Designation of Filters for Theatrical Lighting*†

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The basis of this proposal is that the complete definition of the chromatic properties of filters used in illumination is transmission as a function of wave-length; an approximate definition suitable for commercial specification should, therefore, take the form of an abbreviated notation for the curve of spectral transmission. It is proposed to specify filters for theatrical lighting by a seven-digit number, the first digit of which refers to spectral transmission at the short wave extreme of the spectrum, the second, that at some longer wave portion, and so on throughout to the long wave extreme. The present paper discusses choices of wave-lengths to which the digits should refer and also what range of transmission should be indicated by digit, 0, what by digit, 1, what by digit, 2, and so on for maximum usefulness of the specification. Recommended choices are presented based upon a spectrophotometric examination by William F. Little and Allan E. Parker of the Electrical Testing Laboratories made upon two groups of theatrical gelatines, one group of 11 pink filters and one group of 11 blue filters.

I. HISTORICAL

THE problem of devising a simple specification of filters used for theatrical lighting was informally brought before the Inter-Society Color Council in 1932 by A. L. Powell of the Illuminating Engineering Society. He asked that the Council recommend "terminology of glasses, gelatine, and other media for the production of colored light flux." This problem was discussed by the Committee on Color Problems at its first meeting, April 26, 1932, Washington, D. C. There was considerable difference of opinion among the committee members and according to the report of the chairman, Margaret Hayden Rorke, it was "decided that the problem had so many ramifications and was such a vital one that it should be officially submitted by a Society such as the Illuminating Engineering Society rather than by an individual, and that a letter should be written to Mr. Powell, expressing the Committee's appreciation for bringing the problem to its attention, and urging that he interest the Illuminating Engineering Society or any other scientific organization, of which he is a member, to sponsor this problem officially and represent it to the Council for future action." This was never done, however; and the problem lay dormant until the 1937 Annual Meeting of the Council.

At that meeting work on the problem was reopened by the author who, in his capacity as present chairman of the Committee on Color Problems, proposed a tentative specification for such filters. This proposal was discussed by the Council,[1] and it was presented before the New York Section of the Illuminating Engineering Society by the author in an invited address sponsored by the Council. Discussion following this presentation was generally favorable except for questions as to details of the arbitrary choices of the wave-lengths and of division points in the transmission scale. A. E. O. Munsell, delegate from the Optical Society of America, made some very specific recommendations for revision of the latter; these were accepted as improvements by the present chairman, and appear in Appendix E to the minutes of the 1937 Annual Meeting.

This plan of specification was then brought before the December, 1937 meeting of the Executive Committee of the Inter-Society Color Council who instructed William F. Little, delegate from the Illuminating Engineering Society, to get in touch with filter manufacturers for the purpose of learning what might be done to put the specification into effect. As a preliminary step Mr. Little obtained samples of theatrical gelatines from two manufacturers, and selected from them two groups of similar filters with which to test the proposed specification to see if it would distinguish between all filters

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[1] The proposal is stated in Appendix E to the minutes of the 1937 Annual Meeting; the discussion is summarized in the minutes.

commercially different. One group consisted of 11 pink filters, and the other of 11 blue filters. The spectral transmissions of these 22 filters were obtained and examined by Allan E. Parker at Electrical Testing Laboratories. From his examination of these data, Mr. Parker was able to suggest improvements in the proposed specification.

It is the purpose of the present discussion to give briefly the theoretical basis of the specification, to give the details of the various arbitrary choices so far proposed together with the argument by which they may be supported, and to give details of what is believed to be a still further improved plan of specification which is here recommended for adoption.

II. Theoretical Considerations

Filters are in general use in stage illumination in combination with spot lights or flood lights for producing chromatic effects. The illuminants are chiefly incandescent lamps and carbon arcs. The chromatic effects do not consist merely in projecting spots or areas of chromatic light on a stage filled with nonselectively reflecting (white or gray) objects, but more generally to illuminate selectively reflecting objects, painted scenery and players covered by costumes and cosmetics, which in daylight or incandescent-lamp light display highly chromatic colors.

