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U. S. Submarine Base
New London

PROPOSED SPECIFICATIONS OF RED AND GREEN NAVY SIGNAL LIGHTS

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BuMed Project No. X-265 (Av-153-c)

Prepared by

Lieut. Comdr. Dean Farnsworth, H(S) USNR.

6 October 1947
Revised 1 March 1948

Color Vision Report No. 16

APPROVED: T. L. Willmon, Captain (MC) USN, MO-in-C.

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6 October 1947
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to BuMed X-265 (Av-153-c) of 5 February 1946
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Color Vision Report No. 16

U. S. Naval Medical Research Laboratory
U. S. Naval Submarine Base, New London, Connecticut.

INTRODUCTION

Some thirty or more separate specifications for red, green yellow, and white signal lights were in use in the United States, Great Britain, France, and the Netherlands at the beginning of World War II. When their land, maritime, and air forces were joined, certain differences had to be adjusted and compromised. In addition, new specifications were adopted, sometimes hastily, to accommodate newly developed instruments or changing techniques.

New studies on visibility of colored signal lights by normal persons were made during the war which furnished data which had not been available when most of the specifications were originally written. New data was furnished on the appearance of colors at small subtense. The participation of large numbers of partially red-green blind men in the Services raised the question of the possibility of adjusting color signals for better recognition by the color weak. There was an increase in Naval and amphibious operations which required the use of signals at minimum brightness secured by reduction of current supplied to the lamps.

All of the above factors are to some extent responsible for renewed activity in the re-examination of the present diverse standards. It is expected that they can be made more satisfactory from the standpoint of manufacture and usage, and, when possible without sacrifice of efficiency, that substantial uniformity can be achieved by substituting a few codes for the many now in use.

The following proposals are made with the realization that the problems are so complex and exacting that they can be properly resolved only after the fullest discussion between experienced authorities.

PROPOSED SPECIFICATION OF RED AND GREEN NAVY SIGNAL LIGHTS

1. Specifications for signal lights must meet many requirements:

(a) They must not impose undue manufacturing difficulties.

(b) Colors must be distinguishable at small subtense.

(c) A compromise mustbe made between the brightness of a signal light and the purity of the hue.

