Factors to be Considered in

Selecting Glass

*For Signal Lenses**

A review of the technical aspects of glass manufacture for signaling purposes

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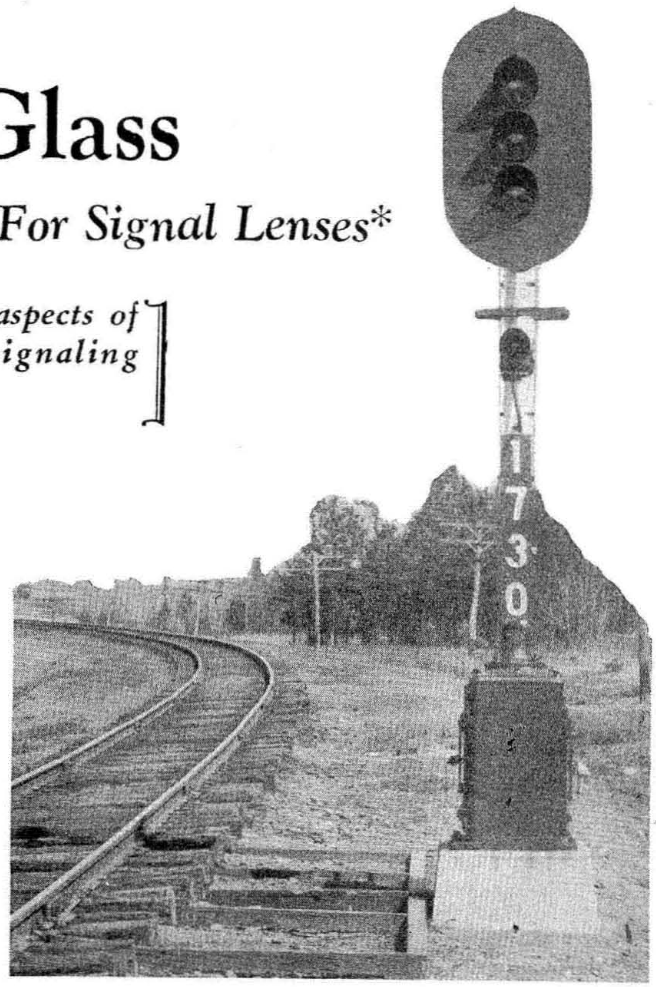


An accurately designed lens in conjunction with a small light source produces an efficient signal beam

IN the selection of glasses for a signal system many practical as well as theoretical factors must be considered before standards can be adopted. In writing a specification defining these standards and setting forth limits of tolerance, the general workability of all possible forms of specification must be carefully weighed and balanced. As examples of workable specifications of enormous practical significance, we may cite those adopted by the Railway Signal Association for lenses, roundels, and lantern globes. The Railway Signal Association, now known as the Signal Section of the American Railway Association, has a definite set of specifications for lenses, lantern globes and colors now in use by the majority of railways in the United States and Canada. The form of these specifications was adopted in 1908 and revised in 1918 to take care of improvements in the art. Having prepared the series of samples which were submitted to the Sub-committee of the A. R. A. and having cooperated in describing in specification form those pieces selected for standards and limits, I can perhaps explain the methods used in assuring to the railroads a uniform supply of colored glassware for use in their signal systems.

Kinds of Signal Glass

For signaling, railways use lantern globes, both clear and colored, lenses either clear or colored, and colored roundels are used in connection with clear lenses.

Hand lanterns are used for special signals which can not be controlled by the automatic signal system. They are used by trainmen in signaling to the locomotive engineman the desired train movement in switching operations, etc.; for signaling other trains in case of emergency and in numberless other ways. One important use of the hand lantern is the placing of a lantern equipped with a blue lantern globe at the end of cars when, on account of inspection or repairs, it is necessary for men to work around and under a string of cars. Upon the reliability of these somewhat irregular but most important hand signals depends the safety of train operation and human life. The railway experience, therefore, demands that hand lanterns be made as free as possible from the danger of being extinguished by high wind or by swinging the lantern around when signaling. Not only must the design of the draft system of the lantern be suitable but the lantern globe must be so accurately finished that a flame can not be blown out by air entering between the globe and the metal parts. Correct design and rugged construction of all metal parts is insisted upon and glassware is chosen which is as less liable to failure as any other part of the lantern.