The designation of the glass or gelatine filters now used for theatrical lighting is by trade names and numbers assigned to them by each manufacturer, the central part of the name for most filters being a color name. The color name serves a very useful purpose by indicating in a general way the appearance of nonselectively reflecting objects illuminated by light projected through the filter. The trade number serves a further useful purpose by providing additional assurance that a "repeat order" from the same manufacturer will be a satisfactory substitute. However, there is little or no correspondence between the designations of different manufacturers nor does this system of designation lend itself to logical expansion or interpolation as new and improved chromatic media are developed.

It might seem that this problem could be solved by promoting an agreement among manufacturers to use the same numbers for the arbitrary designation of filters. The trade numbers now used indicate to the manufacturer the coloring materials in the filter. But since there are, particularly for gelatine filters, so many possible coloring materials, an impractically large list would be required; furthermore, many different dyes will produce what is commercially the same filter, hence, an arbitrary system of numbering would not serve to identify commercial duplicates.

A frequent suggestion is that a colorimetric designation of the illuminant-filter combination is needed; this would require three numbers and would take the form of a tristimulus specification, or the form of a specification by dominant wavelength, colorimetric purity and transmission. Thus, two illuminant-filter combinations having the same colorimetric specification would produce illuminating beams which color-match. This form of specification would be quite suited to filters to be used to illuminate nonselectively reflecting objects (whites or grays) only. But there are filters which would have the same colorimetric specifications yet would produce radically different chromatic effects when used to illuminate an array of selectively reflecting objects. For example, it is easily possible to find two filters, identically blue by carbon-arc lamp, one of which transmits freely the long wave portion of the spectrum, the other of which transmits it scarcely at all. These filters produce the same chromatic effect upon nonselectively reflecting objects (whites and grays) but one brings out red objects brilliantly, while the other makes them look dark gray.

The presence upon the stage of selectively reflecting objects, requires, therefore, a much more complicated numerical specification of the filters used in theatrical lighting. Instead of three numbers for each filter, the spectral transmission throughout the visible spectrum would have to be given. This is the final and fundamental specification; two filters having the same curves of spectral transmission cannot fail to produce the same chromatic effect. To make sure of this identity to the degree that an observer would be able to detect no difference between filters of identical specification would require the use of about 30 values instead of 3. These 30 would

