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ON THE DISTRIBUTION OF ENERGY IN THE VISIBLE SPECTRUM OF AN ACETYLENE FLAME.

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Synopsis.

A knowledge of the distribution of energy in the visible spectrum of an acetylene flame has become important within the last few years through the use of this flame, in cylindrical form, in investigations of the visibility of radiation. It can be shown by computation that the data on acetylene published by Coblentz form a curve in the visible spectrum which will not agree with that of a black body at any temperature to better than 7 or 8 per cent. As this would mean that no color match could be obtained and as previous experience of the authors had led to the conclusion that the energy curve of acetylene differed in shape from that of a black body only in the extreme red, a short investigation was undertaken to verify this conclusion.

Tungsten lamps whose current color-temperature relation was carefully determined in this Laboratory, were sent to the Eastman Kodak Company and to the Bureau of Standards with the request that they be compared with the acetylene flame and the current for color match be found. The results gave an average value of 2360° K. ± 10° K., and neither laboratory reported any difficulty in obtaining a match in color. However the Bureau of Standards reported a difference amounting to about 75° K. between the flame as given by the Eastman standard burner and that given by the "Crescent *Aero*" burner, the latter being higher.

The spectral distribution of the flame was measured by means of a spectrophotometer and a spectral pyrometer and the results gave a curve agreeing within the limits of error with that of a black body at 2360° K. In the extreme red, beyond 0.70 μ there was indication of a higher emissivity for the acetylene. A photographic method gave results corroborating those just mentioned.

A test of the sensibility of the color-match method to show differences in the spectral energy curve, showed that if two spectral curves matched at 0.5 μ and 0.7 μ and differed by as little as 4 per cent. in the middle of the spectrum, the two light sources could not be made to match in color.

In conclusion it is recommended that the relative emission intensities of a cylindrical acetylene flame, at least for that type represented specifically by the Eastman standard burner and for the wave-length interval from 0.4 μ to 0.7 μ should be taken as identical with those of a black body at 2360° K.

THE acetylene flame has frequently been employed in spectroradiometric work, and it has been subjected to investigation with respect to the distribution of energy in its spectrum as well as with respect to its constancy and reproducibility as a standard of luminous intensity. At the present time it demands a special consideration in view of its employment as a standard source in the determination of the visibility of radiation. In the recent investigations of the spectral energy distribution of acetylene a cylindrical flame has been used,—either as produced by a single-jet "Crescent *Aero*" burner as employed by Coblentz,[1] or as given in the standard lamp recommended by the Eastman Kodak Company laboratory, consisting of a 1/4-foot "Bray" tip and a limiting diaphragm restricting the utilizable portion of the flame to 3 mm., as thoroughly described and discussed by Jones.[2] The present note deals exclusively with the cylindrical flame, and the data reported are therefore comparable only with other data obtained with a flame of this form.

In connection with a general survey of the various published investigations of the visibility of radiation, including a careful study of the methods and apparatus employed, the authors observed that the data given by Coblentz for the spectral energy distribution of acetylene showed that the spectral energy curve departed somewhat from that of a black body, indicating that no temperature of a black body could be found for which the distribution of energy in the visible spectrum would be sensibly the same as that of the acetylene flame. This discrepancy is most pronounced in comparing the energy distribution of the two sources in the extreme blue end of the spectrum, when the black-body energy distribution is computed from Wien's equation for a temperature such that at 0.48 μ and at 0.68 μ the emission intensities are relatively the same for the two sources. This comparison is shown in Table I., column 2, where are given the ratios of the emission intensities of a black body at 2434° K. to the published values for acetylene referred to above, the ratios at 0.48 μ and at 0.68 μ arbitrarily being taken as unity. An inspection of this column shows that the relative emission intensity of acetylene at 0.40 μ is approximately 1.6 times that of the black body at 2434° K., and although the deviations in the middle of the spectrum are much smaller,—of a different magnitude,—they would still seem sufficiently large to be indicated by a difference in hue if an attempt were made to match the acetylene and the black body in color, as in the determination of the color temperature of acetylene. It therefore occurred to the authors to obtain the color temperature of the acetylene flame in order

[1] Bul. Bur. of Standards, 13, p. 355, 1916–17.

