABLE XIX

Transmission for Film "C"

5780 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.540 | | |
| 7600 | 0.540 | 0.600 | 0.610 |
| 7400 | 0.575 | 0.610 | 0.620 |
| 7200 | 0.600 | 0.610 | 0.600 |
| 7000 | 0.640 | 0.610 | 0.580 |
| 6800 | 0.640 | 0.625 | 0.620 |
| 6600 | 0.650 | 0.625 | 0.620 |
| 6400 | 0.640 | 0.610 | 0.590 |
| 6200 | 0.620 | 0.610 | 0.590 |
| 6000 | 0.590 | 0.610 | 0.550 |
| 5800 | 0.560 | 0.560 | 0.520 |
| 5600 | 0.500 | 0.500 | 0.470 |
| 5400 | 0.405 | 0.405 | 0.380 |
| 5200 | 0.280 | 0.280 | 0.265 |
| 5000 | 0.150 | 0.160 | 0.140 |
| 4800 | 0.055 | 0.058 | 0.055 |
| 4600 | 0.020 | 0.016 | 0.016 |
| 4400 | 0.008 | | 0.0075 |
| 4200 | | | |

TABLE XX

Transmission for Film "C"

5461 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.270 | 0.205 | |
| 7400 | 0.270 | 0.200 | 0.170 |
| 7200 | 0.280 | 0.210 | 0.180 |
| 7000 | 0.280 | 0.225 | 0.190 |
| 6800 | 0.290 | 0.245 | 0.210 |
| 6600 | 0.320 | 0.280 | 0.220 |
| 6400 | 0.345 | 0.315 | 0.265 |
| 6200 | 0.380 | 0.340 | 0.295 |
| 6000 | 0.440 | 0.410 | 0.360 |
| 5800 | 0.450 | 0.405 | 0.375 |
| 5600 | 0.450 | 0.405 | 0.390 |
| 5400 | 0.380 | 0.355 | 0.355 |
| 5200 | 0.280 | 0.260 | 0.260 |
| 5000 | 0.160 | 0.150 | 0.150 |
| 4800 | 0.065 | 0.055 | 0.060 |
| 4600 | 0.016 | 0.013 | 0.015 |
| 4400 | 0.055 | 0.009 | 0.009 |
| 4200 | | | |

TABLE XXI

Transmission for Film "C"

4472 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | 0.002 | 0.002 | 0.0015 |
| 6200 | 0.0025 | 0.003 | 0.002 |
| 6000 | 0.003 | 0.003 | 0.0025 |
| 5800 | 0.0025 | 0.0025 | 0.002 |
| 5600 | 0.0015 | 0.0015 | 0.0015 |
| 5400 | 0.0015 | 0.0015 | 0.001 |
| 5200 | 0.003 | 0.002 | 0.0025 |
| 5000 | 0.008 | 0.006 | 0.007 |
| 4800 | 0.025 | 0.025 | 0.023 |
| 4600 | 0.042 | 0.033 | 0.032 |
| 4400 | 0.025 | 0.025 | 0.018 |
| 4200 | | | |

4472 AU, Corrected

| | | | |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | | | |
| 6400 | 0.0015 | 0.002 | 0.002 |
| 6200 | 0.0025 | 0.0025 | 0.003 |
| 6000 | 0.003 | 0.003 | 0.003 |
| 5800 | 0.0025 | 0.0025 | 0.0025 |
| 5600 | 0.002 | 0.0015 | 0.0015 |
| 5400 | 0.0015 | 0.0015 | 0.001 |
| 5200 | 0.0025 | 0.0025 | 0.0025 |
| 5000 | 0.007 | 0.009 | 0.006 |
| 4800 | 0.030 | 0.030 | 0.025 |
| 4600 | 0.035 | 0.040 | 0.034 |
| 4400 | 0.025 | 0.025 | 0.032 |
| 4200 | | | |

TABLE XXII

Transmission for Film "C"