Formerly the most frequent cause of failure in lantern globes was breakage due to the heat of the flame particularly when followed by the shock of a dash of rain, sleet or snow. Glass having the greatest heat resistance was therefore developed and has been employed for making hand lantern globes, thereby practically eliminating breakages due to heat shock. Breakages due to mechanical abuses are reduced by improvements in lantern design and manufacture and by the careful attention of the glass manufacturer to workmanship and finish, particularly with regard to grinding the ends of the lantern globe. In order to insure their ability to withstand mechanical abuse, extensive dropping tests were employed to establish the most suitable shape and weight for lantern globes. The great bulk of hand lantern globes are made of clear heat resisting glass but large numbers are also used in the colors red, yellow, green and blue. A description of these colors will be found along with the other railway signal colors.

The specifications for hand lantern globes as employed by the inspection department at the plant of the manufacturer, describes photometric tests to establish the suitability of the colored globes and describes chilling tests to determine their ability to withstand heat shock.

*From a paper presented at the International Congress on Illumination, held at Saranac Inn, N. Y.

Lenses are used in railway signal systems to indicate the position of switches along the main line or in railway yards, also to project a beam of light from a small source such as a small kerosene burner or electric lamp placed on a high signal pole. In the case of switch lamps the lens performs the combined function of projecting the light beam and of giving the required color. Colored lenses must therefore comply with the necessary requirements both as to accuracy of design and suitability of color. The signals on the high semaphore poles are designed to project an accurate beam of white light in the direction of the railway tracks. The signal indication is made by interposing in this beam, colored glass roundels inserted in one end of the semaphore blade so as to give a color indication corresponding to the position of the semaphore arm. Modifications of this generally used system are at present coming into greater use and may be briefly mentioned at this point.

In the position-light signal a number of projectors lighted in a horizontal, diagonal, or vertical row gives the desired signal. The necessary lamps are lighted by a relay somewhat as in the case of the familiar changeable electric sign. Each projector consists of an electric lamp combined with a lens. High accuracy in the design of the lens enables the use of small and economical electric lamps. The position-light signals usually employ cover glasses of a light lemon yellow color in order to distinguish the signals from neighborhood lights and secure greater fog and smoke penetration.

Three projectors equipped with colored glasses; red, yellow or green, are used in color-light signals. The electric lamp in the projector of the color required for the signal indication is lighted by means of a relay.

The "searchlight" signal is similar to the large semaphore signal except that the colored roundel, only one inch in diameter, is interposed between an ellipsoidal reflector and a clear outer lens which in turn projects the colored light passing through this roundel. A type of signaling using a combination of the color-light and position-light signal is being introduced. The necessary projectors fitted with colored glass are lighted in a horizontal red row for stop, a diagonal yellow row for caution and a vertical green row for proceed.

Design of Lenses

Lenses used in railway signals, for example, a lens 5⅜ in. in diameter having a focal point 3½ in. back of the edge of the lens, if made of the plano-convex or bi-convex type, would be heavy and require so much glass that accuracy and speed of pressing would be practically impossible and also the variation in thickness between the edge and the center would be too great when the lenses were made of colored glass. To overcome these difficulties a device, originated by Fresnel, of dividing the lens into annular zones and constructing each zone so that in cross section it is a prism of the correct angle was adopted, thus making the lens of much less weight, more uniform thickness and in a form which readily lends itself to being pressed into shape from hot glass. Pressed lenses of the Fresnel type can be made with a remarkable degree of accuracy. In addition to lenses designed to focus practically at a point and project a round narrow beam, other types have been designed employing cylindrical segments or other refracting patterns on the smooth face in order to obtain a beam distribution suited to particular needs.

Economy of operation demands light sources of small consumption of oil or electric energy. The signal need be seen from only a limited area; namely, the line along which the engineman's eye must travel when approaching the signal. The use of an accurately designed lens in conjunction with the small light source produces a highly efficient signal beam covering this small area. The present requirements are that lenses up to 6 in. in diameter must focus to an area not exceeding ⅜ in. in diameter and lenses larger than 6 in. must focus to an area not exceeding ½ in. in diameter. When observed along the axis from a distance of 20 to 40 ft. a small oil flame being placed in the focus, the whole lens appears equally illuminated, the risers of the steps showing only as narrow dark rings.