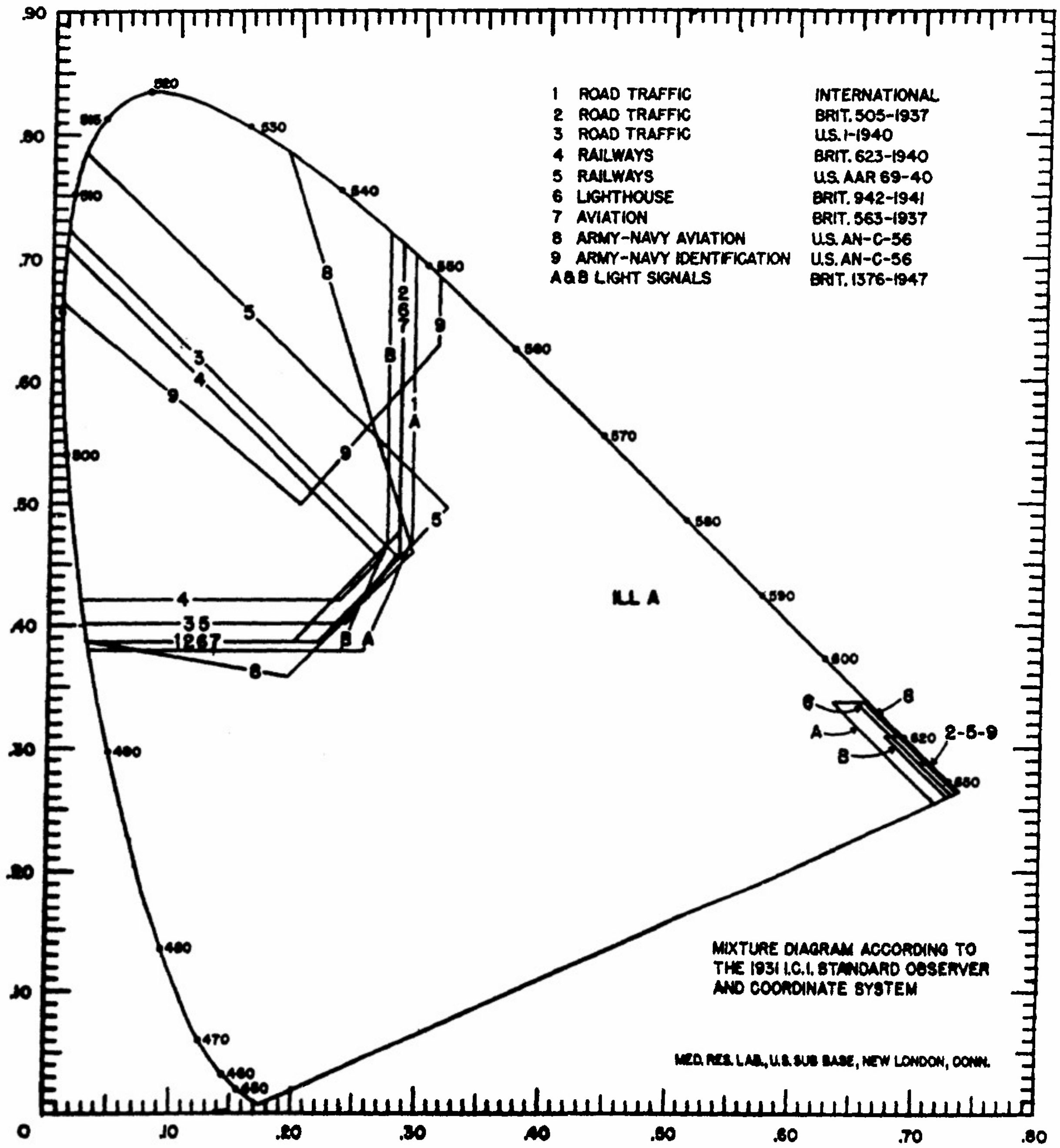
(d) They are influenced by the number of signal lights that will be employed in a given system.

(e) Distinction must be made between lights which will be employed for high visibility as opposed to those whose color must be recognized unerringly.

(f) Certain signal lights will be used with reduced voltages which change the color of the signal.

2. About a dozen slightly differing specifications for lights in various signal services are known to exist in the United States and England. Several of these systems are plotted in Figure 1 to show the lack of agreement. Foreign systems for the most part are not uniform with any of these. The 1947 "British Standard Specifications for Colors of Signal Lights" (1) was prepared in order to reconcile differences which at present exist in the definitions of colors for signalling equipment in Great Britain.

3. The need for simplification is expressed in the foreword to the new British specification: "The existence of several slightly differing specifications was felt to be unnecessary and to lead to manufacturing difficulties which result in delays in supplying the requirements of different users. The problems involved in the recognition of signal colors are largely common to all users and the differences which occur in the various specifications have, in many instances, no fundamental justification, having arisen chiefly from the independent experience of the different users."



1 ROAD TRAFFIC INTERNATIONAL
2 ROAD TRAFFIC BRIT. 505-1937
3 ROAD TRAFFIC U.S. 1-1940
4 RAILWAYS BRIT. 623-1940
5 RAILWAYS U.S. AAR 69-40
6 LIGHTHOUSE BRIT. 942-1941
7 AVIATION BRIT. 563-1937
8 ARMY-NAVY AVIATION U.S. AN-C-56
9 ARMY-NAVY IDENTIFICATION U.S. AN-C-56
A & B LIGHT SIGNALS BRIT. 1376-1947
ILL A
MIXTURE DIAGRAM ACCORDING TO THE 1931 I.C.I. STANDARD OBSERVER AND COORDINATE SYSTEM
MED. RES. LAB., U.S. SUB BASE, NEW LONDON, CONN.

