Effect of Fog on Light Intensity*

Relative Intensities of Different Colored Lights in Fog

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It is the purpose of this investigation to study the transmission of lights of different wave lengths through a fog.

A quantitative determination of the density of the fog was not attempted, but care was taken to reproduce as nearly as possible the conditions upon which the density of the fog depends. In all instances a sufficient number of fogs was produced so that the average of the readings for the different wave lengths represent the effect of a fog of nearly constant density.

Measurements were made on thick, medium and slight fogs, but the data given here is for the medium fog only. What is here called a medium fog is about the density of our moderate fog.

APPARATUS.

In order to compensate for the small absorption of light it was necessary to use a long tube filled with the fog. The apparatus is shown in diagram in Fig. 1. It consists of an air-tight, asbestos-covered tube, A, of galvanized iron, 190.5 cm. in length and 16 cm. in diameter. In the middle of its length was a box M of the same material 40 cm. square. The source of light was a 6-8 volt, 21-candle-power automobile lamp, B. The light was made nearly parallel by a condensing lens at C. In front of this lens was located an adjustable circular opening, D, by means of which the size of the beam of light was regulated. The beam was passed through the tube and allowed to fall on the illuminometer plate, E, where its intensity was measured by means of a Macbeth Illuminometer. The ends of the tubes were closed by glass plates and were made as nearly parallel as possible. At F, small glass windows were placed in order that any scattering of the light might be observed. Thermometers were placed at G. Glass tubes at H and J connected with the inside of the tube A. The one at H was used for the introduction of water. This was necessary in order to keep the air in the tube saturated with water vapor. The opening at J was connected by means of a T-tube to a mercury manometer and to the large glass jar K. This jar was connected to the air pump. Between the jar and the observation tube, A, was placed the ground glass valve, L, so that the air in the tube could be expanded very suddenly after the jar had been evacuated to any desired pressure. The inside of the tube was painted a dead black to prevent the reflection of any scattered light.

METHOD OF MAKING OBSERVATIONS.

The light was made to pass through the empty tube and its intensity in foot-candles at E was measured. The lamp was kept constant at 8 volts throughout the measurements. With the valve, L, closed, the pressure in the jar was reduced a known amount. Then by opening L the air in A was suddenly expanded and the resulting cooling produced the condensation of the water vapor. The intensity of the light at E was again measured.

It was found that by expanding the air in A to the same pressure, i. e., a reduction of 1.1 centimeters of mercury, and by keeping the space from which air was drawn into the tube each time well filled with

Table 1—Summary of results of light transmission through fog.

Mean wave length	ILLUMINATION			
	No fog	Fog	Per cent transmitt.	To deliver to fog to produce 2.52 ft.-c. at E.
	Ft.-candles	Ft.-candles		Ft.-candles
lamp	3.99	2.32	58.1	3.99
6331-Red	0.74	0.45	60.4	5.76
6190-Orange	0.71	0.44	62.5	5.56
6020-O.-Y.	0.08	0.07	84.8	4.10
5920-Yellow	2.02	1.76	87.1	3.99
5860- "	0.04	0.03	87.2	3.99
5570- "	0.86	0.75	87.0	4.00
5396-Green	0.24	0.21	87.3	3.97
5363- "	0.45	0.39	87.4	3.97
5240- "	0.34	0.29	85.2	4.08
4935-Blue	0.21	0.17	82.2	4.23
4605- "	0.05	0.03	71.9	4.84
Con-Auto.	0.39	0.30	79.7	4.36
West-Day.	3.22	1.90	59.0	5.90

*Presented before Philadelphia Section of Ill. Engin. Soc., and reprinted from their Transactions.

dust particles, that a fog of practically the same density could be reproduced. The intensity of the white light transmitted through the fogs varied by less than one per cent. No other method for determining the density was attempted.

The different wave-length ranges were obtained by means of absorption screens.¹

In some instances readings were taken on 6 fogs for one wave-length range, in others 10 readings, and in one case 20 readings. The number of readings depended on the intensity of the light under observation. The transmission bands of the screens were measured by means of a Hilger direct reading spectroscope, employing the diffraction grating. The lamp used in

Fig. 1—Apparatus used to measure light transmission through fog

these determinations was the same one used for transmitting the light through the fogs.