In the early days of the art most of the beams for signaling were produced by a combination of a small kerosene light source with a lens. During the past few years, small electric lamps of suitable design, reliability, ruggedness and life for signal purposes are available. Such lamps may be used to replace kerosene burners in existing equipment. An optical system consisting of two lenses, an outer "optical" type and an inner meniscus lens was designed for use with electric lamps. This doublet system utilizes a greater proportion of the available light flux from an electric lamp than is possible with a single lens. For electric lamps there have been developed other means than lenses to project the signal beam, notably mirrors of highly refined design and manufacture.

Colored Glass

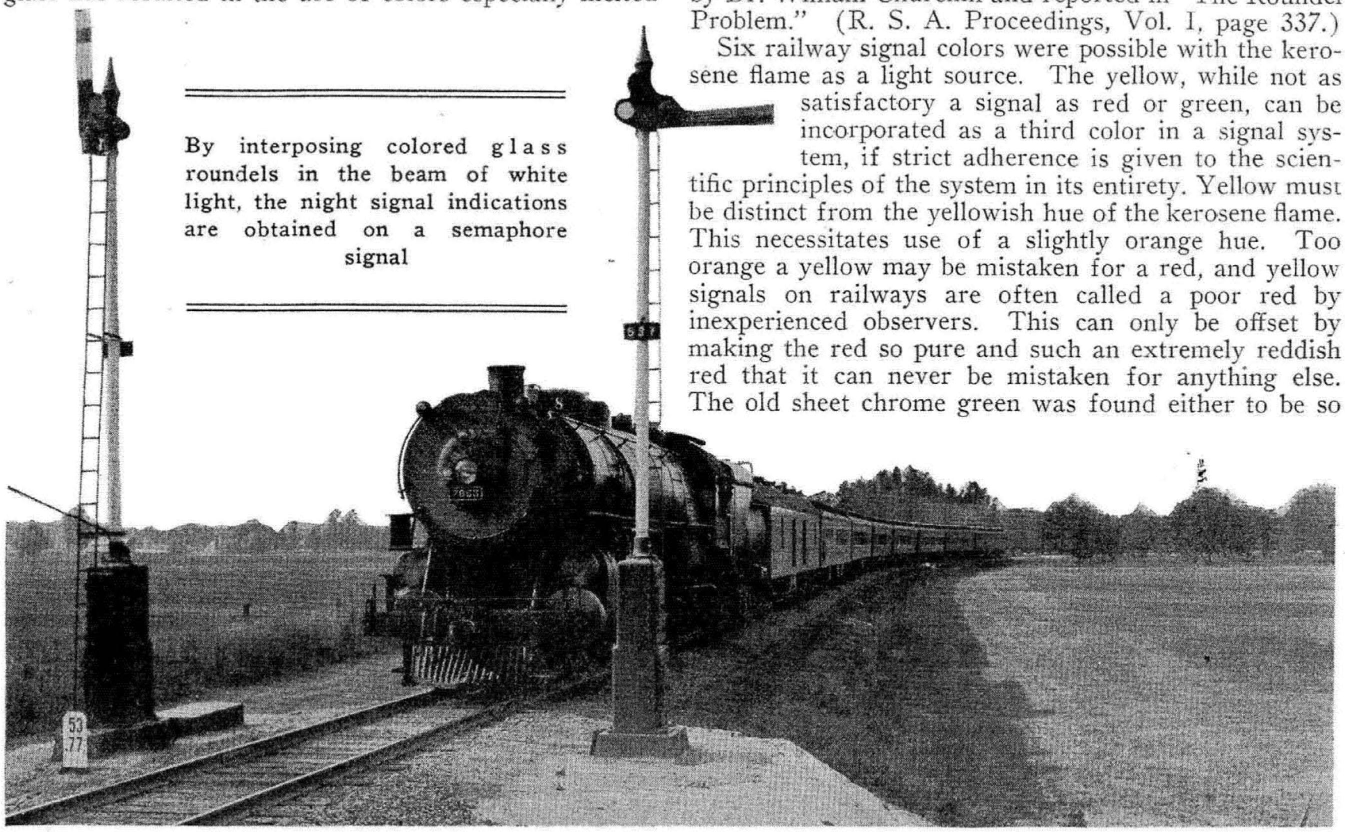
Night signal indications have in the past been made by the use of colored lenses or by placing colored glasses in the beam of light projected by the combination of a kerosene flame with a lens. The more powerful beams projected by the combination of electric lamps with suitable mirrors, or lenses now produce color signals of sufficiently high intensity to be used in the daytime even with the sun shining brightly, thus eliminating the necessity of observing the position of a semaphore blade by day and greatly adding to the flexibility of the design of signal apparatus.