FIGURE 1

4. Among the principal signal systems in the United States are the Signal Section of the Association of American Railroads (AAR) (2) and the Army-Navy Aeronautical Specification of Colors (AN-C-56) (3). These are similar to the new British specifications, but the systems do not agree exactly in any respect. A comparison of the three systems shows certain important differences in the red and green regions:

(a) The British system makes a desirable distinction between Class A and Class B classes. Class A limits permit the highest transmittance; Class B limits have the highest possibility of recognition.

(b) The AAR specifications were selected by experienced engineers, are based upon long usage, have general acceptance, and are backed by carefully calibrated limit standards.

(c) The AN-C-56 Code is similar to the above mentioned two systems but apparently lacks a clear rationale for the distinction between aviation and identification systems.

(d) The British system is believed to err in permitting signal greens which approach the red-green spectral locus close enough to make them confusable with reds and yellows by colorblinds. These areas have been graphed in New London Report No. 13 (4). Such confusion is also possible with AN-C-56 identification green, but not with AAR green.

(e) The extensive work done on the recognition of colored light signals by Holmes (5) and by Hill (6) indicates that the direction of the low saturation locus for green was not chosen by the AAR to accord with psychophysical response loci.

(f) The high recognition attributed to red in the work of Holmes, Hill, and McNicholas (7) indicates that the red tolerances in the AAR specifications are unnecessarily restrictive.

5. The white, yellow, and blue specifications on all three systems are closely similar and it is suggested that either the AAR of the British limits be continued in the interests of securing eventual international agreement. The Class A and B distinction as to white boundaries used by the British is believed, however, to

be a simple solution to the designation of white signal lights used in a 4-color system including yellow.

6. Proposed specifications for red and green are given in Table 1. They are designed to reconcile differences when necessary and to incorporate the soundest boundaries from each system. The boundaries are plotted on the 1931 I.C.I. System in Figure 2. Selected contour lines of recognition from the plates of Holmes and Hill are included for comparison.

7. Explanation of choice of chromatic boundaries:

Green A

(a) "x is not greater than 0.410 y - 0.100." This boundary is the 1947 British extended to y=0.500 for simplicity. It is used because of its close agreement with the contour lines of Holmes and Hill.

(b) "z = 1 -x -y = .195." This is substantially the AAR boundary and is important since it prevents the use of greens which are most confusable with reds by color blinds (4) as permitted by the British code and by the AN-C-56 identification code.

(c) "y not less than 0.380." The y boundary of the 1947 British and of the majority of other codes. Slightly bluer than the AAR limit and therefore desirable (1) for discrimination by color defective personnel, and (2) for signal glasses lighted at low color temperature or at reduced voltage. Observers do not distinguish between green and blue at small subtense and low brightness. Since blue is not used as a long range signal, it is not necessary that a distinguishing boundary be set between blue and green.

Green B

(a) Boundaries are retreated to an amount roughly corresponding to the difference between 80% and 90% certainty of recognition at from 1 - 10 sea-mile candles, or to the change in chromaticity caused by a change of from 2848°K to 2360°K of the illuminant.

Red A

(a) "y not greater than 0.335." This British limit represents a considerable liberalization of AAR limit but appears justified by Holmes and Hill. The increased transmission of red glasses made possible by the new standards is important because it adds high visibility to red's already high recognition. Tests conducted by a

Naval activity (unpublished) indicate that threshold visibility of signal lights is primarily a function of their total transmission, irrespective of hue. Figure 2 shows that red recognition, even within the British limits, exceeds that of green. McNicholas' results should not be interpreted to the contrary for he permitted the naming of orange in his series which greatly reduces the probability of correct red responses.

(b) "z not greater than 0.001." The AAR boundary. Gibson et al (2) notes that "the z limit is a rather liberal tolerance for selenium red glasses, but there is no need to make it more restrictive." The British limits are considered to be so broad that they would permit the use of some copper, manganese or gold ruby glasses with green by color-defective persons.