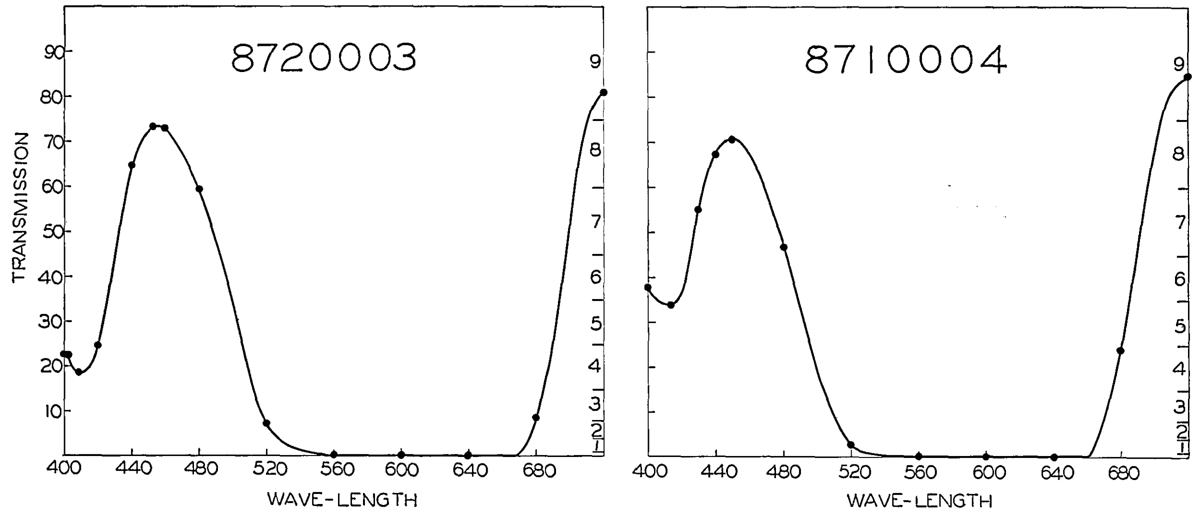

FIG. 1. Spectral transmissions of two blue filters.
They are now designated by the distributor: Medium Blue No. 33 and Medium Navy Blue No. 34; the proposed ISCC designations are 8720003 and 8710004. This pair of filters illustrates closely the smallest difference which would be certainly differentiated by the proposed ISCC system of designation.

adequately specify the curve of spectral transmission for any colorimetric use of the filter. Obviously, however, a 30-parameter designation of filters for theatrical lighting is impractical.

The specification proposed here gives an abbreviated notation for the curve of spectral transmission. Each filter is to be specified by a seven-digit number, each digit indicating approximately (on a scale of ten) the spectral transmission at some wave-length. It is hoped that the loss in accuracy necessitated by accepting a 7-parameter approximate specification instead of a 30-parameter accurate specification will not result in confusing two filters which are commercially different. As a justification for this hope it will be noted that the proposed system provides for the specification of 10,000,000 different filters. This number would seem to be large enough to embrace theatrical needs for some time to come. There remains the problem of making arbitrary choices of wave-length and transmission range so as to make the most practical use of these 10,000,000 specifications.

III. Arbitrary Choices

For the number of parameters to be used in the abbreviated notation seven was chosen because it is about the limit of the average memory span. It is usually possible to repeat without error any seven digits an instant after they have been given; to repeat eight is considerably more confusing.

Next we have to choose what 7 wave-lengths are to be used in the seven-digit specification; and we have to decide what transmission ranges are to be denoted by the digits, 0, 1, 2, and so on.

A. Selection of wave-lengths

The visible spectrum extends roughly from 380 to 770 mμ. The 7 points should be distributed somewhere throughout this range rather more toward the middle than toward the extremes because of the small chromatic contribution made by the extremes. To make the choices easy to remember, the distribution should be uniform.

For a tentative choice of wave-length interval 50 mμ was taken; that is, the first digit would apply to 400 mμ, the second to 450 mμ, and so on up to 700 mμ. The groups of filters examined by Little and Parker indicated, however, that a 50 mμ interval is too large; they showed many examples of filters in which the spectral transmission changed so rapidly with wave-length that a 50 mμ interval might permit important differences in spectral transmission to go unspecified. See Fig. 1 in which two blue filters, one of which brings out red objects somewhat more than the other, differ considerably between

670 and 700 mμ; this difference falls within a 50 mμ interval and would not be shown, for example, either at 660 or 710 mμ. A smaller wave-length interval is therefore needed—obtainable either by using more than 7 digits or by restricting the specification more to the center of the spectrum. Since a 7-digit number has already been fixed upon as the longest number for convenient use, the second possibility was investigated. It was found that neglect of the spectrum extremes brought no undesirable deficiencies in the specification of the filters so far measured. A 40 mμ interval starting with 440 mμ and ending with 680 mμ has therefore been adopted.

In the discussion at the Council meeting, the suggestion was made by K. S. Gibson, National Bureau of Standards, that a first digit, set off from the other seven by a dash, be used to indicate which of ten possible groups of seven wave-lengths is indicated. If the proposed system should be found insufficiently discriminative, this suggestion is worth further study because it increases the flexibility of the specification. A disadvantage is that it increases the complexity of the specification by giving 10 possible designations for each filter instead of a single one.