[2] Trans. Ill. Eng. Soc., 9, p. 716, 1914.

to find: (1) Whether any appreciable color difference between the black body and the acetylene flame would be observed when the former was set at the nearest temperature to match the acetylene in color; and (2) whether the color temperature found would indicate a distribution of energy consistent in some region of the spectrum with that given by Coblentz.

Since a standard acetylene burner was not available in Nela Research Laboratory, two carefully prepared tungsten lamps for which the energy distributions at different voltages were known by comparison with a black body, were sent respectively to Dr. Jones, of the Eastman Kodak Company and to the Bureau of Standards, with the request that the voltage for color match with the standard acetylene flame be determined. No mention of the possible difficulty of obtaining a satisfactory color match was made, the hope being that some statement to this effect would be forthcoming if difficulty were experienced. Previous observations by the authors employing acetylene flames of types other than the standard had shown no such marked selectivity, and consequently it was not expected that such a difficulty would be encountered in the present case.

The two laboratories very kindly made the requested determinations and reported the voltages found for color match. According to the color scale in use in Nela Research Laboratory,[1] these two voltage determinations conduced to the following color temperatures of the standard acetylene flame:

Lamp sent to Bureau of Standards—Voltage 112.3, Color Temp. 2434° K.
Lamp sent to Eastman Kodak Co.—Voltage 102.3, Color Temp. 2352° K.

The difference between these two determinations was so great that it seemed advisable to procure a standard Eastman burner and undertake in Nela Research Laboratory an independent determination of its color temperature. The result of this investigation was a value of 2360° K. ± 10° K. when the lamp was operated at a pressure of 9 cm. and fed with acetylene from a Thorn and Hoddle generator, purified by passage through "Curaze," a material furnished with the generator. A study of the effect of pressure indicated that only very small changes (a few degrees) in color temperature resulted from a change in pressure from 9 cm. to 7.5 cm.,—the pressure employed by Coblentz in his "Crescent *Aero*" burner. Measurements were also made with acetylene obtained from a Prestolite cylinder and passed through a solution of bisulphite of soda to get rid of possible acetone. This experiment gave a somewhat higher

[1] These temperatures are based upon Wien's equation with c_2 taken as 14350 μ deg. and upon the temperature of the gold point taken as 1336° K. On this scale the palladium point has been found to be 1828° K. For convenience, a black body held at this temperature is used in calibrating the pyrometers.

color temperature with a maximum difference of 30°. Owing to uncertainty as to the purity of the gas in the tank these values were given no weight.

During the investigation it was found that for a time after the burner was lighted, when supplied with acetylene from a fresh charge of the Thorn and Hoddle generator, the color temperature was much higher than normal. This may be due to an admixture of air with the acetylene. By permitting the generated acetylene to escape for a while before connecting the supply tube to the burner the effect was eliminated.

In addition to the determinations of color temperature, measurements of the spectral energy distribution were also made with both the spectrophotometer and the spectral pyrometer. With the former instrument readings were made over the range 0.48 μ to 0.68 μ, the results indicating a black-body distribution corresponding to the temperature of 2360° K., the same as found by direct color match. The measurements with the spectral pyrometer extended from 0.45 μ to 0.76 μ and also confirmed the previous results in the region from 0.47 μ to 0.70 μ. The uncertainty of the measurement at 0.45 μ was so great that the observed deviation of 4 per cent. is within the experimental error. Beyond 0.70 μ the measurements indicated that the acetylene flame had a slightly greater emissivity (amounting to about 7 per cent. at $\lambda = 0.75\ \mu$) than that of a black body at 2360° K., consistent with results obtained previously by one of the present authors.[1] Owing to the difficulties of measurement at the extreme wave-lengths too much weight should not be assigned to the observed values in this region; however, all measurements showed the increased emissivity in the red.

It is seen that all the measurements,—those of direct color match and those of spectral energy distribution, conduce to the value 2360° K. as the color temperature of the standard Eastman burner. This result is consistent within experimental errors with the value 2352° K. obtained through the incandescent lamp sent to the Eastman laboratory and compared with a standard burner there through the courtesy of Dr. Jones. It differs, however, by approximately 75° from the value obtained from the incandescent lamp which was matched in color with the "Crescent *Aero*" burner at the Bureau of Standards through the kind collaboration of Messrs. Crittenden and Coblentz.