4358 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | | | |
| 6600 | 0.0045 | 0.0045 | 0.003 |
| 6400 | 0.007 | 0.006 | 0.0045 |
| 6200 | 0.015 | 0.015 | 0.009 |
| 6000 | 0.030 | 0.028 | 0.020 |
| 5800 | 0.074 | 0.064 | 0.050 |
| 5600 | 0.140 | 0.145 | 0.105 |
| 5400 | 0.240 | 0.250 | 0.180 |
| 5200 | 0.320 | 0.320 | 0.215 |
| 5000 | 0.375 | 0.380 | 0.295 |
| 4800 | 0.380 | 0.400 | 0.320 |
| 4600 | 0.380 | 0.370 | 0.320 |
| 4400 | 0.330 | 0.320 | 0.260 |
| 4200 | 0.250 | 0.230 | 0.180 |

TABLE XXIII

Transmission for Film "D"

6563 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.150 | | |
| 7600 | 0.140 | 0.120 | 0.080 |
| 7400 | 0.130 | 0.090 | 0.050 |
| 7200 | 0.125 | 0.090 | 0.038 |
| 7000 | 0.125 | 0.085 | 0.038 |
| 6800 | 0.110 | 0.080 | 0.033 |
| 6600 | 0.110 | 0.072 | 0.040 |
| 6400 | 0.105 | 0.078 | 0.040 |
| 6200 | 0.085 | 0.063 | 0.035 |
| 6000 | 0.055 | 0.045 | 0.030 |
| 5800 | 0.038 | 0.023 | 0.018 |
| 5600 | 0.010 | 0.009 | 0.007 |
| 5400 | 0.004 | 0.004 | 0.0035 |
| 5200 | 0.003 | 0.0035 | 0.003 |
| 5000 | 0.004 | 0.005 | 0.0045 |
| 4800 | 0.007 | 0.007 | 0.006 |
| 4600 | 0.006 | 0.006 | 0.006 |
| 4400 | | | 0.004 |
| 4200 | | | |

6563 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | − 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.170 | 0.140 | |
| 7400 | 0.180 | 0.125 | |
| 7200 | 0.160 | 0.110 | 0.055 |
| 7000 | 0.160 | 0.110 | 0.050 |
| 6800 | 0.145 | 0.105 | 0.050 |
| 6600 | 0.140 | 0.100 | 0.050 |
| 6400 | 0.130 | 0.095 | 0.050 |
| 6200 | 0.100 | 0.074 | 0.045 |
| 6000 | 0.053 | 0.058 | 0.033 |
| 5800 | 0.032 | 0.030 | 0.020 |
| 5600 | 0.011 | 0.008 | 0.009 |
| 5400 | 0.004 | 0.004 | 0.0035 |
| 5200 | 0.0035 | 0.0035 | 0.003 |
| 5000 | 0.005 | 0.005 | 0.004 |
| 4800 | 0.008 | 0.006 | 0.006 |
| 4600 | 0.007 | 0.0075 | 0.005 |
| 4400 | 0.004 | 0.004 | 0.004 |
| 4200 | | | |

TABLE XXIV

Transmission for Film "D"

6158 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | 0.160 | | |
| 7600 | 0.180 | 0.164 | 0.240 |
| 7400 | 0.220 | 0.160 | 0.225 |
| 7200 | 0.200 | 0.170 | 0.220 |
| 7000 | 0.185 | 0.165 | 0.220 |
| 6800 | 0.185 | 0.160 | 0.200 |
| 6600 | 0.160 | 0.140 | 0.190 |
| 6400 | 0.140 | 0.125 | 0.160 |
| 6200 | 0.110 | 0.105 | 0.115 |
| 6000 | 0.090 | 0.060 | 0.080 |
| 5800 | 0.031 | 0.034 | 0.040 |
| 5600 | 0.012 | 0.014 | 0.019 |
| 5400 | 0.004 | 0.0045 | 0.006 |
| 5200 | 0.0035 | 0.004 | 0.005 |
| 5000 | 0.0045 | 0.0045 | 0.008 |
| 4800 | 0.006 | 0.008 | 0.013 |
| 4600 | 0.006 | 0.006 | 0.013 |
| 4400 | 0.004 | 0.004 | 0.010 |
| 4200 | | | |