Other questions during discussion were aimed at selection of wave-lengths in accord with some more apt principle than the two actually followed. L. C. Lewis, Meade Corporation, suggested that uniform distribution throughout the visible spectrum be given up in favor of choosing the seven most important wave-lengths; Verne H. Rechmeyer, Agfa Ansco Corporation, suggested that wave-lengths might be chosen to accord with the stimuli for typical red, orange, yellow, green, blue and violet. In reply, it should be noted that an obstacle to selection of the seven most important wave-lengths is that we do not know what they are, but we do know that the stimuli for the seven Newtonian hues are not the

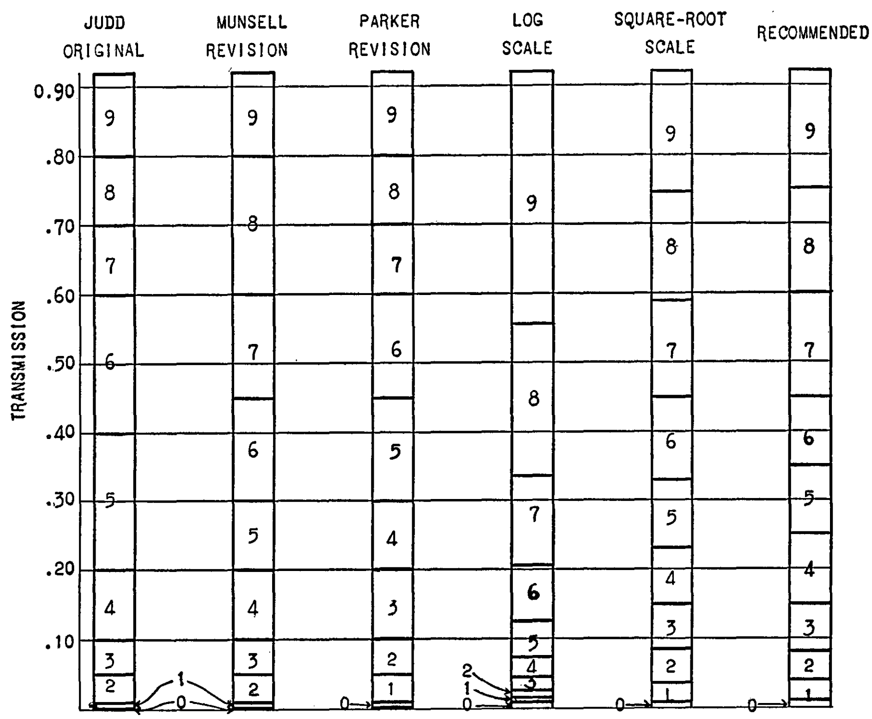

FIG. 2. Divisions of the transmission scale.

Four proposed arbitrary divisions including the recommended division, and two systematic divisions are shown. The recommended division is also indicated by a table of values, see Table II. Note that the recommended division resembles closely that based on square-root of transmission for which: $100\ T_{min}=0.92\ D^2$, $100\ T_{max}=0.92\ (D+1)^2$, where D is the digit indicating the transmission range from T_{min} to T_{max}.

most important because we have many filters which require two separate specifications in the red region (630 to 770 mμ) of the spectrum.

B. Subdivision of the transmission scale

Change in spectral transmission near zero produces a greater chromatic effect than the same change at high transmissions; for example, the stage designer will find that it is more important in the production of chromatic effects to have a yellow filter transmit nothing instead of one percent in the short wave part of the spectrum than it is to have it transmit 90 percent instead of 80 percent in the long wave part. It has been shown by Helson and Judd in work not yet completely published[2] that a change from one-tenth of one percent to zero in spectral transmission of a chromatic filter is easily detectable as a change in the surface color of the illuminated object. Accordingly, the original division of the scale[1] used the digit 0 to indicate the transmission range from zero to 0.001 (see Fig. 2). The ranges in transmission designated by the digits 1, 2, 3, 4, and 5 grew progressively larger in accord with the above generally accepted principle. The ranges designated by the other digits varied up and down in accord with no principle other than to have the division points fall upon easily expressible transmissions: 0.60, 0.70, and 0.80. This irregularity was criticized by Mr. Munsell who pointed out that it might give the false impression that changes in transmission near the middle of the scale are less important than those near the upper end. He also showed how this irregularity could be avoided without the use of inconveniently expressible division points (see Fig. 2).