Another determination through an incandescent lamp was therefore requested of the Bureau of Standards, with a transmitted statement of the results given above. The Bureau courteously undertook a second determination, this time making measurements on both the "Crescent

[1] Jour. of Frank. Inst., **170**, p. 30, 1910.

Aero" burner and on the Eastman standard burner for which Dr. Coblentz had reported[1] the same spectral energy distribution except for a slightly greater emissivity in the extreme red end of the spectrum beyond 0.68 μ. The results of this determination showed a color temperature of 2450° K. as compared with the value 2435° K. previously obtained for the "Crescent *Aero*" burner, and a color temperature of 2370° K. for the Eastman burner. The latter value agrees very well with that (2360° K.) obtained in this Laboratory, but the value found for the other burner, though fairly consistent with the previous determination, indicates clearly that the Eastman burner has an energy distribution distinctly different from that of the "Crescent *Aero*" burner. According to the measurements of Dr. Coblentz the only difference is to be found in the spectral region beyond 0.70 μ, but it is impossible to account for the difference in color temperature of 75° or 80° on this basis. It would also seem inadequate to account for the difference on any such grounds as the quality of acetylene gas used or the effect of atmospheric conditions, since the various determinations on the Eastman burner, made at different places and under different conditions, show a maximum variation of only 18°.

As already stated, the present study was suggested by the deviation of the published results of the energy distribution of the standard acetylene burner from that of a black body. By reference to Table I. in which are given the ratios of the emission intensities of both the "Crescent *Aero*" and the Eastman standard burners, as reported by Coblentz, to those of a black body at 2360° K. and at 2450° K., the ratio at 0.48 μ arbitrarily being taken as unity, it is seen that the reported energy distribution of neither acetylene burner corresponds to that of a black body at any temperature. Not only would it appear that acetylene has an extremely high emissivity in the region of short wave-lengths (0.40 μ to 0.45 μ) but also that in the middle region of the visible spectrum (0.5 μ to 0.7 μ) the deviations are sufficiently large to justify the expectation that no exact color match could be obtained with a black body at any temperature. One would expect, if the published data were accurate, that the acetylene flame would have a slightly purplish color in comparison with which the black body would appear slightly greenish by contrast. Neither of the other two laboratories has reported any such observed effect, and careful observation in Nela Research Laboratory with the phenomenon especially in mind has failed to detect such an effect.

The question naturally arises as to the sensibility of the color-match method. Long experience in this Laboratory has established the conclu-

[1] *Loc. cit.*

TABLE I.

Ratio of Emission Intensities of a Cylindrical Acetylene Flame as Found by Coblentz for the 'Crescent Aero" and the "Eastman Standard" Burners, to those of a Black Body at Various 'Temperatures. (Ratio at 0.48 μ taken as unity in each case.)

Wave-length.	Ratios Black Body to "Crescent *Aero*" Burner.			Ratios Black Body to "Eastman Standard" Burner.	
	2434° K.	2360° K.	2450° K.	2360° K.	2450° K.
0.40 μ	0.62	0.58	0.62	0.58	0.62
.42	.74	.70	.75	.70	.75
.44	.86	.83	.87	.83	.87
.46	.94	.93	.95	.93	.95
.48	1.00	1.00	1.00	1.00	1.00
.50	1.04	1.06	1.04	1.06	1.04
.52	1.05	1.09	1.04	1.09	1.04
.54	1.05	1.10	1.04	1.10	1.04
.56	1.06	1.12	1.04	1.12	1.04
.58	1.05	1.12	1.04	1.12	1.04
.60	1.05	1.14	1.03	1.14	1.03
.62	1.04	1.14	1.02	1.14	1.02
.64	1.03	1.14	1.01	1.14	1.01
.66	1.01	1.12	.99	1.12	.99
.68	1.00	1.11	.97	1.11	.97
.70	.99	1.11	.96	1.10	.95
.72	.98	1.10	.95	1.09	.93
.74	.97	1.10	.93	1.08	.91

sion that a relative change in emission intensity at 0.5 μ and at 0.7 μ of 2 per cent., corresponding to a change of approximately 0.5 per cent. in the temperature of a black body in the region of 2400° K. is readily observable. But although this sensibility obtains in matching a black body with another source having approximately a black-body distribution, it tells nothing about the sensibility of the method in comparing with a black body a source which has a relatively high or relatively low emissivity in the middle of the visible spectrum. An important point to determine is the necessary magnitude of this departure from a black-body distribution in order that it should be observed in the color difference as seen in the photometer.