Red B

(a) British Standard. The y boundary has been retreated to a degree comparable in subjective difference to the restriction on Green B glasses.

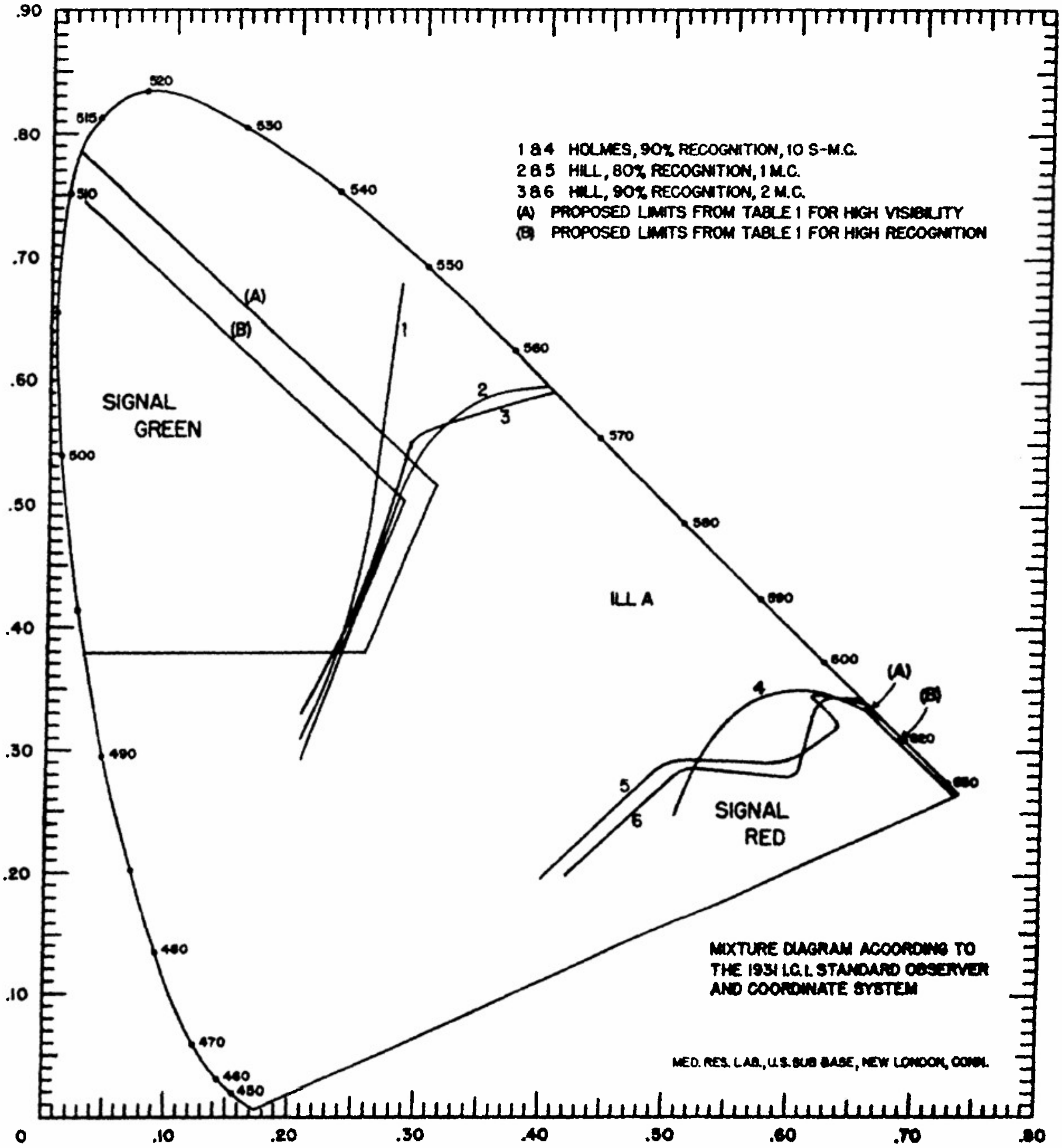
8. This report is not intended to cover questions concerned with kerosene lamps, total transmission values, methods of sampling, inspection, testing, etc.