The colors used in railway signaling for long distance indications are red, yellow, green and sometimes lunar white. For short distance indications blue and purple are used and in addition a lemon yellow is used with position-light signals to distinguish them as signals from other lights. The reason for the choice of the above mentioned colors as the most desirable for railway use can perhaps best be elucidated by a short historical review of the development and standardization of the present railway signal system.

Historical Review

A picture of the situation of the signal colors used on railways in 1905 may be gleaned from the Proceedings of the Railway Signal Association, Vol. I. Prior to this time there were two general systems of colors in use: (1) red for danger, green for safety, or (2) red for danger, green for caution and white (kerosene color) for safety. Letters from England described the red for danger, and green for the "all right" signal. No other color was used. The red, judging from samples in our possession in Corning, N. Y., was the ordinary flashed sheet copper red, and the green was sheet chrome green, a somewhat yellowish green. It was pointed out that if a colored glass broke, the signal showing would be white (kerosene color). Unless this was to be acted upon as a danger signal, there would be a liability of passing a signal set at danger if the red glass were broken out. It would be better practice to use some positive indication such as green, when it was "all right" to proceed.

The early discussion of signal colors was based on increasing the strength of the colored glass used, and the desirability of a third signal color. Proposals for increasing the strength of signal glass included the use of a thicker article about ¼-in. thick and pressed round to fit the spectacle casting in which it is to be mounted. Also the use of a protecting wire cover for the glass and the use of wire inserted glass was advocated. The subsequent adoption of the pressed roundel, particularly the convex shape has greatly reduced breakage. The abandonment of glasses cut from thin colored sheet glass has resulted in the use of colors especially melted for signal purposes which are better adapted to the rigid signal requirements under all weather conditions.



By interposing colored glass roundels in the beam of white light, the night signal indications are obtained on a semaphore signal

Early experience in the United States with automatic signal systems soon revealed the desirability of separate indications for the track conditions not only in the block of track immediately ahead of a train, but also to give advance information as to the condition of the block next ahead of that, so a train could be brought under control prepared to stop, before entering a block containing a train or other obstruction. The discussion of this distant signal, so easily indicated in the daytime by the position of a semaphore arm, revealed the complications involved in night signaling with only two available long range colors.

There followed a time of extensive experimentation by the signal engineers of various railroads using all available colors in an attempt to build up a system of colors for night indications. To the red and green was added an amber for the distant signal. This was not entirely satisfactory at first, for if the amber was too light it was indistinguishable from the clear kerosene flame, and if too dense, the signal appeared reddish. Not only was the situation difficult for the signal engineer, but it was becoming intolerable to the glass manufacturers in an attempt to supply the multiplicity of colors and shades desired by the signal engineers of different railroads. A stock of colored glass made up for one railroad would not be acceptable to another railroad. There must be some best color combination which could be used by all railroads. This best color combination would be limited by the knowledge of glass manufacture at the time, as well as by the theoretically best colors from the physical, the physiological and the psychological standpoints. Two lines of intensive scientific study were carried out: one series by Dr. Nelson M. Black working with colored glasses submitted by different glass manufacturers as the best they could produce and tested both spectroscopically and under railway conditions. The other series was carried out by Dr. William Churchill and reported in "The Roundel Problem." (R. S. A. Proceedings, Vol. I, page 337.)

Six railway signal colors were possible with the kerosene flame as a light source. The yellow, while not as satisfactory a signal as red or green, can be incorporated as a third color in a signal system, if strict adherence is given to the scientific principles of the system in its entirety. Yellow must be distinct from the yellowish hue of the kerosene flame. This necessitates use of a slightly orange hue. Too orange a yellow may be mistaken for a red, and yellow signals on railways are often called a poor red by inexperienced observers. This can only be offset by making the red so pure and such an extremely reddish red that it can never be mistaken for anything else. The old sheet chrome green was found either to be so dense and of such poor transmission that its range of visibility was insufficient, or so pale in hue that at a distance the signal would be seen as a light of indistinguishable color. This necessitated the choice of a somewhat bluish green known as "Admiralty Green," a modification of the color adopted by Germany for lighthouses after extensive scientific tests.

