A NEW PRECISION COLORIMETER

By P. G. Nutting

It is well known that any color may be analyzed and specified in either of two different ways: (1) In terms of three primary components, red, green, and blue (*trichromatic* analysis); or (2) in terms of wave length of dominant hue or its complementary and per cent white (*monochromatic* analysis). In mathematical terms, the color point may be located by either trilinear or by polar coordinates. Of the three elements of color; hue, tone, and luminosity, *hue* and *tone* are determined with a colorimeter, *luminosity* with a photometer or a photometric part of the colorimeter.

Colors to be analyzed consist of light either *emitted* from some source, *transmitted* through some selective screen, or *reflected* from some mat or semi-mat surface. Any of these colors to be analyzed may be either *spectral* or *purple*, according to whether or not its dominant hue lies in the visible spectrum. Any analyzing colorimeter must then be applicable to emitted, transmitted, or reflected light of either spectral or purple dominant hue.

A trichromatic analyzer, the Ives [1] colorimeter, has been in successful use for several years. A monochromatic method of analysis was devised and used by Abney [2] in a laboratory investigation as early as 1890. The colorimeter here described is a monochromatic analyzer and was designed to be a practical working instrument of wide range, high precision, and of great simplicity.

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[1] F. E. Ives: J. Franklin Inst., **164**, pp. 421–423; 1907.

[2] W. de W. Abney: Color Measurements and Mixtures, 1891, pp. 162–166.

The advantage of monochromatic analysis lies in the elimination of the arbitrary reference standards (red, green, and blue), readings being given directly in wave length and per cent white. Both methods involve the definition and adoption of some standard of white. The trichromatic method may be used for either spectral or purple hues indifferently; the use of the monochromatic method involves an interchange of two sources or arms in passing from spectral to purple hues. Both methods give readings varying somewhat with the observer, involving, in some cases, correction to the absolute color scale based on the average properties of a number of normal eyes.

The new colorimeter is so arranged that light of a pure spectral hue may be mixed with white light to match the unknown; or, in

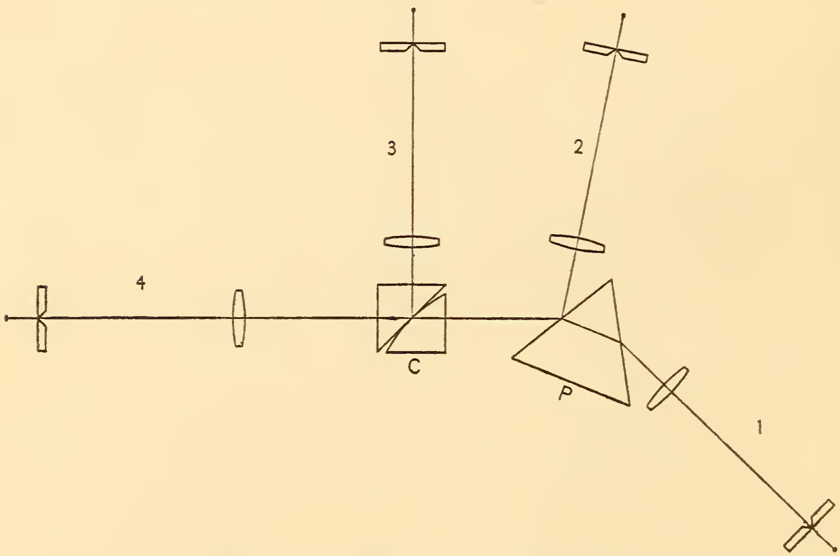

Fig. 1.—*Optical diagram of precision colorimeter*

the case of purples, it is mixed with the unknown to match white. The match is made with a photometer cube.

Fig. 1 is a diagram of the optical parts of the instrument. Collimator 1 is movable; all the remaining parts are fixed. Collimators 1 and 4 with prism P form an ordinary spectroscope with pinhole ocular. The white and the unknown lights enter through collimators 2 and 3, in direct or in inverse order, according as the match is to be made with the dominant hue or its complementary. In analyzing reflected light the necessary collimator is raised or rotated or even removed entirely if sunlight is used.

