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Colorimetric and Photometric Properties of a 2° Fundamental Observer

The availability of tables with standardized data on the properties of a normal visual observer has been a great help in scientific communication. For daily practice these data, going back to the 1920s, still suffice. For basic science they show shortcomings, however. The present paper gives new and extended tables which are intended to be complementary to, rather than to compete with, the old CIE tables.

Introduction

In 1924 the CIE published collected data on the average luminosity function V_λ of the normal 2° observer. These data formed the basis for the present "standard 2° observer." In 1931 this was followed by the definition of his colorimetric properties in the form of the $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$ colour-matching functions. Since then the CIE standard observer has been generally accepted, in particular because of the easy availability of tabulated data on $\bar{x}_\lambda$, $\bar{y}_\lambda$, and $\bar{z}_\lambda$, and of their derivatives, the chromaticity coordinates x_λ, y_λ.

Of course, measurements done since have shown that the standardized data were not completely correct, but to update the definition was never seriously considered because the corrections concerned only the very ends of the visible spectrum and were therefore insignificant for the daily practice of colorimetry and photometry.

They are significant, however, for visual scientists who work with monochromatic stimuli. Mainly to serve them, Judd[1] calculated colour-mixture functions for a revised standard observer with the same colorimetric properties as the old one, but with a definitely higher sensitivity in the blue part of the spectrum, in accordance with the then known new data. Judd's tables are only available with 10-nm intervals, however, and that may be the reason that his data have never found general acceptance in visual science.

Ourselves having experienced the absence as a handicap we decided to redo and complete Judd's work on this point, and to calculate colour-matching functions, tabulated at 1-nm steps and adapted to our present state of knowledge. The table presented here, for reasons of space, has to be a 5-nm version only. The full 1-nm version is available, however, on request from the author.

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The Data Used

To calculate the tables several data sets were used.

(a) Since Judd used the same colorimetric data to form the basis of the CIE 1931 tables, his chromaticity diagram should be a projective transformation of the CIE 1931 diagram. Judd never gave the transformation formulas and obtained his tables by a method of successive approximations. With present-day computer facilities it was easy to obtain the exact formulas by demanding an exact imaging at four arbitrary, but amply spaced wavelengths. In fact we took 450, 500, 550, and 650 nm as reference points, and thus obtained as projective transformation between $(x_\lambda, y_\lambda)_{\mathrm{CIE\ '31}}$ and $(x'_\lambda, y'_\lambda)_{\mathrm{Judd\ '51}}$:

$$x'_\lambda = \frac{1.0271\, x_\lambda - 0.00008\, y_\lambda - 0.00009}{0.03845\, x_\lambda + 0.01496\, y_\lambda + 1},$$

$$y'_\lambda = \frac{0.00376\, x_\lambda + 1.0072\, y_\lambda + 0.00764}{0.03845\, x_\lambda + 0.01496\, y_\lambda + 1}.$$

The (x'_λ, y'_λ) chromaticity diagram thus computed shows only minor last-decimal deviations from Judd's data, these probably being due to Judd's approximation technique. Because the CIE 1931 data are available in seven decimals and with 1-nm intervals, the same degree of definition of the revised chromaticity data could be obtained. In fact we did not go further than five chemicals in floating-point notation.

(b) The CIE 1931 data assumed constant colorimetric properties beyond 700 nm, but since then an infrared colour reversal has been discovered[2] that makes a revision of the old data necessary. The effect seems to be independent of field size (ref. 3, p. 561), and we could therefore use the well-defined data on the infrared colour reversal of the CIE 1964 10° tables. Therefore we imaged the CIE 10° chromaticity diagram on the Judd diagram by a transformation

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TABLE I. Table of chromaticities, colour-matching functions, and receptor system primaries for a 2° fundamental observer