In addition blue and purple were studied with a view to a compromise between a saturated color and the best available light transmission. With the kerosene flame as light source these are short range indications at best.

A sixth color was suggested, a light blue, which placed in front of a kerosene flame gives a whitish signal. The density was adjusted until the apparent light transmission and hence range of visibility was about the same as the red and green. The hue is distinct from the other colors, and differs markedly from the open kerosene flame and neighborhood lights. The new color was called Lunar White and it has its distinct uses in a signal system.

Between 1905 and 1908, the American glass companies and in particular Corning Glass Works under the direction of Dr. Churchill developed signal glasses to meet the scientific requirements of railway signaling. At Corning, N. Y., a series of glasses were assembled in each of the six colors: red, yellow, green, lunar white, blue and purple. These glasses were measured in a photometer against an arbitrary standard to determine their comparative photometric transmission. That is, all reds were photometered against a red standard;

yellows against a yellow standard; green against green and so on. The photometric values formed a convenient grading system. The railway signal engineers were then invited to Corning to observe these colored glasses, both at short and at long range and to choose those best adapted for signal systems, allowing a certain variation so as to be within the possibility of practical glass manufacture. As a result specifications were drawn up and in 1908 were adopted by the Railway Signal Association as their standard. The individual railroads have since generally accepted these specifications for testing colored glassware for their signal systems. It may be noted that the indications of the colors are now designated as red for stop; yellow for proceed with caution prepared to stop short of the next signal, or obstruction; and green for proceed. In modern railway practice there are supposed to be no dangerous conditions.

Selection of Colors

The preparation of the specification can perhaps best be illustrated in the case of yellow, as the color presenting the greatest difficulties, the other colors being treated similarly but with greater simplicity. Yellow must be distinguishable from both red and from the open kerosene flame. Previous to 1908 there was no great variety of yellow glasses available for signal purposes, and an amber type glass was chosen, which, with only a slight modification, is the best for roundels and lenses today. If amber glass is either dilute, or thin, it serves merely to tint the light source without appreciably changing its color. With increased concentration of coloring matter, or increased thickness, the light transmission is diminished, and the color of the signal is modified towards a distinct yellow approaching that of the yellow sodium line. Still greater concentration, or thickness, results in further reduction in light from the signal and at the same time reddens its hue until it may be mistaken for a red.

The responsibility for determining the limits between which the yellow signal is distinct from the open kerosene flame on the one hand and a pure red on the other, rested with the signal engineers inspecting a series of samples outdoors from a considerable distance under as nearly actual operating conditions as seemed desirable. All colors were considered at the same time, as it was necessary to build a consistent signal system in which no one color would appear noticeably brighter than the others, or have a disturbingly greater range of visibility. The red selected had such a high purity, was such a reddish red, that the yellow could be of a distinctly orange hue without danger of confusion.

Photometric Color Scales

After inspection of the exhibits, agreement was finally reached that certain glass samples could be taken as the two limits called light and dark. With the limits chosen, specifications could be written describing them. It was found that if the total transmission of light from an electric lamp for a certain amber glass, afterwards called the medium, was arbitrarily assigned the value of 100 per cent, then the light or pale limit transmitted 20 per cent more, or 120 per cent and the dark or red limit transmitted 20 per cent less light, or 80 per cent. Thus was established the photometric scale for testing colored signal glass. As long as the same type of amber glass was used in its manufacture, glass testing 120 per cent had the hue of the pale limit and 80 per cent had the hue of the red limit. A departure from the type of amber originally used would change the hue of glass transmitting the same amount of light, but while the photometer would indicate the same light transmission it would be apparent that the color was different and the glass was rejected as "off color." To guard against change in type of amber used, a spectrophotometric table of the 100 per cent medium standard was incorporated in the 1908 specifications. If all standards and copies of it were to be destroyed and a new glass could be found whose spectral transmission corresponded to this table, the new glass could then be used as a standard. The accuracy of such a new standard would thus depend on the accuracy of the spectrophotometric determinations of the original standard as published in the specifications and of the similar measurements made on the new glass. In the 1918 specification the spectrophotometric analysis covers the present high transmission medium red, yellow, and green rather than the 100 per cent standards.