The next revision was made by Mr. Parker from an examination of the curves of spectral transmission of the 22 filters procured by Mr. Little. He noted that of this group of filters many would be better specified by using two digits in the transmission range 0.60 to 0.80 instead of 1; he proposed to do this by eliminating the use of two digits for the transmission range 0.00 to 0.01 which he described as a "little extravagant." The writer has attempted to defend his original use of two digits for this latter transmission range but without success. The pronounced effect found by Helson and Judd to be due to the admixture of one-tenth of one percent of stray light could not be demonstrated under practical conditions of illuminating a stage, apparently because one must expect at least one or two percent of stray light to be present. Furthermore, there were no pairs of filters among the approximately 50 measured which required this division of the transmission scale for their differentiation. Accordingly this feature of the Parker revision has been accepted as being a distinct improvement.

However, the upper portion of the transmission-scale division suggested by Parker shows, though in less degree, the same fault criticized by Munsell in the original scale. There has, therefore, been a further attempt to improve the division. As steps toward this improvement a logarithmic division of the transmission scale passing through 0.01 and 0.92 has been plotted (see Fig. 2) and a square-root division passing through 0.0092 and 0.92. A glance at the logarithmic division shows its complete unsuitability for the present purpose in spite of the frequency with which the term, logarithmic, is used to

TABLE I. *Designations of the 22 filters examined by Little and Parker.*

Trade Name	Trade Number	Proposed ISCC Number
Pink Series		
Dark rose pink	7	5100999
Rose pink	6	7301999
Rose pink	39	7513699
Medium pink	37	8404799
Deep pink	8	8514999
Pink	5	8514999
Shubert pink	35	9616999
Medium pink	4	9735999
Dubarry pink	9	9754899
Flesh pink	3	9857999
Light flesh pink	2	9978999
Blue Series		
Daylight blue	25	9985448
Light sky blue	26	8875458
Light blue	27	9974217
Light navy blue	28	9952238
Special steel blue	29	8863337
Light blue special	30	8851004
Medium sky blue	31	8840003
Medium blue special	32	9850007
Medium blue	33	8720003
Medium navy blue	34	8710004
Dark sky blue	35	7710001

[2] H. Helson and D. B. Judd, "A Study of Photopic Adaptation," J. Exp. Psychology **15**, 380 (1932); D. B. Judd, "Surface Color," J. Opt. Soc. Am. **25**, 44 (1935); H. Helson and D. B. Judd, "An Experimental and Theoretical Study of Changes in Surface Colors under Changing Illuminations," Psych. Bull. **33**, 740 (1936); H. Helson, "Tri-Dimensional Analysis and the Non-Film Modes of Color Appearance," J. Opt. Soc. Am. **27**, 59 (1937).