Table 1

LIMITS FOR RED AND GREEN SIGNAL COLORS
Type A and Type B

Type A is for high visibility
Type B is for high recognition and on variable voltage

		x	y	z
Green	A	not greater than 0.410 y + 0.100 not greater than z = 1 -x -y = .195	not less than 0.380	
	B	not greater than 0.410 y + 0.080 not greater than z = 1 -x -y = .230	not less than 0.380	
Red	A		not greater than 0.335	not greater than 0.001
	B		not greater than 0.310	not greater than 0.001



1 & 4 HOLMES, 90% RECOGNITION, 10 S-M.C.
2 & 5 HILL, 80% RECOGNITION, 1 M.C.
3 & 6 HILL, 90% RECOGNITION, 2 M.C.
(A) PROPOSED LIMITS FROM TABLE 1 FOR HIGH VISIBILITY
(B) PROPOSED LIMITS FROM TABLE 1 FOR HIGH RECOGNITION
SIGNAL GREEN
ILL A
SIGNAL RED
MIXTURE DIAGRAM ACCORDING TO THE 1931 I.C.I. STANDARD OBSERVER AND COORDINATE SYSTEM
MED. RES. LAB., U.S. SUB BASE, NEW LONDON, CONN.

FIGURE 2

Comment by DEANE B. JUDD
In Charge, Research on Colorimetry
National Bureau of Standards

"The comment made on page 2 of the proposed specification of Red and Green Navy Signal Lights, paragraph 4. (c) that "the AN-C-56 Code... apparently lacks a clear rationale for the distinction between aviation and identification systems." interests me because I collaborated in the draft of AN-C-56. This draft was prepared under heavy time pressure by collaboration between persons having fundamental differences of opinion and was further turned inside out in an attempt to make it conform to the Army style of writing specifications. The various government agencies using AN-C-56 received numerous complaints from manufacturers and inspectors that they could not understand the specification without great loss of time in studying its provisions. Accordingly the Aeronautical Board authorized the Bureau of Aeronautics to prepare a simplified version of AN-C-56, and I was placed in charge of preparing a preliminary draft. This draft was finished last October and one of the new paragraphs incorporated in it explained in some detail the reason for the two systems of colors, Aviation and Identification. It is very similar to the British distinction summarized in 4.(a) of your communication of September 4.

"Incidentally the Bureau of Aeronautics has not yet got around to calling a meeting to discuss our preliminary draft of a simplified AN-C-56.

"Since you are interested in possible unification of signal light specifications, it may be worthwhile to mention that the Bureau of Ships is planning to put their specification for ship's running lights into more up-to-date form, and have requested our assistance in drafting the revision.

"Finally, as Mr. Holmes may have told you, there are technical subcommittees of the ICI on signal lights. I am a member of the American subcommittee, and the chairman is Mr. K. W. Mackall, Crouse-Hinds Co., Wolfe & 7th North Sts., Syracuse 8, N.Y. So far our activity has been confined to a letter that I wrote to the chairman transferring copies of Holmes' publications including the proposed British standard. In spite of the fact that there is a great deal of work to be done to unify even Navy specifications for signal lights, let alone those of all other agencies dealing with such lights in America, I am sufficiently hopeful of eventual international unification that I am sending a copy of your suggestions to Mr. Mackall so that he will at least be informed, and may see fit to initiate some discussion of the suggestion at the Paris meeting of the ICI next July."