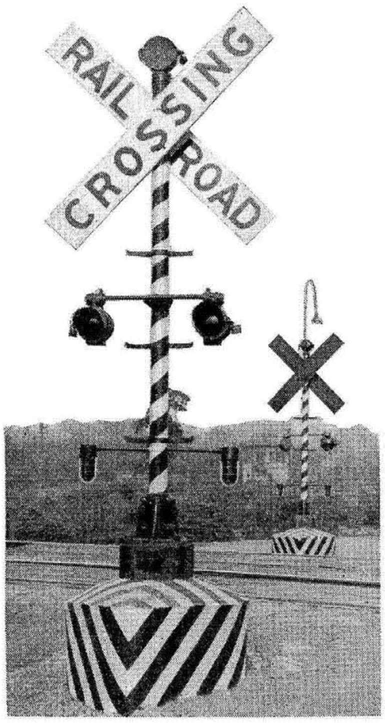
Since the acceptance of these specifications, the manufacture of colored signal glass is controlled and the product graded by the photometric method. It furnishes the simplest criterion as to whether the combined effects of color concentration and thickness of pressing is such as to give desirable reults. Routine photometric inpection of all railway colored glass can be carried out on a suitable apparatus with such rapidity as not to add greatly to the burden of inspection.

Since the first standardization accepted in 1908, new types of colored glasses were developed having higher light transmission for the same hue and purity of color. To incorporate the advantages of these improvements into signals required a review of the entire system of color signals. Following such a review the signal engineers recommended the new high transmission colors and specified them in the revision accepted by the American Railway Association in 1918. In the case of yellow, there were now two types of yellow to be seriously considered. Besides a new amber of improved light transmission, there was a new type characterized by a transmission spectrum showing almost complete transmission of red and part of the green but an abrupt termination in the middle of the green, with no transmission of shorter wave-lengths. This sharp cut-off type of glass has almost twice as much light transmission as does the amber type, when the thickness of the amber glass is adjusted to have the same hue. Otherwise expressed, the amber glass, in addition to removing the blue and part of the green, has a general absorption of red and yellow resulting in a somewhat muddy appearance. The new sharp cut-off type of yellow was chosen for use in lantern globes where maximum distance of visibility is essential, but it was not desirable in the semaphore or switch signals for the yellow to appear much brighter or be seen at a greater distance than the red or green. The more subdued amber type of yellow was therefore chosen as being more in keeping with the other colors.

Selecting Green

Of the long-range signal colors, green has been the one having the shortest range and most likely to lose its distinctiveness in hue. Sheet chrome green, a somewhat yellow green, usually associated in people's minds as green glass, if thin or dilute is particularly lacking in distinctiveness. It may be difficult to distinguish it from yellow or from a clear light. This is particularly noticeable at the distance necessary for signaling. A chrome green sufficiently dense to serve as a distinctive color absorbs so much light that its distance of visibility is greatly reduced.

The difficulty of choosing a green has been simplified by adopting a somewhat bluish green known as Admiralty green. Used in front of kerosene flame, a source markedly deficient in blue, the Admiralty green glass gives a satisfactory green signal. With the introduction of Mazda incandescent lamps it was feared that the resulting signal would appear too blue. Such has not, however, proved to be the case, as the blue green is a perfectly satisfactory "go ahead" indication whether called blue or green by the individual observer. It has been argued that the color blind can often distinguish between red and blue green, while unable to distinguish between red and yellow green, a great help to the general public when compelled to act upon the indications of traffic signals. Possible confusion between Admiralty green with an electric light source and blue was feared. The locomotive enginemen who must act differently with these two indications see so many of each that there is no resulting confusion. The difference in hue is readily apparent to anyone seeing the two side by side. As light an Admiralty green as possible was chosen, but if much lighter than 175 per cent it loses distinctiveness as a signal indication. If denser than the dark limit 125 per cent, it becomes bluish in hue, is dark and loses distance of visibility.