LAMBDA	X′	Y′	$\bar{x}'$	$\bar{y}'$	$\bar{z}'$	R	G	B	LOG R	LOG G	LOG B
380	0.17755	0.01320	0.26899E-02	0.20000E-03	0.12260E-01	0.71592E-04	0.38621E-04	0.89786E-04	-4.14514	-4.41318	-4.04679
385	0.17744	0.01322	0.53105E-02	0.39556E-03	0.24222E-01	0.14107E-03	0.77106E-04	0.17738E-03	-3.85057	-4.11291	-3.75108
390	0.17723	0.01315	0.10781E-01	0.80000E-03	0.49250E-01	0.28195E-03	0.15737E-03	0.36067E-03	-3.54983	-3.80307	-3.44288
395	0.17699	0.01316	0.20792E-01	0.15457E-02	0.95135E-01	0.53954E-03	0.30947E-03	0.69671E-03	-3.26798	-3.50938	-3.15695
400	0.17676	0.01303	0.37981E-01	0.28000E-02	0.17409E 00	0.96154E-03	0.56353E-03	0.12749E-02	-3.01703	-3.24908	-2.89452
405	0.17644	0.01301	0.63157E-01	0.46562E-02	0.29013E 00	0.15750E-02	0.95644E-03	0.21247E-02	-2.80272	-3.01934	-2.67269
410	0.17599	0.01303	0.99941E-01	0.74000E-02	0.46053E 00	0.24572E-02	0.15702E-02	0.33726E-02	-2.60957	-2.80405	-2.47203
415	0.17549	0.01306	0.15824E 00	0.11779E-01	0.73166E 00	0.38316E-02	0.25889E-02	0.53582E-02	-2.41661	-2.58689	-2.27098
420	0.17480	0.01333	0.22948E 00	0.17500E-01	0.10658E 01	0.56079E-02	0.40865E-02	0.78053E-02	-2.25120	-2.38864	-2.10761
425	0.17368	0.01401	0.28108E 00	0.22678E-01	0.13146E 01	0.72059E-02	0.58449E-02	0.96272E-02	-2.14231	-2.23322	-2.01650
430	0.17223	0.01512	0.31095E 00	0.27300E-01	0.14672E 01	0.86961E-02	0.78592E-02	0.10744E-01	-2.06067	-2.10462	-1.96882
435	0.17022	0.01677	0.33072E 00	0.32584E-01	0.15796E 01	0.10467E-01	0.10549E-01	0.11538E-01	-1.98016	-1.97678	-1.93675
440	0.16720	0.01907	0.33336E 00	0.37900E-01	0.16166E 01	0.12393E-01	0.13668E-01	0.11839E-01	-1.90682	-1.86429	-1.92670
445	0.16433	0.02199	0.31672E 00	0.42391E-01	0.15682E 01	0.14042E-01	0.16864E-01	0.11485E-01	-1.85259	-1.77303	-1.93988
450	0.15980	0.02589	0.28882E 00	0.46800E-01	0.14717E 01	0.15683E-01	0.20339E-01	0.10778E-01	-1.80458	-1.69167	-1.96746
455	0.15404	0.03092	0.25969E 00	0.52122E-01	0.13740E 01	0.17674E-01	0.24385E-01	0.10063E-01	-1.75265	-1.61289	-1.99729
460	0.14690	0.03787	0.23276E 00	0.60000E-01	0.12917E 01	0.20826E-01	0.29715E-01	0.94595E-02	-1.68140	-1.52703	-2.02413
465	0.13828	0.04803	0.20999E 00	0.72942E-01	0.12356E 01	0.26399E-01	0.37494E-01	0.90438E-02	-1.57841	-1.42604	-2.04341
470	0.12668	0.06505	0.17476E 00	0.90980E-01	0.11138E 01	0.35245E-01	0.47578E-01	0.81567E-02	-1.45291	-1.32259	-2.08849
475	0.11185	0.09499	0.13287E 00	0.11284E 00	0.94220E 00	0.46979E-01	0.58966E-01	0.69001E-02	-1.32810	-1.22943	-2.16115
480	0.09316	0.14086	0.91944E-01	0.13902E 00	0.75596E 00	0.61746E-01	0.71738E-01	0.55362E-02	-1.20939	-1.14425	-2.25679
485	0.07007	0.20838	0.56985E-01	0.16987E 00	0.58640E 00	0.79363E-01	0.86217E-01	0.42944E-02	-1.10038	-1.06441	-2.36710