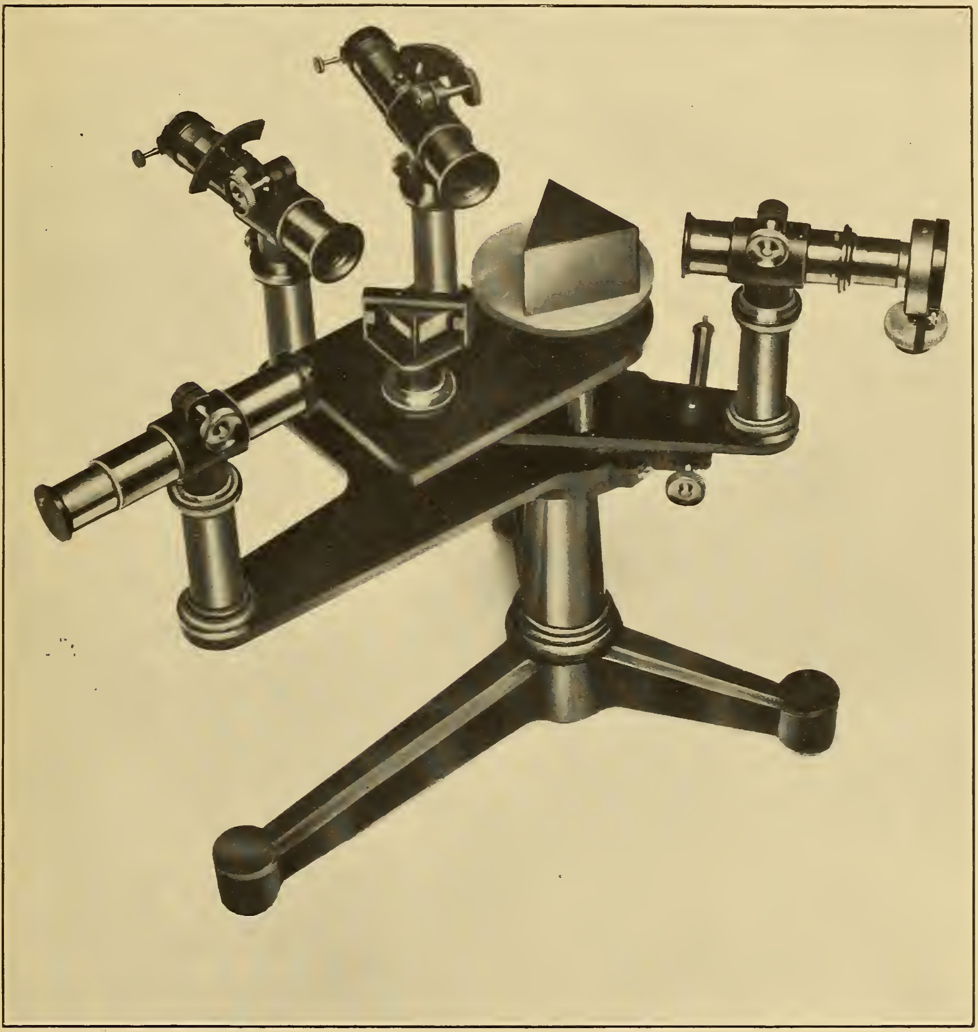

Fig. 2.—*Precision colorimeter*

Wave lengths are varied simply by rotation of collimator 1. Intensities may be varied by (1) varying slit widths, (2) rotating sectors, or (3) by rotating one of a pair of nicols placed just inside each slit. The colorimeter now in use is provided with a bilateral slit on the first collimator while collimators 2 and 3 are provided with pairs of nicols.

After a match has been secured, the wave length of the dominant hue is either read from the position of collimator 1 or is determined by throwing in a small hand spectroscope before the pinhole ocular of 4.