An experiment was arranged to establish this point. A piece of plate glass was selected which by absorption changed the color of the light from a tungsten lamp to a slightly greenish hue. The change in color was so small that close observation was required to detect it. That it was appreciable was indicated, however, by the fact that out of eleven trials an observer judged correctly ten times whether the glass was or was not interposed, and the condition of the experiment was such that no other indication than the greenish tint due to the absorption of the glass could be used as a basis of judgment. Having shown that the color difference between the direct light from the lamp and that transmitted by the glass was appreciable a determination of the spectral transmission of the glass was undertaken. This determination was made using both a spectro-

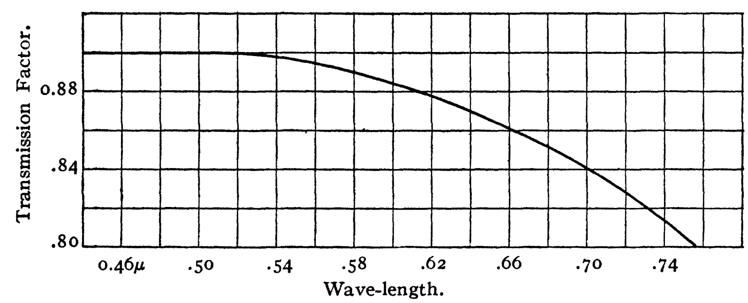

Fig. 1.

Transmission of a Selected Piece of Plate Glass of Slightly Greenish Hue.

photometer and a spectral pyrometer, the two methods giving relative transmission curves differing by not more than 1 per cent.

The resultant transmission curve for the glass is shown in Fig. 1. It is seen that the glass is slightly bluish as well as having a relatively larger transmission in the green, and consequently the nearest color temperature of light transmitted through the glass would be higher than that of the direct light from the lamp. For the source employed these two color temperatures were found by experiment to be 2414° K. and 2374° K. respectively. If now the computed emission intensities of a black body at 2374° K. are multiplied by the relative transmission factors given in Fig. 1, and the resultant values compared with the computed emission intensities of a black body at 2414° K., the magnitude of the excess in green of the light transmitted by the glass is shown. The results of these computations are given in Table II., computed for every 0.04 μ. It is seen that the relative difference between the two energy distributions which were observed by the color-match method to be appreciably different, is at most 3.8 per cent. between the wave-length limits of 0.48 μ and 0.72 μ, so that it may safely be concluded that corresponding relative differences as large as 6 or 7 per cent., such as would be indicated by comparison of the measurements on acetylene by Dr. Coblentz with the energy distribution of a black body at the nearest color temperature and over the same wave-length interval, should easily be observed.

As stated in a previous paragraph the largest deviation between the published emission intensities of acetylene and the computed emission intensities of a black body at color match (2360° K. for the Eastman standard burner and approximately 2440° K., the average of the two values given by the Bureau of Standards, for the burner used by Coblentz)

TABLE II.

Modification of Black-Body Radiation by Transmission through a Piece of Slightly Selective Plate Glass.

Wave-length.	Transmission Factor of Glass.	(*a*) Relative Emission Intensities of Black Body at 2374° K. as Modified by Glass.	(*b*) Relative Emission Intensities of Black Body at 2414° K.	Column (*a*) − Column (*b*) in Per Cent.
0.48 μ	0.90	120	120	±0.0
.52	.90	212	208_5	+1.7
.56	$.89_5$	333	326	+2.1
.60	$.88_5$	480	468	+2.6
.64	.87	641	630	+1.7
.68	.85	806	804	+0.2
.72	.83	969	981	−1.2

is to be found in the blue end of the spectrum. The authors' measurements with spectrophotometer and spectral pyrometer could be extended in this region only to 0.45–0.48 μ, so that some other method was required. For this purpose photography was employed, and although its indications as used are not accepted as conducing to accurate quantitative results, they may be depended upon for approximate values.