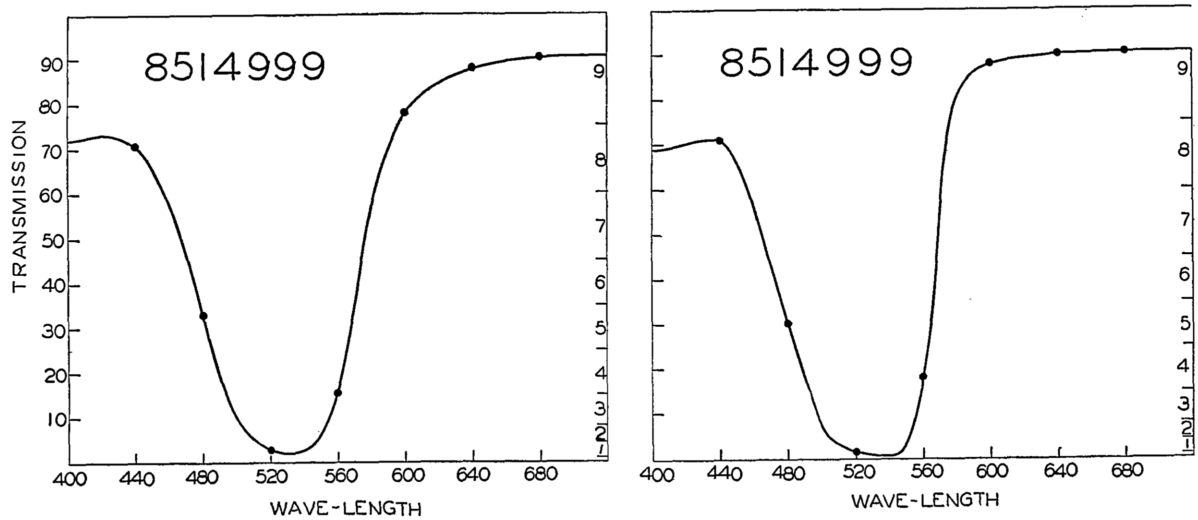

FIG. 3. Spectral transmissions of two pink filters.
They are now designated by the distributor: Deep Pink No. 8 and Pink No. 5; they both would receive proposed ISCC designation 8514999. This pair of filters illustrates closely the largest difference which can go undifferentiated by the proposed ISCC system of designation.

describe the ideal choice. The unsuitability comes from the fact that the logarithm of transmission varies over an infinite range as the transmission varies from 0 to 1. There is, therefore, no way to divide the transmission scale in a strictly logarithmic way into ten ranges; a lower part of the transmission scale must be chopped off. Even by this device, there is obtained a division of the transmission scale which is obviously unsuitable. These objections do not apply to the square-root division of the scale.

The recommended subdivision of the transmission scale is therefore based upon the square-root scale, and it embodies one further improvement which has so far not received explicit attention—the recognition that the practical upper limit of the transmission scale because of reflectance losses is about 0.92 instead of 1.00. The recommended subdivision may be described as a rounded-off square-root scale. The lower transmission limit designated by any digit is obtained approximately in percent by taking 0.92 of the square of the digit; of course, the upper limit is approximately obtained by taking 0.92 of the square of the next higher digit. From Fig. 2 it may be seen that the recommended scale includes all of the best features of the previously proposed scales.

In the discussion at the Council meeting it was suggested by A. G. Worthing, University of Pittsburgh, that if the 10-point subdivision of the transmission scale should prove to be not sufficient, use might be made of a scheme of mathematicians who deal with systems of more than ten digits and of genealogists who have to consider families in which there are more than ten children. In this scheme, the 11th member is designated, *P*; the 12th, *Q*; then *R*, *S*, *T*, and so on, up to whatever is necessary. Another suggestion was that the total number of designations might be raised to 13 by the addition of symbols: *J* (ack), *Q*(ueen), *K*(ing).

IV. Experimental Tests

The spectrophotometric curves of the 22 filters selected by Mr. Little were obtained on a General Electric automatic recording spectrophotometer. The designation by the system proposed was read from these curves directly and appears in Table I together with the manufacturer's name and number. All of the filters of the blue series were obtained from the same manufacturer. The pink series comprises filters from two manufacturers, filters Nos. 35, 37, and 39 from the second manufacturer being added to those of the first for the purpose of investigating the correspondence between filters with similar color names supplied by different manufacturers.

Examination of the proposed designations, hereinafter called the proposed ISCC designations, for the two pairs of filters of the same name (medium pink and rose pink) shows immediately that there is not much correspondence. As might well have been expected, the filters bearing the same color name from different manufacturers differ considerably more than filters bearing different color names from the same manufacturer. Visual inspection of the filters corroborates this conclusion.

It will be noted that generally the proposed ISCC designations are quite definitely different for the different filters; it may be concluded therefore that the proposed system of designation is generally successful in differentiating between filters which have been found to be commercially different. This is true even for these two groups of filters particularly chosen because they contained many close visual duplicates for which it seemed legitimate to raise the question whether there is really a commercially important difference. However, two pairs of filters, one pink pair and one blue pair, are exceptions to this general conclusion and deserve special attention; they are Deep Pink No. 8 and Pink No. 5 for which the ISCC designations are identical (8514999) and Medium Blue No. 33 and Medium Navy Blue No. 34 for which the ISCC designations are 8720003 and 8710004, respectively. The spectral transmissions of these four filters are shown in Figs. 1 and 3.