Comment by K. S. GIBSON
Chief, Photometry & Colorimetry Section
National Bureau of Standards

"With respect to your item 4(f) I doubt if the railroad engineers would think their signal red is too restrictive. In my contacts with them they have been rather emphatic on this point. Although their "lantern red" and "highway-crossing red" are less restrictive (yellower limits), they wish to avoid any danger of yellow confusion in their main line red signals. Even with the present red, there have been accidents where the engineer claimed he had seen a yellow signal. As you may know, high-intensity red signals tend to appear yellowish."

Comment by HENRY PHELPS GAGE
Corning, New York.

'''The original purpose of the A. A. R. specifications (originally R. S. A.) was to enable the glass manufacturers to determine what pieces of glass would and what would not be acceptable to the railroads and to have it possible for the railway inspectors to agree on the same limits. When in 1931, the AAR limits were re-examined, the limits selected for the green represent the typical method of investigation. It was desired to determine first the type of glass to employ, whether blue-green, the high transmission admiralty green, or a slightly more yellow green, 2) what thickness of glass of a given melt to use, hence its transmission, 3) whether the range of glasses (light to dark) of the type, bluish to yellowish selected for electric signals was also the type best suited for kerosene signals. The observations were made by experienced railway signal engineers, and their choice depended not only upon their particular type of color sensitivity but all their accumulated experiences and prejudices and the complaints and alibis of engine drivers.

"Four types of glass were used which I will designate by their laboratory numbers, as some of them have no others.

G 403 E D	Blue-green, the transmission at 400 mu is about as high as the maximum.
G 40 D	High transmission admiralty green, in use since the 1918 revision of specification, selected for kerosene sources, has considerable absorption at 400 mu.
G 408 F	A more yellow green, gives somewhat the same chromaticity with electric source as the G 40 D with kerosene.
G 401 C Z	A yellow green or "chrome green".

A long series of thicknesses of the G 40 D glasses were tried, with daylight observation and electric source. The lightest acceptable tested 205 on the AAR scale (old 205% on the RSA Scale). To allow manufacturable tolerance the darkest would be 150. While there were individual differences as to what the best range should be, all were agreed that this range was entirely safe and suitable, also that for distinctive green, pieces next either lighter or darker would also be satisfactory. Corning however agreed that the range was manufacturable. Next a series of the same transmission, I believe 150 of the blue-green, yellow-green range were tried. The blue-green G 403 E D was rejected as appearing too white, and not distinctive. The only doubt concerned G 408 F. It gave an indubitably good distinctive green signal with the electric source; it was however no more distinctive than the G 40 D. The decision was however made on the desirability of using the same glass with either electric or kerosene source and not requiring two separate stocks all the way thru for lenses and roundels. The G 408 F was too yellow with kerosene so only G 40 D remained.

"This gave us limit glasses of G 40 D, of Taar 205 and Taar 150. Mr. Irwin G. Priest and Dr. K. S. Gibson of the National Bureau of Standards measured these glasses at the Bureau and their position on the ICI diagram was subsequently determined for sources 2848°K, 2360°K, and 1900°K (Kerosene).

"The glasses are acceptable limits for the glass maker, all glass within these limits is satisfactory for railway use with either Kerosene or Incandescent electric lamps of size and life used in signals. The location on the diagram of these limits is shown in R. P. 1688. Note that for the same source there is but slight difference between light and dark, the big difference is caused by change in temperature of source. The direction of the line marked 6 in your diagram 1 going in a north east direction aimed at 568 mu is a result of change in color temperature of source used in conjunction with pale limit green. By observation it is known that the saturation is sufficient to make a good signal. Note also as a color temperature is increased, so also is brightness. This complicates the whole situation. To get a slope as shown in fig. 2 more nearly vertical would require an enormous number of separate glasses, each adapted to its own color temperature. It may conform to eye sensitivity but is it practical?

"Our criticism of the ANC 56 is that while it tells what final color is desired, it is only with enormous difficulty that we can determine whether a given glass meets the requirements, and we must judge whether a given melt of glass while still hot should be worked into one of several moulds and at what thickness these should be blown or pressed. If the specification is in the form of what glass will be accepted, the customer takes the responsibility if that glass is supplied, the result will be what is wanted.