490	0.04623	0.30304	0.31731E-01	0.20802E 00	0.44669E 00	0.10134E 00	0.10341E 00	0.32713E-02	-0.99423	-0.98544	-2.48529
495	0.02380	0.42042	0.14613E-01	0.25808E 00	0.34116E 00	0.12978E 00	0.12580E 00	0.24985E-02	-0.88679	-0.90031	-2.60233
500	0.00819	0.54540	0.48491E-02	0.32300E 00	0.26437E 00	0.16637E 00	0.15470E 00	0.19361E-02	-0.77893	-0.81052	-2.71308
505	0.00378	0.66062	0.23215E-02	0.40540E 00	0.20594E 00	0.21289E 00	0.19100E 00	0.15082E-02	-0.67185	-0.71897	-2.82155
510	0.01393	0.75440	0.92899E-02	0.50300E 00	0.15445E 00	0.26888E 00	0.23299E 00	0.11311E-02	-0.57044	-0.63267	-2.94649
515	0.03922	0.81453	0.29278E-01	0.60811E 00	0.10918E 00	0.33075E 00	0.27656E 00	0.79956E-03	-0.48051	-0.55820	-3.09715
520	0.07502	0.83492	0.63791E-01	0.71000E 00	0.76585E-01	0.39264E 00	0.31680E 00	0.56086E-03	-0.40600	-0.49922	-3.25115
525	0.11517	0.82638	0.11081E 00	0.79510E 00	0.56227E-01	0.44691E 00	0.34778E 00	0.41177E-03	-0.34978	-0.45870	-3.38535
530	0.15596	0.80538	0.16692E 00	0.86200E 00	0.41366E-01	0.49250E 00	0.36920E 00	0.30294E-03	-0.30760	-0.43274	-3.51865
535	0.19425	0.78070	0.22768E 00	0.91505E 00	0.29353E-01	0.53118E 00	0.38365E 00	0.21496E-03	-0.27476	-0.41606	-3.66764
540	0.23106	0.75311	0.29269E 00	0.95400E 00	0.20042E-01	0.56277E 00	0.39109E 00	0.14678E-03	-0.24967	-0.40773	-3.83334
545	0.26722	0.72295	0.36225E 00	0.98004E 00	0.13312E-01	0.58795E 00	0.39199E 00	0.97490E-04	-0.23066	-0.40672	-4.01104
550	0.30300	0.69089	0.43635E 00	0.99495E 00	0.87823E-02	0.60771E 00	0.38717E 00	0.64316E-04	-0.21630	-0.41210	-4.19168
555	0.33865	0.65749	0.51513E 00	0.10001E 01	0.58573E-02	0.62286E 00	0.37723E 00	0.42895E-04	-0.20561	-0.42340	-4.36760
560	0.37423	0.62322	0.59748E 00	0.99500E 00	0.40493E-02	0.63292E 00	0.36205E 00	0.29654E-04	-0.19865	-0.44123	-4.52791
565	0.40965	0.58858	0.68121E 00	0.97875E 00	0.29217E-02	0.63713E 00	0.34160E 00	0.21397E-04	-0.19578	-0.46648	-4.66965
570	0.44471	0.55396	0.76425E 00	0.95200E 00	0.22771E-02	0.63551E 00	0.31648E 00	0.16676E-04	-0.19688	-0.49968	-4.77792
575	0.47910	0.51977	0.84394E 00	0.91558E 00	0.19706E-02	0.62810E 00	0.28746E 00	0.14431E-04	-0.20197	-0.54142	-4.84069
580	0.51245	0.48653	0.91635E 00	0.87000E 00	0.18066E-02	0.61459E 00	0.25539E 00	0.13230E-04	-0.21141	-0.59279	-4.87843
585	0.54436	0.45477	0.97703E 00	0.81623E 00	0.15449E-02	0.59482E 00	0.22140E 00	0.11314E-04	-0.22562	-0.65482	-4.94638
590	0.57431	0.42489	0.10230E 01	0.75700E 00	0.12348E-02	0.56979E 00	0.18720E 00	0.90432E-05	-0.24428	-0.72769	-5.04368
595	0.60168	0.39768	0.10513E 01	0.69483E 00	0.11177E-02	0.54042E 00	0.15440E 00	0.81850E-05	-0.26727	-0.81136	-5.08698
600	0.62539	0.37406	0.10550E 01	0.63100E 00	0.90564E-03	0.50634E 00	0.12465E 00	0.66323E-05	-0.29556	-0.90430	-5.17833
