A METHOD FOR CONSTRUCTING THE NATURAL SCALE OF PURE COLOR.

By P. G. Nutting.

The color sensation is known to vary far from uniformly with the wave length of the exciting radiation. In a normal spectrum the variation is much more rapid in the yellowish-orange and bluish-green regions than in the midgreen or in the extreme red and violet. Hence, a color scale of say one unit for each 10 $\mu\mu$ difference in wave length would represent far from equal color steps. The difference in wave length just perceptible as a difference in color is roughly 5 $\mu\mu$ in the two most sensitive regions, 15 $\mu\mu$ in the midgreen, and much greater in the violet and red. The method here described makes use of data on this difference limen.

Given the least perceptible difference (difference limen) for an eye throughout the visible spectrum, the reciprocal will be proportional to color sensibility as a function of wave length. But sensibility is the derivative[1] of a scale-reading curve, in this case the color scale desired. A method based on this principle will be applied to some of the best recent data on difference limen to illustrate the construction of a color scale.

Steindler[2] has recently published data on the difference limen of twelve subjects having normal color vision. The characteristics of the color limen curve are shown in the figure. It has two deep minima at about 490 $\mu\mu$ and 580 $\mu\mu$, a maximum in the green at 535 and a slight maximum and minimum at either end. The location and heights of these seven maxima and minima are given for each of the twelve subjects in the following table:

[1] This Bulletin **5**, p. 266, 1908.

[2] Sitz. Ak. Wiss. Wien, **115**, IIa; Jan., 1906.

	First Minima		First Maxima		Second Minima		Second Maxima		Third Minima		Third Maxima		Fourth Minima	
	λ	$\delta\lambda$	λ	$\delta\lambda$	λ	$\delta\lambda$	λ	$\delta\lambda$	λ	$\delta\lambda$	λ	$\delta\lambda$	λ	$\delta\lambda$
Dr. O. St	435	23.6	454	37.6	495	11.6	535	32.8	585	7.6	626	40.0	638	31.0
Dr. E	434	25.7	450	38.0	488	11.0	532	36.4	587	8.0	630	47.0	651	34.5
Prof. E	430	14.5	444	18.0	480	5.0	523	34.2	586	9.0	624	34.2	637	28.6
Dr. Sch	435	16.0	462	21.6	498	12.0	535	20.4	582	12.4	612	26.0	628	24.0
Dr. A. St	446	26.0	465	34.0	494	25.5	540	49.5	585	22.4	620	38.0	637	32.0
Dr. Ma	......	......	......	......	488	15.9	520	22.0	572	9.1	622	24.0	638	17.2
Dr. Me	436	13.8	448	24.2	478	5.2	545	37.2	598	11.2	630	36.0	646	20.0
Dr. Bi	447	18.0	462	24.0	505	12.0	540	22.2	583	11.2	608	21.2	614	19.2
Hr. B	454	30.4	462	35.5	492	19.6	530	46.0	568	24.0	605	44.0	618	43.0
Frl. M	442	14.0	468	24.4	490	16.0	540	32.0	572	20.0	633	60.0	642	45.5
Dr. H	450	51.0	460	54.6	497	22.4	530	46 0	583	19.2	......	......	......	......
Dr. G	437	39.3	435	39.3	501	7.6	536	22.1	571	12.8	625	42.4	640	34.6
Means	440	24.7	455	29.3	492	13.6	534	33.4	581	13.9	621	37.5	635	30.0