"Referring to Proposed Specifications, my comments are:

1. (a) O.K.

(b) Railway signals are acted upon at distances where signals appear as small areas, not as points, also highway crossing, and traffic. Aviation and lighthouse and marine, probably often as points.

(c) Add, as controlled by the thickness of the same glass.

(d) It is necessary to keep a proper balance in a system so that one color as yellow does not toogreatly outshine the green or red.

(e) O.K. Lighthouse and aviation must be seen at great distances; railway, etc. must be especially distinctive as yellow (slightly orange) is included in the system.

(f) With the same lens, the variation in voltage changes color to an excessive extent with Purple and Lunar White, hence two types of glass are required, electric and kerosene. With green, yellow, red, and blue, the best results for all temperatures (although differences in color and brightness do occur) are secured with the same lens.

2. & 3. In the U. S. each piece of colored signal glass is compared with the limit glasses on a photometer. In England they are merely held up side by side, so the U.S. limits are really lived up to. Specifications differing only slightly, could readily be combined.

4. (a) Class A specification for Aviation of ANC56 and for Lighthouse.
Class B for railway and ANC56 Identification. For green, it is not good to go lighter than 205 AAR for any purpose; green transmits more than red anyway.

(b) O.K.

(c) ANC56 does not define acceptable limit glasses but such glasses are supplied by Government to manufacturer.

(d) O.K.

(e) Low saturation locus chosen to fit glass in AAR with change temperature of source. Hill shows that the low temperature end should be less distinctive than high temperature end except that low temperature end is not so bright and does not fatigue the eye as quickly.

(f) The red tolerance of the AAR is restrictive at the request of signal engineers as one instance occurred of engineer after staring at a very bright near-by red signal fatiguing eye to extent that he thought it had changed from red to yellow. Original 1931 recommendation was Red Taar 160 - 240, reduced to Taar 85 - 160. Reasons recorded in AAR Signal Section proceedings. The color shown in "Hill" fig. 2 is red purple. Sharp cut glass (Selenium Red) has no blue. Some dyed gelatines (Rhodamine, Fuchsine, Methyl Violet) have a good sharp red in long wave region, appear red-purple, but used in a long range signal the blue (there is no yellow or green permissible) disappears and it looks exactly the same as a red glass.

"Red A probably allows too much orange in Aviation red. We never went to the light limit allowed by specification, 140 on the Orange scale, we only went to 125 for light limit.

"For Green B, I cannot recommend y less than .400 after the experiences with the G 403 E D blue-green.

"I would be glad to discuss these matters in greater detail even if it involves digging into records and further experiment."

Comment by A. J. WERNER
Physical Laboratory
Corning Glass Works

"An adequate signal system using colored lights must take into account the characteristics of normal and abnormal color vision. In this respect the work of Holmes, Hill, Pitt, et. al. is important. Having chosen a set of colors most desirable on the basis of color vision data, it then becomes necessary to consider the possibilities of producing these colors with combinations of available glasses and illuminants.

"In studying the green color field as defined in the proposed specification, we note that the low saturation boundary does not agree well with the chromaticity-color-temperature locus for the present type of signal glass. The proposed specification does not state the color temperature range within which illuminants will be operated. It therefore becomes difficult to appraise the definition of the green field from the standpoint of signal manufacture.

"In practice, the color density of the signal lens will be determined by the lowest color temperature illuminant to be used, in such a manner so that the signal color will be just noticeably more saturated than the nearest color lying on the low saturation boundary of the green field. When this signal lens is used with a higher color temperature illuminant, the signal color will be appreciably more saturated than the minimum saturation allowable for a color of the same "y" value. This signal lens would have a luminous transmission of approximately 80% of that for a lens which would have the minimum allowable saturation for the same "y" value. The proposed specification fails to state minimum luminous transmission values, so that it is not possible to properly appraise the 80% transmission figure.