6158 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.220 | 0.165 | 0.085 |
| 7400 | 0.250 | 0.140 | 0.085 |
| 7200 | 0.220 | 0.140 | 0.085 |
| 7000 | 0.220 | 0.140 | 0.085 |
| 6800 | 0.210 | 0.130 | 0.085 |
| 6600 | 0.170 | 0.120 | 0.082 |
| 6400 | 0.150 | 0.110 | 0.076 |
| 6200 | 0.090 | 0.090 | 0.070 |
| 6000 | 0.045 | 0.060 | 0.050 |
| 5800 | 0.019 | 0.034 | 0.029 |
| 5600 | 0.007 | 0.010 | 0.010 |
| 5400 | 0.005 | 0.004 | 0.004 |
| 5200 | 0.009 | 0.0035 | 0.0035 |
| 5000 | 0.013 | 0.005 | 0.005 |
| 4800 | 0.010 | 0.007 | 0.007 |
| 4600 | | 0.007 | 0.007 |
| 4400 | | | |
| 4200 | | | |

## TABLE XXV

### Transmission for Film "D"

### 5893 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.094 | 0.090 | 0.090 |
| 7200 | 0.090 | 0.072 | 0.065 |
| 7000 | 0.090 | 0.072 | 0.050 |
| 6800 | 0.088 | 0.070 | 0.050 |
| 6600 | 0.088 | 0.070 | 0.048 |
| 6400 | 0.082 | 0.070 | 0.050 |
| 6200 | 0.072 | 0.065 | 0.045 |
| 6000 | 0.055 | 0.048 | 0.038 |
| 5800 | 0.036 | 0.025 | 0.021 |
| 5600 | 0.010 | 0.0095 | 0.008 |
| 5400 | 0.0045 | 0.0045 | 0.004 |
| 5200 | 0.004 | 0.004 | 0.004 |
| 5000 | 0.005 | 0.005 | 0.005 |
| 4800 | 0.008 | 0.009 | 0.0075 |
| 4600 | 0.0075 | 0.006 | 0.006 |
| 4400 | | | 0.003 |
| 4200 | | | |

### 5893 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.160 | 0.125 | |
| 7400 | 0.140 | 0.095 | |
| 7200 | 0.130 | 0.080 | 0.042 |
| 7000 | 0.125 | 0.078 | 0.040 |
| 6800 | 0.120 | 0.075 | 0.040 |
| 6600 | 0.120 | 0.075 | 0.044 |
| 6400 | 0.115 | 0.075 | 0.044 |
| 6200 | 0.095 | 0.065 | 0.040 |
| 6000 | 0.060 | 0.048 | 0.033 |
| 5800 | 0.040 | 0.024 | 0.020 |
| 5600 | 0.015 | 0.010 | 0.009 |
| 5400 | 0.0055 | 0.0045 | 0.0045 |
| 5200 | 0.005 | 0.004 | 0.004 |
| 5000 | 0.006 | 0.0055 | 0.0055 |
| 4800 | 0.010 | 0.008 | 0.009 |
| 4600 | 0.006 | 0.006 | 0.006 |
| 4400 | | | |
| 4200 | | | |

# TABLE XXVI

## Transmission for Film "D"

### 5780 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2 \theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.475 | 0.425 | 0.370 |
| 7400 | 0.480 | 0.440 | 0.425 |
| 7200 | 0.475 | 0.440 | 0.425 |
| 7000 | 0.460 | 0.440 | 0.425 |
| 6800 | 0.485 | 0.450 | 0.440 |
| 6600 | 0.490 | 0.450 | 0.450 |
| 6400 | 0.490 | 0.450 | 0.440 |
| 6200 | 0.480 | 0.460 | 0.440 |
| 6000 | 0.460 | 0.460 | 0.425 |
| 5800 | 0.435 | 0.410 | 0.390 |
| 5600 | 0.390 | 0.375 | 0.330 |
| 5400 | 0.330 | 0.295 | 0.280 |
| 5200 | 0.240 | 0.230 | 0.220 |
| 5000 | 0.160 | 0.150 | 0.140 |
| 4800 | 0.080 | 0.075 | 0.075 |
| 4600 | 0.040 | 0.032 | 0.030 |
| 4400 | 0.023 | 0.020 | 0.023 |
| 4200 | 0.023 | 0.023 | 0.023 |