605	0.64622	0.35333	0.10362E 01	0.56654E 00	0.69467E-03	0.46843E 00	0.98111E-01	0.50873E-05	-0.32936	-1.00828	-5.29351
610	0.66344	0.33627	0.99239E 00	0.50300E 00	0.42885E-03	0.42713E 00	0.75862E-01	0.31406E-05	-0.36944	-1.11997	-5.50298
615	0.67749	0.32227	0.92861E 00	0.44172E 00	0.31817E-03	0.38396E 00	0.57757E-01	0.23301E-05	-0.41571	-1.23840	-5.63263
620	0.68869	0.31109	0.84346E 00	0.38100E 00	0.25598E-03	0.33778E 00	0.43222E-01	0.18746E-05	-0.47137	-1.36430	-5.72709
625	0.69761	0.30223	0.73983E 00	0.32052E 00	0.15679E-03	0.28885E 00	0.31663E-01	0.11482E-05	-0.53932	-1.49944	-5.93998
630	0.70478	0.29510	0.63289E 00	0.26500E 00	0.97694E-04	0.24211E 00	0.22886E-01	0.71544E-06	-0.61598	-1.64044	-6.14543
635	0.71077	0.28913	0.53351E 00	0.21702E 00	0.68944E-04	0.20064E 00	0.16384E-01	0.50490E-06	-0.69758	-1.78559	-6.29679
640	0.71566	0.28424	0.44062E 00	0.17500E 00	0.51165E-04	0.16340E 00	0.11596E-01	0.37470E-06	-0.78674	-1.93570	-6.42632
645	0.71958	0.28034	0.35453E 00	0.13812E 00	0.36016E-04	0.13002E 00	0.81015E-02	0.26376E-06	-0.88599	-2.09143	-6.57880
650	0.72248	0.27746	0.27862E 00	0.10700E 00	0.24238E-04	0.10134E 00	0.56600E-02	0.17751E-06	-0.99422	-2.24719	-6.75079
655	0.72457	0.27537	0.21485E 00	0.81652E-01	0.16915E-04	0.77679E-01	0.39726E-02	0.12387E-06	-1.10970	-2.40093	-6.90702
660	0.72593	0.27400	0.16161E 00	0.61000E-01	0.11906E-04	0.58203E-01	0.27964E-02	0.87192E-07	-1.23505	-2.55340	-7.05952
665	0.72721	0.27273	0.11820E 00	0.44327E-01	0.81489E-05	0.42413E-01	0.19149E-02	0.59677E-07	-1.37251	-2.71786	-7.22419
670	0.72820	0.27174	0.85753E-01	0.32000E-01	0.56006E-05	0.30684E-01	0.13160E-02	0.41015E-07	-1.51309	-2.88073	-7.38705
675	0.72891	0.27103	0.63077E-01	0.23454E-01	0.39544E-05	0.22524E-01	0.92949E-03	0.28959E-07	-1.64735	-3.03176	-7.53822
680	0.72940	0.27054	0.45834E-01	0.17000E-01	0.27912E-05	0.16344E-01	0.65609E-03	0.20441E-07	-1.78665	-3.18304	-7.68951
685	0.72970	0.27025	0.32057E-01	0.11872E-01	0.19176E-05	0.11422E-01	0.45081E-03	0.14043E-07	-1.94227	-3.34600	-7.85254
690	0.72987	0.27008	0.22187E-01	0.82100E-02	0.13135E-05	0.79012E-02	0.30878E-03	0.96193E-08	-2.10231	-3.51035	-8.01686
695	0.73003	0.26992	0.15612E-01	0.57723E-02	0.91519E-06	0.55572E-02	0.21513E-03	0.67022E-08	-2.25514	-3.66730	-8.17378
700	0.73010	0.26985	0.11098E-01	0.41020E-02	0.64767E-06	0.39497E-02	0.15227E-03	0.47431E-08	-2.40343	-3.81739	-8.32394
705	0.73006	0.26989	0.79233E-02	0.29291E-02	0.46352E-06	0.28201E-02	0.10898E-03	0.33945E-08	-2.54973	-3.96266	-8.46922
710	0.72995	0.27000	0.56531E-02	0.20910E-02	0.33304E-06	0.20127E-02	0.78287E-04	0.24390E-08	-2.69622	-4.10631	-8.61279
715	0.72979	0.27016	0.40039E-02	0.14822E-02	0.23823E-06	0.14262E-02	0.55998E-04	0.17446E-08	-2.84582	-4.25183	-8.75830