"From a manufacturing standpoint there should be no difficulty in obtaining red signal ware of suitable color so that the signal color will have a "y" value not greater than 0.335. If it should prove desirable from the standpoint of color confusion tests, this value could be changed to 0.325 and the luminous transmission would be approximately equal to that for the green signal."

Comment by JOHN HOLMES
Holophane Limited
London

"I have read the draft specification sent with your letter of 26th August, and I think it is an excellent document. There are one or two comments to be made, largely in explanation of the choice of those limits in BS. 1376, which you have not adopted.

"Regarding your comment 4(d), on the yellow side of the green tolerance, we found that the transmittance limits in the specification effectively prevented the supply of green filter glasses in the region which you consider unsatisfactory. On the other hand, we had evidence that self-coloured sources could be made to give satisfactory recognition in this region. An example of this is the mercury line at 546 mu.

"In Section 7 - Red A, paragraph (b), the British limits are criticised in respect of the liberal tolerance for z, but again it will be found that the transmittance limits preclude the use of manganese pink glasses and ensure that copper and gold glasses give colours of sufficiently high purity. We consider it undesirable to restrict the specification to Selenium glasses only, and we had no evidence indicating that this was necessary. There is also the point that self-coloured sources such as Neon are quite satisfactory, and they may give a value of z up to 0.005 approximately.

"The total transmission factors mentioned in Section 8 are of importance in considering a specification, as indicated above. The dark limit may restrict the tolerance on colour quite considerably at the blue side of the green region, and it certainly does in the red region. Although the colour specification is of prime importance, it can only be applied in practice in conjunction with a specification of transmission factors and I think it desirable that some indication of these should be given or, possibly, some suggestion of a standard method of specifying them. The principal difference between the A and B tolerance, for example, lies in the transmission factors of the light limit glasses.

"Your draft specification appears to have been written largely to control the coloured glasses used with incandescent filament lamps and not for self-coloured sources, although this is not explicitly stated. I think it would be helpful if the scope of the specification were stated rather more clearly, either to include self-coloured sources or explicitly to exclude them.

"I find that some of my comments are not endorsed by Dr. Gage, but that is doubtless due to differences in experimental technique which have not yet been explained, and it is for this reason that I have been pressing for an International discussion of this problem now that more of the fundamental data is available as a basis for correlation of the observational data from field experiments."

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(1) "British standard specifications for colors of signal lights", British Standard 1376:1947, London, 18 April 1947.

(2) K. S. Gibson, G. W. Haupt, H. J. Keegan, "Specification of railroad signal colors and glasses", Research Paper RP 1688, Jour. Res. Natl. Bur.Standards, 36, January 1946.

(3) "Army-Navy aeronautical specification of colors", (AN-C-56), Bur. of Aeronautics, Navy Dept., Washington, D.C. 25 July 1942.

(4) Dean Farnsworth, "Preliminary report on confusions of colored lights at small subtense by protans and deutans." Color Vision report No. 13, BuMed X-263, U. S. Naval Med.Res.Lab.,Submarine Base, New London, Conn. 25 September 1946.

(5) J. G. Holmes, "The recognition of colored light signals" Trans. Ill. Engr. Soc. (British) 6, 71-97, (1941).

(6) N. E. G. Hill, "The recognition of colored light signals which are near the limit of visibility", Proc. Phys. Soc.(London) 59, part 4, 560 - 573, (1947) and "The measurement of the chromatic and achromatic thresholds of colored point sources against a white background", 59, 574-585 (1947)

(7) H. J. McNicholas, "Selection of colors for signal lights", Jour. Res. Nat.Bur. Standards, 17, 955-980, (1936).

Additional references from which limits were plotted in Figure 1 are:

"British standard formulae for calculating the intensities of lighthouse beams," No. 942-1941, London, Feb. 1941.

"Adjustable face traffic control signal head standards", Tech. Report No. 1, Inst.Traf.Engr., New York, (1940).