As has already been mentioned, Fig. 1 shows the curves for the two blue filters, and the use of these filters reveals the fact that filter 8710004 brings out red objects somewhat more definitely than filter 8720003 as it would be expected to do from the notation. This was brought out as a part of a demonstration of these filters during presentation of the paper. A test object composed of 8 papers having highly selective pigment-coated matte surfaces was illuminated first by light through one filter, then the other. This pair of filters may be taken as an example of the smallest difference which will certainly be differentiated by the system of designation. It is a matter of opinion whether the filters themselves are characteristic of the smallest difference in chromatic effect which it is commercially desirable to differentiate, but it seems to many people that they are. The opinion that commercial tolerance is considerably larger than this difference, was expressed in discussion at the Council meeting by Charles Bittinger, Naval Research Laboratory and by Dean Farnsworth, New York University.

TABLE II

Digit	Spectral Transmission
0	Less than 0.01
1	0.01 to 0.04
2	0.04 to 0.08
3	0.08 to 0.15
4	0.15 to 0.25
5	0.25 to 0.35
6	0.35 to 0.45
7	0.45 to 0.60
8	0.60 to 0.75
9	More than 0.75

It was suggested by Frederic H. Rahr, Color Consultant, that it would be a good idea to extend the test object used in evaluating subjectively the chromatic effect of the filters. He expressed the opinion that if gelatin transparencies and dyed fabric were to be used on the test object in addition to the pigmented papers actually used, that a different conclusion might have been reached and one more representative of stage illumination.

Figure 3 shows the curves for the two pink filters.[3] Note that there is a definite difference between the curves, that for the Pink No. 5 filter being considerably higher than that for Deep Pink No. 8 in the region 570 to 590 mμ. Since this principal difference happens to fall almost exactly in the center of one of the 40 mμ wave-length intervals, this pair of samples may be taken as representative of the largest difference between filters which would go undetected by the proposed ISCC system of designation. If it is considered by stage designers that the difference between these two filters is commercially important and that they would not be satisfied to accept one of the filters as a substitute for the other, then the proposed system of designation

[3] Following attention drawn by Gibson and Keegan (J. Opt. Soc. Am. 28, 180 (1938)) to the inapplicability to fluorescent samples of spectrophotometers which, like the General Electric instrument, do not disperse the light after it leaves the sample, it was discovered that the Deep Pink No. 8 filter was definitely more fluorescent than the Pink No. 5 filter. The curves in Fig. 3, therefore, fail to show quite fairly the transmission differences between the two filters. However, the error is not sufficient to change the proposed ISCC designation for either.

would fail of its purpose and if it could not be modified to distinguish such pairs of filters the whole plan might as well be given up. Visual examination of test objects illuminated by light from these two filters, however, shows them to be but slightly different, the Deep Pink filter yielding a slightly more bluish pink than the Pink filter when both are used to illuminate a white screen. Chromatic test objects tried have failed to differentiate these two filters any more definitely. Since the actual difference found between the filters is different from the one to be expected from their names, it seems likely that the difference is too small to be of commercial importance.

V. Recommended Method of Specification

The method applies to all light filters for which more precise specification is unnecessary, but it is particularly useful for colored gelatins used in illumination of theater stages. The plan is to supplement the present designation of each filter by a seven-digit number, the first digit to refer to the spectral transmission at wave-length 440 mμ, the second at 480 mμ, the third at 520 mμ, and so on by 40 mμ steps up to the seventh digit, which refers to 680 mμ. The 7-digit number would be known as the ISCC number. Table II gives the meaning of the various digits. This division of the transmission scale is by square root rounded off to convenient values of transmission. The lower limit of transmission referred to by any digit is given in percent approximately by 0.92 times the square of the digit.

As an example, the filters shown in Fig. 3 would be known as Pink 8514999, in which "Pink" is included merely for its descriptive value, the proposed ISCC number being a sufficient specification.

The designations found by this system are, of course, not as complete as that by a curve of spectral transmission, but they may be easily written or telegraphed, and for purposes such as those indicated above will probably give a sufficiently complete specification.