The average temperature throughout the investigation was 19.5°C.

At no time was there enough scattered light to be detected at the windows F.

[The observed and calculated data are summarized in Table 1.—EDITOR.]

An accuracy in observation of approximately one per cent was obtained.

The last column of the table shows the intensity of illumination of different wave-lengths necessary to be delivered to the fog in order to produce on the plate

Fig. 2—Curves of transmission through fog and through water. Note relative displacement toward violet of maximum transmission through water.

E the same illumination as was produced from the uncolored light from the lamp, i. e., 2.32 ft. candles.

SUMMARY OF DATA.

From our data it appears that the transmission is highest for wave-lengths from about 5,300 to about 5,900 and falls off very rapidly toward the red but not so rapidly toward the violet. The difference between the maximum transmission obtained and the lowest transmission in the red is 31.0 per cent while this difference for the lowest transmission in the blue is 17.7 per cent.

A similar difference was found by Abbott² in the

transmission of light through water vapor when there were dust particles in the air.

Investigations by Dr. T. Ewan³ on the transmission of colored light through pure water gave results similar to those found in this study, as is indicated by Curves I and II.

Dr. Ewan's results agree with those obtained by Huffner and Albrecht.⁴

Curve I is the curve obtained for the transmission through fog. Curve II is the one obtained by Dr. Ewan for transmission through pure water. The maximum transmission through pure water is displaced toward the violet with respect to the maximum transmission through fog as found by the writer.

The mean wave-length for maximum transmission through fog is found to be about 5,620.

Wave-length 5,240 is not on the curve. The screen from which this light was taken had a slight transmission band in the red which had not been taken into account in determining the mean wave-length.

Curve I also shows that in order to have maximum transmission through fog, light must be composed of wave-lengths between the limits 5,300-5,900, and must not contain any red or blue, as is shown by the Conaphore lens and the Westinghouse Daylight glass.

CONCLUSION.

The data of this investigation shows that an automobile light, or any searchlight, will have the maximum transmission through fogs if the light is composed of wave-lengths from 5,300 to 5,900 only.

DISCUSSION.

T. D. Cope, Pennsylvania: It is of interest to compare the results of this investigation with the results of other investigations in the same field. In the *Proceedings of the Railway Signal Association*, 1905, page 291, in a paper on "The Roundel Problem," Dr. William Churchill of Corning, N. Y., states:

"The great absorption of light in an atmosphere laden with water vapor is a well-known fact. It is not so generally known, however, that some kinds of light penetrate a fog more effectively than others. Two years ago the German Lighthouse Board instituted a series of experiments to determine the relative percentages of absorption of waves at various points in the spectrum. A spectrum was projected through a box covered with glass at opposite ends and filled with steam condensed to fog by a cold water jacket. Photometric measurements proved that the greatest absorption occurred at the red end of the spectrum with a gradual decrease toward the violet end. Figuring the absorption at the D line as 100, the extreme red showed 108.7 per cent under the same conditions, the extreme violet 87.7 per cent. These figures are quoted from an unpublished report furnished to the writer through the courtesy of Geheimrat Koertor of the German Lighthouse Board. The results are of considerable interest since they prove conclusively that the tendency of all lights to shift in color toward the red end of the spectrum (the aspect of the sun or moon when just rising or setting being the best known illustration) is not due to the presence of water vapor. The effect of vapor is precisely the opposite.

"One other point which requires notice in this connection is that the light produced by a kerosene flame shows more penetrative power in a fog than some other kinds of artificial light. A striking illustration of this fact occurred a few years ago, when the German Government installed lights of 1,000,000 computed candlepower in an important lighthouse upon the island of Heligoland, superseding an oil light of 10,000 candlepower. The arc light proved of far shorter range in fog than the oil lamps and was accordingly soon discarded. It is true, the arc light shows a preponderance of blue rays which possess a higher penetration in water vapor than red or yellow, but for some reason not clearly understood, the waves emanating from the arc are all very feeble against a fog. Kerosene so far as fog is concerned, is a relatively satisfactory illuminant for signal purposes."