720	0.72958	0.27037	0.28253E-02	0.10470E-02	0.17026E-06	0.10070E-02	0.40023E-04	0.12469E-08	-2.99698	-4.39769	-8.90417
725	0.72932	0.27062	0.19947E-02	0.74015E-03	0.12207E-06	0.71146E-03	0.28691E-04	0.89394E-09	-3.14785	-4.54226	-9.04869
730	0.72904	0.27091	0.13994E-02	0.52000E-03	0.87107E-07	0.49953E-03	0.20472E-04	0.63791E-09	-3.30144	-4.68883	-9.19524
735	0.72873	0.27121	0.96980E-03	0.36093E-03	0.61455E-07	0.34645E-03	0.14441E-04	0.45006E-09	-3.46031	-4.84041	-9.34673
740	0.72840	0.27154	0.66847E-03	0.24920E-03	0.43162E-07	0.23906E-03	0.10144E-04	0.31609E-09	-3.62150	-4.99380	-9.50019
745	0.72806	0.27189	0.46141E-03	0.17231E-03	0.30379E-07	0.16517E-03	0.71396E-05	0.22248E-09	-3.78206	-5.14632	-9.65272
750	0.72769	0.27226	0.32073E-03	0.12000E-03	0.21554E-07	0.11493E-03	0.50652E-05	0.15785E-09	-3.93955	-5.29541	-9.80176
755	0.72730	0.27264	0.22573E-03	0.84620E-04	0.15493E-07	0.80981E-04	0.36396E-05	0.11346E-09	-4.09162	-5.43895	-9.94515
760	0.72699	0.27305	0.15973E-03	0.60000E-04	0.11204E-07	0.57368E-04	0.26319E-05	0.82053E-10	-4.24133	-5.57973	-10.08591
765	0.72646	0.27348	0.11275E-03	0.42446E-04	0.80873E-08	0.40546E-04	0.18998E-05	0.59226E-10	-4.39205	-5.72129	-10.22749
770	0.72601	0.27392	0.79513E-04	0.30000E-04	0.58340E-08	0.28630E-04	0.13703E-05	0.42724E-10	-4.54318	-5.86318	-10.36933
775	0.72555	0.27438	0.56067E-04	0.21210E-04	0.42110E-08	0.20221E-04	0.98897E-06	0.30839E-10	-4.69419	-6.00482	-10.51091
780	0.72508	0.27486	0.39541E-04	0.14989E-04	0.30383E-08	0.14275E-04	0.71359E-06	0.22250E-10	-4.84541	-6.14655	-10.65267
785	0.72459	0.27535	0.27852E-04	0.10584E-04	0.21907E-08	0.10070E-04	0.51451E-06	0.16043E-10	-4.99699	-6.28861	-10.79471
790	0.72409	0.27587	0.19597E-04	0.74656E-05	0.15778E-08	0.70950E-05	0.37054E-06	0.11555E-10	-5.14904	-6.43116	-10.93725
795	0.72358	0.27636	0.13770E-04	0.52592E-05	0.11348E-08	0.49927E-05	0.26649E-06	0.83106E-11	-5.30167	-6.57432	-11.08037
800	0.72306	0.27687	0.96700E-05	0.37028E-05	0.81565E-09	0.35113E-05	0.19148E-06	0.59733E-11	-5.45453	-6.71788	-11.22379
805	0.72253	0.27740	0.67918E-05	0.26076E-05	0.58626E-09	0.24699E-05	0.13763E-06	0.42934E-11	-5.60731	-6.86127	-11.36720
810	0.72199	0.27794	0.47706E-05	0.18365E-05	0.42138E-09	0.17376E-05	0.98931E-07	0.30859E-11	-5.76006	-7.00467	-11.51062
815	0.72144	0.27848	0.33550E-05	0.12950E-05	0.30319E-09	0.12239E-05	0.71173E-07	0.22203E-11	-5.91227	-7.14769	-11.65358
820	0.72089	0.27903	0.23534E-05	0.91092E-06	0.21753E-09	0.85985E-06	0.51063E-07	0.15931E-11	-6.06558	-7.29189	-11.79777
825	0.72034	0.27958	0.16377E-05	0.63564E-06	0.15476E-09	0.59931E-06	0.36327E-07	0.11334E-11	-6.22235	-7.43977	-11.94562
TOTALS			0.10702E 03	0.10748E 03	0.10505E 03						