### 5780 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | 0.425 | 0.340 | 0.330 |
| 7400 | 0.440 | 0.410 | 0.410 |
| 7200 | 0.450 | 0.425 | 0.420 |
| 7000 | 0.470 | 0.455 | 0.420 |
| 6800 | 0.475 | 0.450 | 0.440 |
| 6600 | 0.475 | 0.450 | 0.440 |
| 6400 | 0.480 | 0.460 | 0.450 |
| 6200 | 0.480 | 0.450 | 0.425 |
| 6000 | 0.470 | 0.450 | 0.420 |
| 5800 | 0.440 | 0.400 | 0.380 |
| 5600 | 0.380 | 0.370 | 0.345 |
| 5400 | 0.320 | 0.305 | 0.280 |
| 5200 | 0.245 | 0.230 | 0.210 |
| 5000 | 0.160 | 0.145 | 0.125 |
| 4800 | 0.080 | 0.070 | 0.074 |
| 4600 | 0.030 | 0.030 | 0.034 |
| 4400 | 0.020 | 0.020 | 0.020 |
| 4200 | 0.023 | 0.020 | 0.020 |

# TABLE XXVII

## Transmission for Film "D"

### 5461 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.160 | 0.160 | 0.110 |
| 7200 | 0.175 | 0.160 | 0.095 |
| 7000 | 0.180 | 0.145 | 0.105 |
| 6800 | 0.190 | 0.160 | 0.115 |
| 6600 | 0.205 | 0.190 | 0.135 |
| 6400 | 0.245 | 0.210 | 0.160 |
| 6200 | 0.270 | 0.255 | 0.210 |
| 6000 | 0.325 | 0.305 | 0.255 |
| 5800 | 0.365 | 0.350 | 0.285 |
| 5600 | 0.390 | 0.360 | 0.300 |
| 5400 | 0.360 | 0.355 | 0.310 |
| 5200 | 0.290 | 0.285 | 0.250 |
| 5000 | 0.200 | 0.185 | 0.170 |
| 4800 | 0.115 | 0.110 | 0.080 |
| 4600 | 0.050 | 0.045 | 0.035 |
| 4400 | 0.023 | 0.030 | 0.018 |
| 4200 | 0.030 | | 0.030 |

### 5461 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | 0.110 | | |
| 7200 | 0.115 | 0.080 | 0.100 |
| 7000 | 0.110 | 0.085 | 0.105 |
| 6800 | 0.123 | 0.100 | 0.110 |
| 6600 | 0.140 | 0.110 | 0.115 |
| 6400 | 0.165 | 0.150 | 0.170 |
| 6200 | 0.200 | 0.190 | 0.200 |
| 6000 | 0.260 | 0.200 | 0.220 |
| 5800 | 0.300 | 0.270 | 0.305 |
| 5600 | 0.320 | 0.310 | 0.310 |
| 5400 | 0.315 | 0.335 | 0.320 |
| 5200 | 0.240 | 0.265 | 0.260 |
| 5000 | 0.160 | 0.175 | 0.180 |
| 4800 | 0.080 | 0.085 | 0.095 |
| 4600 | 0.035 | 0.038 | 0.035 |
| 4400 | 0.025 | 0.025 | 0.025 |
| 4200 | | | 0.023 |

TABLE XXVIII

Transmission for Film "D"