(Continued on page 128)

¹Details about screens in original paper.—EDITOR.
²*Annals of the Astrophysical Observatory*, Washington, vol. 3, p. 214-218.

³*Proc. Royal Soc. of London*, 1894, vol. 57, 117-162.
⁴*Pogg. Ann.*, 1891, vol. 42, p. 1-17.

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The results of the tests just quoted may be stated to be in substantial agreement with the results of the tests reported by Mr. Utterback.

Mr. M. Luckiesh of the Nela Research Laboratory in a paper on "Yellow Light," read before the Illuminating Engineering Society at Washington, D. C., in September, 1915, reports a test which is of significance in that its results do not disagree with those of Mr. Utterback. Experiments were made with automobile headlights on a foggy night. One headlight was provided with a greenish yellow glass, the other with a white glass. Four observers agreed that distant objects in the fog were better seen by the greenish-yellow light, although the luminosity of the greenish-yellow beam was 25 per cent lower than that of the white beam.

The effect of a fog in transmitting a smaller percentage of red light and a larger percentage of yellow and green light than of any other color as reported by Mr. Utterback and other experimenters may perhaps be attributed to the selective action of water upon these colors. As is well known a fog consists of small drops of water suspended in the air. In passing through a fog part of the light at least must pass through the water drops. Water absorbs red light strongly and transmits yellow and especially green much better. Red objects when lowered into water lose color and turn black. White objects acquire a greenish color when immersed in water. If an empty tube closed at the bottom with glass be lowered into the water and the white object be viewed through the tube when close to its lower end, its green color is still observed. This shows that the light which penetrates the water is greenish by absorption. In the *Journal of the Franklin Institute*, March, 1919, Professor Bancroft of Cornell University gives an interesting review of experiments which prove that water absorbs red and transmits green.⁵

In considering the bearing of the results reported in this paper upon practice it must be remembered that of the factors which tend to reduce the transparency of the atmosphere only one is here investigated, namely, fog, suspended water drops. Small solid particles suspended in the air undoubtedly seriously affect its transparency and in a way differently from fog. The deep red color of the sun observed through smoke or haze indicates that an atmosphere laden with solid particles is best penetrated by red light. The complete study of transmission of light through the atmosphere must involve studies of each of the factors which affect its transparency.

Enoch Karrer and E. P. T. Tyndall: The subject of the transmission of light through fog is an important one in headlight illumination, in military searchlight illumination, and in aerial photography.

The work now under way at the Bureau of Standards on the transmission of light through the atmosphere was undertaken in connection with the tests of military searchlamps.

The subject has a two-fold importance in connection with military searchlamps, viz.: (1) in the standardizing and comparing of searchlamps; (2) in the actual use of searchlamps.

In the former case it is necessary to make measurements of the intensity of illumination upon targets at great distances from the searchlamp. It is desirable to know what effect the atmosphere traversed by the beam may have upon the data obtained at different hours of the night and on different nights.

In the second case, a knowledge of the effect of the atmosphere upon a searchlight beam is important from two standpoints:

1. The intensity of illumination at the target and at the eye of the observer is dependent in part upon the transparency of the atmosphere.

2. The seeing of the target is conditioned by the brightness of the path of the beam, through which and along which the observer must look in order to see an object illuminated by the searchlamp.

The path of the beam is made apparent by the diffusion of light by the atmosphere.

It is of interest to divide the mechanisms by which the light is diffused into three, viz.:

1. Diffusion by the molecules of gases in the atmosphere.
2. Diffusion by the particles of water and water vapor.
3. Diffusion by the solid particles suspended in the atmosphere.

Examples of the first are, the blue sky and the path of the searchlight beam on clear nights and at high

altitudes. Examples of the second may be seen during rainy, foggy and misty weather. Examples of the third are seen in hazy and smoky atmosphere.