The method employed consisted in taking a spectrogram of the acetylene flame, and then on an adjacent portion of the plate, a spectrogram with the same exposure time of a standard tungsten lamp operating at the voltage corresponding to the color temperature (2360° K.) of the acetylene burner. From previous measurements of the brightness temperatures of the two sources, it was known to be necessary to interpose a 45° rotating sectored disk in the path of the light from the tungsten lamp in order to bring the two spectra to approximately the same intensities at 0.55 μ. The two spectrograms thus obtained were measured for photographic density at the two wave-lengths 0.55 μ and 0.41 μ, the method of measurement consisting in determining the transmission (corrected for the plate) of the two spectrograms at the two wave-lengths by the use of a pyrometer. A pyrometer with a very small filament was found to be a most convenient instrument for measurements of this kind.

The results of this experiment showed roughly the same relative emission intensities of the Eastman standard acetylene flame and a black body at 2360° K. between the two wave-lengths,—0.55 μ, in the central region of the visible spectrum, and 0.41 μ, well out in the extreme blue end of the spectrum. If Coblentz's values for acetylene were accepted the emission intensity at 0.41 μ for acetylene should be about 75 per cent. more than that of the black body at 2360° K., as compared with the same emission intensities at 0.55 μ, and so the photographic density of the spectrogram for acetylene should be relatively much greater in the short wave-length region.

As a check experiment a series of spectrograms were taken as before, except that the 45° sectored disk was replaced by a 60° disk. For the same exposure time this would expose the plate to 60/45 or 4/3 the quantity of light for the tungsten source, and would show whether an increase of 33-1/3 per cent. in the luminous flux would produce a very appreciable difference. The result was without question the photographic density of the tungsten spectrograms being uniformly greater throughout the spectrum, and yet the difference in exposure for the two spectrograms was less than one half that which would have resulted between the two chosen wave-lengths of the acetylene spectrogram if the relative emission intensities of acetylene were of the order of magnitude found by Coblentz.

It should be noted that the color temperature of acetylene has been assumed to be 2360° K., or that of the Eastman burner, rather than 2440°, that found at the Bureau of Standards, for the burner employed by Coblentz in his principal measurements. But it should also be noted that he found the same emission intensities for the Eastman burner throughout the visible spectrum except in the red beyond 0.68 μ. Moreover, the results would suffer no change in magnitude if the higher color temperature had been assumed.

From these various experiments it must be concluded that the emission intensities published by Coblentz for a cylindrical acetylene flame of the type found in the Eastman standard burner are subject to considerable uncertainty. In the central portion of the visible spectrum the results would seem to be uncertain to the extent of at least 5 per cent., and in the blue end of the spectrum the values given are too high by many per cent. At 0.41 μ for example, the published value would seem to be too high by at least 50 per cent.

In connection with the above experiments measurements were made of the variation of the brightness temperature and of the color temperature for the different parts of the flame seen through the 3 mm. diaphragm used with the Eastman standard burner. There was found a variation of about 25° in the brightness temperature and somewhat more in the color temperature between the top and bottom of the flame. The brightness temperature of the flame at the middle of the diaphragm was found to be 1728° K. at 0.665 μ, which agrees well with the average brightness temperature of the entire portion of the flame exposed by the diaphragm.

Until more accurate data are available the authors would recommend that the relative emission intensities of a cylindrical acetylene flame, at least for that type represented specifically by the Eastman standard burner and for the wave-length interval 0.4 μ to 0.7 μ, should be taken as identical with those of a black body at 2360° K. As stated in the previous paragraph, the brightness temperature at 0.665 μ was found to be 1728° K. From these two sets of data a table of emission intensities may readily be computed.

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When the manuscript of this paper was sent to the printer, a copy was forwarded to Dr. Coblentz who later informed the authors that the "Crescent *Aero*" burner used in the color-matching tests at the Bureau of Standards, was not the same as the one used in his work on visibility. The burner used in the visibility work had an opening of 8 mm., whereas that used in the color-match had a 10 mm. opening. He also stated as the result of a correction in the blue end of the spectrum, his revised data give a distribution agreeing with that of a black body at 2360°K to within 3% from 0.50μ to 0.74μ.