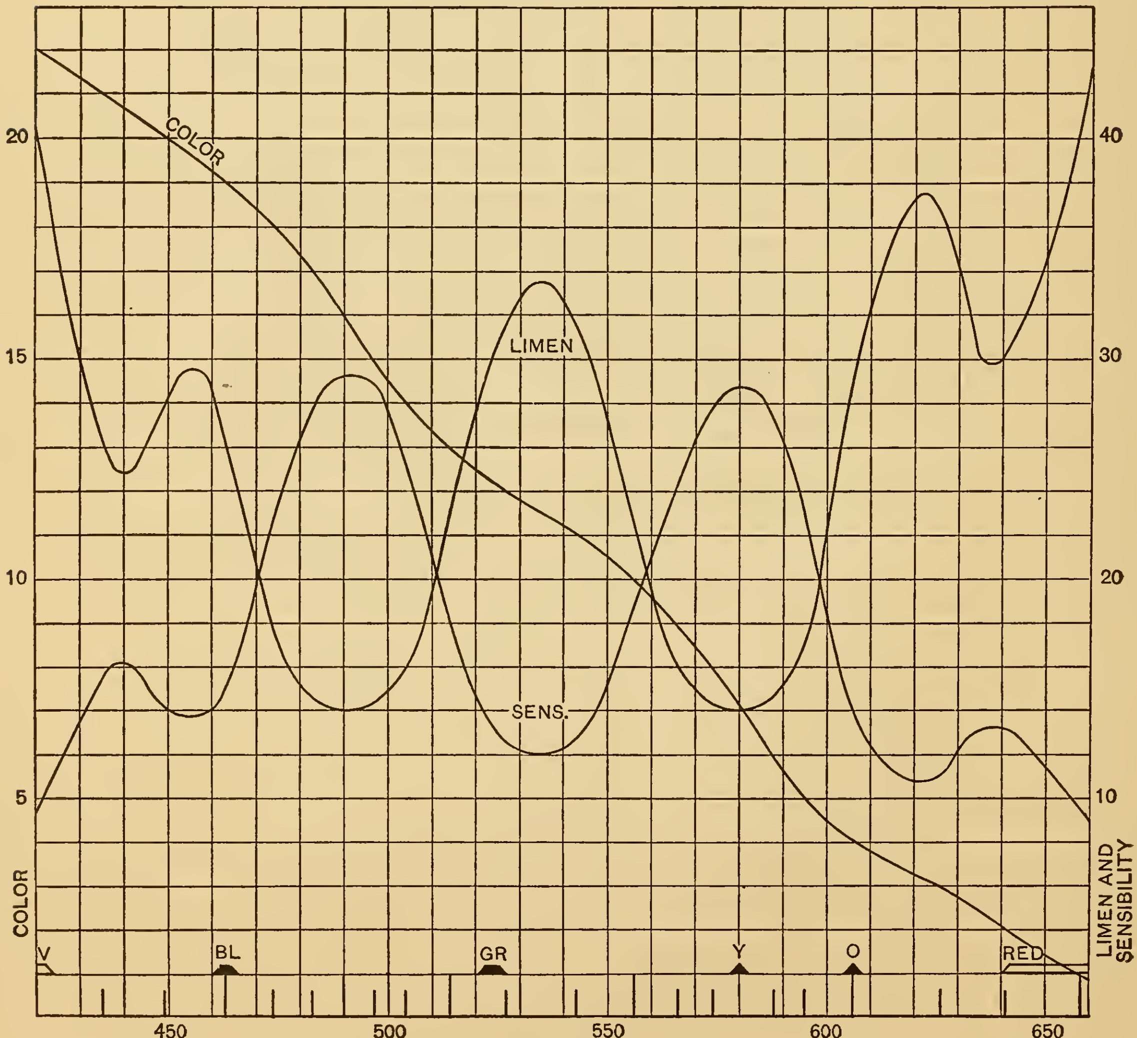

Fig. 1.

While variations from the mean positions of the maxima and minima are not excessive they are so large that a simple average of all the curves would be smoother than any of them. Adjusting the positions of the maxima and minima of each curve to the means, the following data were obtained for the properties of average (of these twelve) eyes.

TABLE II.

Wave Length ($\mu\mu$)	Color Limen ($\mu\mu$)	Sensibility	Ordinate Area	Color Scale
420	41.0	244	5.45	21.96
425	36.0	278		
430	30.0	333	7.51	21.41
435	26.1	384		
440	24.7	405	7.55	20.66
445	26.3	380		
450	28.5	351	6.90	19.91
455	29.3	341		
460	28.8	347	8.00	19.22
465	24.6	407		
470	20.6	485	11.60	18.42
475	17.0	588		
480	15.2	658	13.12	17.26
485	14.0	714		
490	13.7	730	14.44	15.95
495	13.7	730		
500	14.5	690	12.04	14.50
505	16.5	607		
510	19.4	515	8.70	13.30
515	22.9	436		
520	27.4	365	6.56	12.43
525	30.9	324		
530	32.7	306	6.04	11.77
535	33.4	300		
540	32.5	308	6.60	11.17
545	30.3	330		
550	27.1	369	8.80	10.51
555	22.7	440		
560	19.2	520	11.72	9.63
565	17.1	588		
570	15.4	650	13.90	8.46
575	14.3	700		
580	13.9	720	14.00	7.07
585	14.1	709		
590	15.2	658	11.36	5.67
595	17.3	578		
600	22.2	450	7.32	4.53
605	28.2	355		
610	32.8	305	5.58	3.80
615	35.6	281		
620	37.5	267	5.48	3.24

TABLE II—Continued.

Wave Length ($\mu\mu$)	Color Limen ($\mu\mu$)	Sensibility	Ordinate Area	Color Scale
625	36.9	271	...	...
630	33.5	298	6.48	2.69
635	30.1	332	...	...
640	30.3	330	6.24	2.04
645	32.0	313	...	...
650	35.6	281	5.21	1.42
655	38.6	259	...	...
660	...	...	9.00	0.90

The ordinates of the curve of color as a function of wave length are given in the last column. They were obtained by integration of the sensibility curve, the partial areas (divided by two on the scale of the figure) being given in the fourth column. Each number in the last column is the sum (divided by 10) of the ordinate areas of the fourth column added from the bottom to and including that wave length. The color-wave length curve is plotted in the figure.

A difference of one unit in the color scale represents a difference in color that is just easily perceptible, hence forms a convenient natural unit, although any other subdivision might be used. In Fig. 1, each unit of the color scale is indicated on the wave-length axis and just above are indicated roughly the positions of six spectral hues.

To test the theoretical color curve, a normal spectrum was projected on a black screen in which had been cut slits spaced according to the wave lengths of the color units, the slits being covered with ground glass. No departure from uniformity in the color steps could be detected by the ten or more individuals who carefully examined them.

The wave lengths of each of these color steps is given in Table III.

These computations have been carried through merely to illustrate the method. They may easily be made for any eye for which the sensibility curve is known.

If the sensibility curves of a large number of subjects were known, the properties of an average normal human eye might be deduced and a scale of color constructed and adopted.

TABLE III.

Color	Wave Length
1	420 Violet
2	435
3	449
4	463 Blue
5	474
6	483
7	490
8	497
9	504
10	514
11	527 Green
12	543
13	556
14	566
15	574
16	580 Yellow
17	588
18	595
19	606 Orange
20	626
21	641
22	658 Red

There is a widespread demand for reference standards of color in terms of which other colors may be specified. Such standards may easily be prepared of any desired hue or shade, but the great difficulties are in choosing rational and uniform divisions on the one hand and in obtaining dyes and pigments that are permanent on the other. Both difficulties would be largely obviated by the adoption of a fixed rational chromatic scale for use as a primary standard.

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