similar to that mentioned under (a). Of course this transformation could not be expected to give a perfect match since the CIE 10° and the CIE 2° data are based on completely different colorimetric data, but the differences are rather small, so that a smooth transition in the 650-nm region from the converted 2° data to the converted 10° data could easily be obtained.

As reference wavelengths we used 450, 500, 550, and 652 nm, the latter seemingly odd choice being determined by trial and error finding that with that choice the rate of change of x and y with λ allowed a smooth transition as well. The projective transformation obtained between $(x_\lambda, y_\lambda)_{\mathrm{CIE}\ 10°\ '64}$ and $(x'_\lambda, y'_\lambda)_{\mathrm{Judd}\ '51}$ reads:

$$x'_\lambda = \frac{0.39564\, x_\lambda - 0.12666\, y_\lambda + 0.08853}{-0.54397\, x_\lambda - 0.51866\, y_\lambda + 1},$$

$$y'_\lambda = \frac{-0.03833\, x_\lambda + 0.50787\, y_\lambda + 0.01056}{-0.54397\, x_\lambda - 0.51866\, y_\lambda + 1}.$$

(c) Judd postulated a luminosity function that was higher in the blue region than the CIE 1924 data. However, there are indications (ref. 3, p. 435) that his corrections were slight overcorrections below 410 nm. For our V_λ values, we did follow the revisions suggested by Stiles[4] taking 0.2-log-units-lower values in the extreme-short-wavelength part.

(d) On the above-mentioned basic data, two "aesthetic" corrections were applied. In the first place the data below 380 nm were omitted. The CIE data rest almost completely on unfounded extrapolation, and there seemed to be no reason to incorporate them in the definition of a fundamental observer. In the future we hope to be able to extend the data farther into the ultraviolet on the basis of Tan's[5] colorimetric data of aphakes.

In the second place the CIE 2° data show some completely unnecessary irregularities in the 380–400-nm region and a colorimetrically insignificant last-decimal concavity of the spectral locus between 435 and 445 nm. Corrections for these inequities were applied.

All the above-mentioned corrections apply only to the ends of the visible spectrum and can be considered as only second-order corrections to Judd's modification of the CIE 1931 data. For that reason no new transformation of the chromaticity diagram was sought to locate the equal-energy point E at $x' = y' = 1/3$ exactly. From the totals of $\bar{x}'_\lambda$, $\bar{y}'_\lambda$, and $\bar{z}'_\lambda$ (for the 1-nm interval version) it appears that E is located now at $x' = 0.334$, $y' = 0.336$, not more than 1 jnd off the ideal location.

The resulting "fundamental chromaticity diagram" is shown in Fig. 1. The points marked E, R, G, and B indicate the equal-energy point and the three receptor primary points (see following section).

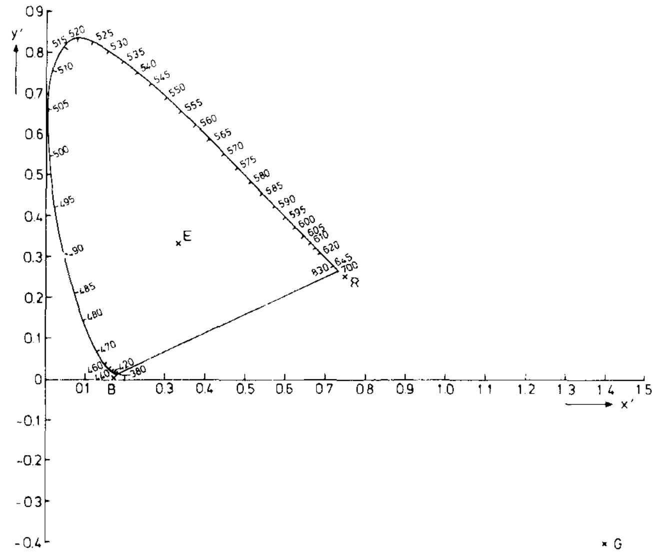

FIG. 1. Fundamental chromaticity diagram with equal energy point E and the three receptor primary points.