4472 AU, Uncorrected

| Wavelength (AU) | Transmission ($cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | 0.003 | 0.0015 | 0.0015 |
| 6600 | 0.0025 | 0.002 | 0.0025 |
| 6400 | 0.003 | 0.003 | 0.003 |
| 6200 | 0.004 | 0.004 | 0.004 |
| 6000 | 0.0045 | 0.004 | 0.004 |
| 5800 | 0.0045 | 0.004 | 0.004 |
| 5600 | 0.0045 | 0.003 | 0.003 |
| 5400 | 0.003 | 0.0025 | 0.002 |
| 5200 | 0.004 | 0.004 | 0.003 |
| 5000 | 0.005 | 0.009 | 0.0075 |
| 4800 | 0.025 | 0.028 | 0.024 |
| 4600 | 0.043 | 0.039 | 0.049 |
| 4400 | 0.043 | 0.039 | 0.048 |
| 4200 | 0.038 | 0.039 | 0.048 |

4472 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | 0.0015 | 0.0015 | 0.0015 |
| 6600 | 0.002 | 0.0025 | 0.0015 |
| 6400 | 0.003 | 0.003 | 0.0025 |
| 6200 | 0.0035 | 0.0035 | 0.004 |
| 6000 | 0.004 | 0.004 | 0.004 |
| 5800 | 0.004 | 0.004 | 0.004 |
| 5600 | 0.003 | 0.003 | 0.0025 |
| 5400 | 0.002 | 0.002 | 0.002 |
| 5200 | 0.003 | 0.0035 | 0.003 |
| 5000 | 0.007 | 0.007 | 0.0065 |
| 4800 | 0.022 | 0.025 | 0.020 |
| 4600 | 0.036 | 0.036 | 0.030 |
| 4400 | 0.030 | 0.035 | 0.028 |
| 4200 | | | 0.028 |

# TABLE XXIX

## Transmission for Film "D"

### 4360 AU, Uncorrected

| Wavelength (AU) | Transmission ($\cot^2\theta$) + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | 0.150 |
| 7200 | | | 0.155 |
| 7000 | 0.019 | | 0.160 |
| 6800 | 0.018 | 0.004 | 0.200 |
| 6600 | 0.022 | 0.005 | 0.240 |
| 6400 | 0.034 | 0.008 | 0.240 |
| 6200 | 0.050 | 0.018 | 0.270 |
| 6000 | 0.080 | 0.039 | 0.315 |
| 5800 | 0.130 | 0.072 | 0.380 |
| 5600 | 0.200 | 0.140 | 0.430 |
| 5400 | 0.250 | 0.190 | 0.460 |
| 5200 | 0.290 | 0.245 | 0.450 |
| 5000 | 0.325 | 0.290 | 0.450 |
| 4800 | 0.340 | 0.305 | 0.410 |
| 4600 | 0.305 | 0.290 | 0.410 |
| 4400 | 0.255 | 0.235 | 0.330 |
| 4200 | 0.170 | 0.200 | 0.270 |

### 4360 AU, Corrected

| Wavelength (AU) | + 50% | ± 0% | - 50% |
|---|---|---|---|
| 8000 | | | |
| 7800 | | | |
| 7600 | | | |
| 7400 | | | |
| 7200 | | | |
| 7000 | | | |
| 6800 | 0.029 | 0.004 | 0.004 |
| 6600 | 0.033 | 0.005 | 0.004 |
| 6400 | 0.050 | 0.006 | 0.005 |
| 6200 | 0.075 | 0.014 | 0.010 |
| 6000 | 0.110 | 0.030 | 0.022 |
| 5800 | 0.190 | 0.060 | 0.045 |
| 5600 | 0.260 | 0.110 | 0.086 |
| 5400 | 0.310 | 0.170 | 0.140 |
| 5200 | 0.350 | 0.220 | 0.185 |
| 5000 | 0.385 | 0.270 | 0.215 |
| 4800 | 0.385 | 0.280 | 0.240 |
| 4600 | 0.360 | 0.270 | 0.245 |
| 4400 | 0.320 | 0.190 | 0.205 |
| 4200 | 0.210 | 0.130 | 0.180 |

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