Intensities are determined by interposing between collimator 4 and photometer cube C, a white 180° (Whitman) rotating disk illuminated by a standard lamp. This gives the intensity in meter candles of each of the three component beams separately. Instead of this flicker photometer arrangement, a simple equality of brightness photometer may be used to determine the relative brightness of any two beams. To intercompare beams 1 and 2, for example, the top half of the objective of collimator 1 is covered with a black card and the lower half of 2 and then the width of slit 1 is varied until equality of brightness is secured. This slit width, compared with the original width used to secure a color match, gives the relative intensities of the two beams.

An experimental colorimeter of the type above described was assembled at the Bureau of Standards in the early spring of 1911 and given a thorough test. Later, special optical parts were ordered from Fuess and the instrument constructed in the Bureau shops. This new instrument has been in constant use at the Bureau since the first of January, 1912, in routine tests and special research work. A patent dedicated to the public has been granted.

Several sets of data are given below to show the sensibility of the instrument and the systematic errors to which its readings are subject. The first set was on a piece of the cover of this bulletin, a dull greenish gray, a fairly difficult test as regards wave length of dominant hue and per cent white but with reflecting power (luminosity) easily determinable. The second set was taken on a card colored a nearly spectral orange sent in as a secondary standard for test. On this the wave-length determination could be made with ease while the per cent white and reflecting power were difficult. The data is given as taken, no observations being rejected. Both observers have normal trichromatic vision. One observer (J) has a wave-length sensibility curve closely approximating that of the average eye, while the other observer (N) is abnormally sensitive to both quality and quantity of light in the yellow-orange region.

The sensibility is, of course, that of the observer's eye in each case, since the known and unknown fields are viewed side by side without a dividing line. The uncertainty in the wave length of the dominant hue is about 1 or 2 $\mu\mu$ except in the extreme red and and violet and for colors of very nearly a neutral gray or very dark shades.

TABLE I

Greenish Gray, Bulletin Cover

Dominant hue (in $\mu\mu$)		Per cent white		Reflecting power	
N	J	N	J	N	J
574	571	60	62	0.25	0.23
569	572	65	69	.27	.28
571	570	65	70	.26	.23
568	571	65	67	.28	.28
568	568	76	62	.27	.24
570	570	66	66	.26	.25

TABLE II

Mat Orange, Nearly Spectral

Dominant hue (in $\mu\mu$)		Per cent white		Reflecting power	
N	J	N	J	N	J
600	599	28	23	0.56	0.40
600	598	26	24	.59	.38
600	596	26	29	.53	.36
599	598	22	22	.66	.38
600	599	23	24	.55	.38
600	598	25	24	.58	.38

Complete color analyses of a few familiar and fairly definite colors are given in the following tables by way of illustration.

TABLE III

Source	Trichromatic analysis: Red	Green	Per cent blue	Monochromatic analysis: Dominant hue (in $\mu\mu$)	Impurity (per cent white)
Blue sky	23.8	27.2	49.0	473	73
Cloudy sky	31.6	33.9	34.5	....	....
Hefner flame	52.0	38.8	9.2	589	34
Carbon lamp (3.1 W)	48.3	40.4	11.3	....	....
Acetylene	46.1	40.5	13.5	582	36
Tungsten (1.25 W)	44.9	41.1	14.0	587	37
Nernst (0.8 amp)	46.2	40.7	14.1	586	35
Moore tube (CO_2)	28.3	31.0	40.7	....	....
Helium tube	....	....	....	591	33
Mercury tube	....	....	....	482	55
Neon tube	....	....	....	616	11

TABLE IV

Materials.	Monochromatic analysis: Dominant hue (in $\mu\mu$)	Impurity (per cent white)	Reflecting coefficient
Sulphur	571	46	0.80
Cork	586	56	.26
Dandelion	580	9	....
Tobacco leaf (medium)	597	65	.14
Chocolate	595	70	.05
Butter, light	580	45	....
Butter, dark	580	28	.64
Navy blue (U. S.)	472	90	.019
Paris green	511	56	.386
Manila paper (about)	582	65	.57
Copper	597	70	.23
Brass, light	575	60	.32
Brass, dark	583	61	.28
Gold, medium	591	44	.21

The author is indebted to Mr. Lloyd Jones for making nearly all of the above determinations.

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