Additional Data

For fundamental work in vision, a conversion to more basic primaries in terms of cone system sensitivity is wanted. This can be done by using the locations of the dichromatic confusion centres on the premise that dichromats can be considered as normal trichromats missing one receptor system.[6,7]

The protanopic confusion centre was located by Thomson and Wright[8] at $x'_P = 0.7465$, $y'_P = 0.2535$, a location never challenged to our knowledge. The location of the deuteranopic confusion centre is less certain,[9] but recent psychophysical arguments have considerably narrowed the range of possibilities, so that $x'_D = 1.40$, $y'_D = -0.40$ seems to be the most accurate location for the moment.[7]

The data on the tritanopic confusion centre were recently reevaluated by Walraven.[10] His study led to a best choice at $x'_T = 0.1747$, $y'_T = 0.0060$. On the basis of these confusion loci and the above-mentioned explanation of dichromatism, the following conversion formulas of $\bar{x}'_\lambda$, $\bar{y}'_\lambda$, and $\bar{z}'_\lambda$ to the cone system fundamentals R_λ, G_λ, and B_λ can be defined:

$$R_\lambda = 0.1551646\, \bar{x}'_\lambda + 0.5430763\, \bar{y}'_\lambda - 0.0370161\, \bar{z}'_\lambda$$

$$G_\lambda = -0.1551646\, \bar{x}'_\lambda + 0.4569237\, \bar{y}'_\lambda + 0.0296946\, \bar{z}'_\lambda$$

$$B_\lambda = 0.0073215\, \bar{z}'_\lambda$$

The values of R_λ, G_λ, and B_λ, calculated with these conversion formulas, and the corresponding values of $\log R_\lambda$, $\log G_\lambda$, and $\log B_\lambda$ are listed as the last six columns of Table I. Figure 2 gives a graphical illustration of these spectral sensitivities.

Notes to Table I

LAMBDA is the wavelength in nanometers.

x', y' are the chromaticity coordinates on the basis of an E-centred chromaticity diagram.

$\bar{x}'$, $\bar{y}'$, $\bar{z}'$ are the colour-matching functions on the same basis, and on the basis of a revised course of the CIE luminosity function in the extreme blue.

R, G, B are the spectral sensitivities of, respectively, the long-wavelength (R), middle-wavelength (G), and short-wavelength (B) cone systems.

$\log R$, $\log G$, $\log B$ are the corresponding logarithmic values.

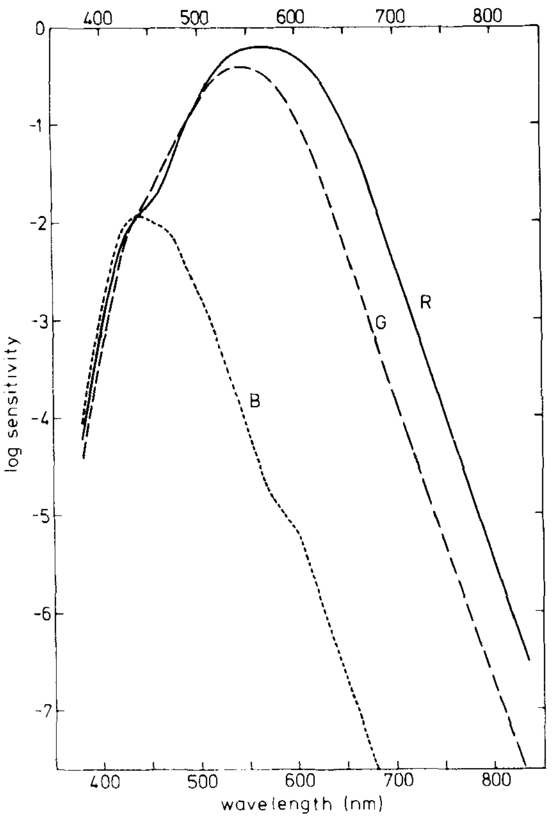

FIG. 2. Spectral sensitivity of the three receptor primary systems.

Table of Data on the Proposed 2° Fundamental Observer

In Table I, x' and y' mean chromaticity coordinates on the basis of an E-centred chromaticity diagram, and $\bar{x}'$, $\bar{y}'$, and $\bar{z}'$ mean the colour-matching functions on the same basis, and on a revised course of the luminosity function in the extreme blue.

We have considered several ways to distinguish these "fundamental x, y, z values" from the CIE standard values. It did not seem wise to proceed further in the direction from x to x', and to introduce x'' or x^*, etc. Since we consider our table a logical continuation of the fundamental updating started by Judd we have opted for a continuation of his indication, so use x', y', z'.

We have the opinion that the values tabulated here reflect the present state of knowledge. We can be sure, though, that new experimental data will sooner or later lead to better tables. Therefore, and to underline its temporary character by definition, it may be suggested to refer to them as the "1978 2° fundamental observer data."

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