Colors for highway crossing signals are selected according to a predetermined photometric color scale

Red, of transmission suitable to go with the green, was selected. The hue of the red which is of the sharp spectral cut-off type does not lose much distinctiveness in hue as its transmission is increased to a point much beyond that used for semaphore signals. For hand lanterns, red lantern globes are used as signals in case of emergency stops to prevent collisions. Being thus used to keep trains apart, distance of visibility is important. Red lantern globes have a luminous transmission about one and one-half times that of roundels and lenses.

Purple might be mentioned as a scientific curiosity in signaling. It is distinguishable as a signal not so much by its difference in hue from blue as by a spectroscopic analysis performed by each observer. Purple transmits extreme red and extreme blue, absorbing all wavelengths between. A normal eye focuses the red as a spot upon the retina, but on account of chromatic aberration is short sighted for the blue, focusing it in front of the retina. The result is a red spot surrounded by a blue halo. Eyes other than normal may produce the appearance of a blue spot surrounded by a red ring, by a horizontal red bar crossed by a vertical blue bar or other effects. For any observer the effect is typical and once observed, purple is always a distinct, although short range indication. Blue and lunar white are best described by their spectral characteristics as given in the A. R. A., Signal Section, specifications.

Parts of the R. S. A. Specification 6918 Signal Roundels, Lenses, and Glass Slides are quoted in the following paragraphs.

A. R. A. Signal Section
R. S. A. Specification 6918
Signal Roundels, Lenses and Glass Slides

(a) Design.

1. Roundels shall either be of the convex or flat type, as specified, and of high transmission glass, and be between 0.21 in. and 0.29 in. in thickness. 1918.

2. New designs shall be confined to 8⅜ in. in diameter for high signals and 5⅜ in. in diameter for low signals. 1918.

(b) Photometric values.

1. Roundels will be subjected to spectro-photometric analysis. The following table gives an analysis of roundels of the various colors of medium intensity, the first row of figures, marked "Wave Length," being the wave length of the light in different parts of the spectrum measured in thousandths of a millimeter, and the other rows of figures are the percentages of light of the wave length given in the first row, which the different roundels transmit. Roundels of medium intensity should transmit light as nearly as possible of this composition:

Wave Length	Red	Yellow	Green	Blue	Purple	Lunar White
0.41	0	0	40	80	90	90
0.43	0	0	53	73	82	80
0.45	0	0	62	68	74	69
0.47	0	0	68	54	59	65
0.49	0	0	70	27	18	54
0.51	0	2	64	10	5	38
0.53	0	8	48	2	1	22
0.55	0	18	30	2	.5	23
0.57	0	29	16	1	.5	26
0.59	0	42	6	0	0	11
0.61	0	50	3	0	0	12
0.63	47	54	1	0	0	11.5
0.65	74	57	0	0	0	10.5
0.67	78	57	0	0	.2	23
0.69	75	55	0	1	12	51
0.71	74	52	0	2	52	79

2. Comparison of old and new R. S. A. photometric scales. The R. S. A. in 1908 adopted certain medium photometric standards for the respective signal colors, designating such medium values as 100. The present high transmission colors corresponding to the table of wave lengths above permit an increase of the medium photometric values as shown in the following table. Manufacturing conditions require a reasonable variation from the medium as shown by the light and dark limits respectively.

	Light Limit	Medium Intensity	Dark Limit	Extreme Variations from Medium
Red	160	130	100	23%
Green	175	150	125	16⅔%
Yellow	140	120	100	16⅔%
Blue	125	100	75	25%
Purple	125	100	75	25%
Lunar white	120	100	80	20%

3. Red.—Shall be of such quality that all yellow rays of light emitted by the sodium flame are absorbed, the spectrum being either red, or red and orange.

4. Green.—Shall be of the color known as Admiralty green, having a slightly bluish tint as seen in daylight. The spectrum shall show most of the blue and green, a slight amount of yellow and not more than a trace of orange and red.

5. Yellow.—Shall give a spectrum showing most of the red, all of the yellow, and part of the green, but no blue.

6. Blue.—Shall give a spectrum showing most of the blue, some green, and almost no red.

7. Purple.—Shall give a spectrum showing most of the blue, some green, and a narrow band of the extreme red.

8. Lunar white.—Shall show blue and green, with about 10 per cent of yellow and orange, and some red. It shall appear a light blue when viewed by daylight, and when placed in front of a yellow kerosene flame, it shall make this flame appear white.