The kind of diffusion in the three cases may be different. Diffusion by the molecules and very small insulating particles varies inversely as the fourth power of the wave-length of the light. When the particles become comparable in size to the wave-length of light and larger, this law no longer holds. The exact nature of the diffusion will depend somewhat upon the optical and electrical properties of the material of the particles and upon their shape. This fact is brought out in the differently colored smokes for military and other purposes.

A close study of the diffusion of light by foggy atmospheres has not been made, particularly not during natural fogs.

There is then a point of uncertainty in connection with Mr. Utterback's fogs, as to whether they may be called typical of an outdoor natural fog.

There must have been considerable scattering of the beam by the fog in the tube to account for the low transmission, for, most probably, there was not present a sufficient quantity of water to absorb the light to this extent. It would be interesting to have had on record the amount of water that was actually suspended within the tube. This scattered light should have been detected at the windows (*F* in Fig. 1).

In certain cases the illumination was very low where errors of observation are high. The method of isolating regions of the spectrum by glass screens leaves much to be desired for phenomena of this kind.

There must have been present very pronounced color differences when the fog was present and when no fog was present.

Some preliminary data obtained at the Bureau do not indicate the existence of such pronounced selectivity. Rather there is a definite rise of transmission toward the red even though minor elevations and depressions may be present. This is in accord with general observations by lighthouse engineers.

More work must be done, however, to establish this.

In conclusion it may be said that so far as the detrimental effects of diffusion of light are concerned, blue light is the least desirable kind of light to have in searchlight beams and in headlight beams. The fact that the eye cannot accommodate so well for short wave-lengths is a concurrent cause for pronouncing blue undesirable.

It may be pointed out, however, that for military purposes, blue may be desirable and necessary in detection of camouflaged targets.

C. L. Utterback (in reply to T. D. Cope): The results of the tests performed by Mr. M. Luckiesh have no bearing on the results given in this paper. Mr. Luckiesh determined relative visibility, while the writer measured the intensity of colored light after it had passed through a definite length of fog.

In regard to dust particles in the air; it is, in general, when they are present that fogs are formed in nature. It was only under these conditions that measurements were made.

C. L. Utterback (in reply to Messrs. Karrer and Tyndall): The fogs studied were produced in air which was filled with dust particles and it is believed that such a fog is fairly typical of outdoor fogs, at least in cities.

In quoting from the results obtained by the U. S. Bureau of Standards no information is given as to the character of the fogs used and, if the contention of Mr. Karrer is correct that the kind of dust particles is an important factor, then his comparison of the selectivity of the two fogs has no point.

The scattering of the beam by the fog in the tube was not considerable as was shown by the failure to obtain readings at the windows, *F*.

The pronounced color difference on the plate *E* were only differences in shade and this difficulty as well as the low illumination was partly overcome by taking a large number of readings for each condition, and by having three different persons take readings.

It is hoped that in the near future a report can be made on the effect of different dust particles in a fog, and also the effect produced by outdoor fogs. The amount of water in the fogs will also be noted.

The Ultra-Violet and Visible Transmission of Eye-Protective Glasses

MANY glasses are on the market and extensively advertised to protect the eyes from injurious radiant energy. Unfortunately, but little authoritative information concerning the properties of these glasses has been available. The public and even oculists and physicians have had little to guide them in selecting such

glasses except the claims of makers and agents. One purpose of such glasses is to absorb the injurious radiant energy which is emitted with the light from certain lamps as well as from welding arcs and industrial furnaces, while transmitting sufficient light for vision. They thus act as filters. Another purpose in certain cases may be to absorb part of the light so as to reduce a blinding brilliance. Glasses of different types are required for different needs. The degree to which these glasses actually fulfill their avowed purpose can only be determined by measurements of their "transmission" (i. e., the ratio of transmitted energy to the energy falling on them) for the various forms of radiant energy in question. The Bureau of Standards has made such measurements on a great number of glasses now on the American market and the results are published in this paper. (Abstract from U. S. Bureau of Standards, Technologic Paper No. 119.)—*Mech. Engineering*.

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⁵See SCIENTIFIC AMERICAN SUPPLEMENT, Nos. 2267, 2268, 2269, 2273.