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Spectral Transmissive Properties of Five Selected Optical Glasses*

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Measurements of the spectral transmittance and internal transmittance of five optical glasses for the wavelength region 200 to 1,000 millimicrons are reported.

1. Introduction

The transmittance, T, of a plate is defined as the ratio of radiant flux (P_2) transmitted by the plate to the flux (P_1) incident upon it. Internal transmittance (T_i) is defined as the ratio of the flux (P) arriving at the second surface of the plate to that flux (P_0) penetrating the first surface. All values of T and T_i are functions of wavelength.

The transmittances and internal transmittances reported were determined for glasses of the NBS melts for which the chemical compositions are given in Research Paper 2504.

The samples were prepared in the NBS Optical Shop in the form of cylinders or plates, 30 mm in diameter, with surfaces plane, parallel, and polished. The rare earth glass, $n=1.673$,[2] $\nu=56.2$, was prepared in thicknesses of 5 and 105 mm. The other four glasses were prepared in a thickness of 1 mm in addition to greater thicknesses. The thin samples were compared against a blank beam, and spectral transmittance was so obtained. The thick samples were compared to the thin sample of the same kind of glass, the resulting ratios being taken as internal transmittance for a sample of thickness equal to the difference between thick and thin specimens.[3]

2. Spectrophotometric Measurements

Most spectrophotometers are designed primarily for samples between 0- and 10- to 50-mm thickness, but can be used with samples of somewhat greater thickness. The greater the thickness, however, the more the instrument is subject to errors resulting from refraction of the various rays in the beam, for although these rays are approximately parallel and at right angles to the surfaces, they are in general not strictly so. The result is, in effect, a change in P_1 to P_0 of the above defining relations for transmittance, P_2/P_1, or for internal transmittance, P/P_0. This is particularly true when, as in the present measurements with the thick samples, the compensation beam of the spectrophotometer does not contain a sample of the same length (as it usually does, for example, in measuring the transmittance of a solution relative to its solvent).

Four types of spectrophotometers were available for this work. The designs of two of these instruments (the General Electric recording spectrophotometer and the König-Martens visual spectrophotometer) are such as to give confidence in the results for thick samples. The other two instruments (the Beckman quartz photoelectric spectrophotometer and the Gibson photoelectric spectrophotometer [9])[4] were sensitive to beam disturbance with thick samples. In the work on the rare-earth glass 1.673, it was found that the latter instrument was too sensitive to beam disturbance on insertion of the thick sample to give valid results, and it therefore was not used in the later measurements on the other glasses.

In the General Electric spectrophotometer (GE) [1, 2, 3] the beam of radiant energy, after transmission through the sample, is incident upon a diffusing white surface of uniform reflectance forming part of the interior wall of a white-lined integrating sphere. Any deviation or dispersion of the beam should not, therefore, cause appreciable error, if not so great that part of the beam impinges on the entrance aperture of the sphere.

On the König-Martens spectrophotometer (K-M) [4] the reverse but equivalent condition exists. The radiant energy is reflected from a diffusing surface of MgO, which is part of an enclosure completely covered with MgO, except for the part containing the bases of the lamps from which the radiant energy originates. Multiple reflections should give a wall surface of essentially uniform radiance, and any displacement of this source in the photometric field by the thick sample should not introduce important error in the results.

The principal value of the K-M measurements was to confirm the reliability of the GE data even for the thickest samples. However, the precision of the visual measurements is less than the photoelectric, and except with the rare-earth glass 1.673, only a few check measurements were made on the K-M spectrophotometer.

The Beckman quartz photoelectric spectrophotometer (model DU) (BQ) [5, 6] is somewhat susceptible to errors resulting from beam disturbance on insertion of the sample, and the thicker the sample the greater may be the error. On this instrument, the

*The companion papers in this issue present values of the index of refraction, densities, and coefficients of linear thermal expansion for five different types of optical glasses produced by the Optical Glass Section of the National Bureau of Standards. These measurements have been made in the different organizational parts of the Bureau appropriate to each type of measurement, and are, therefore, presented separately. For each type of glass the samples have been taken from the same melt, and, therefore, these papers present, collectively, a consistent set of data for the five glasses studied.

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[2] n=index of refraction for the sodium D lines, and ν, the Abbe value=$(n-1)/(n_F-n_C)$, where n_F and n_C are refractive indices for the hydrogen F and C lines, respectively.

[3] Glass DF, $n=1.649$, $\nu=33.8$ was prepared in greater thickness of 97 mm and compared to the 5-mm sample. Values of T_i for 100 mm for this glass are computed from the values of T_i, for 92 mm so determined.

[4] Figures in brackets indicate the index references at the end of this paper.

beam of radiant energy, after passage through the sample, is incident directly on the photocell. Although the window of the photocell is made diffusing, this is undoubtedly far from completely so, and any deviation or dispersion of the beam may well affect the response because of varying sensitivity of the photosensitive surface. The principal value of the Beckman spectrophotometer in the present work was to obtain the values of transmittance or internal transmittance in the ultraviolet, and it was not used at wavelengths longer than 460 millimicrons (mμ).

Consistent with the above, the GE recording spectrophotometer was used over the range 400 to 1,000 mμ, and the Beckman spectrophotometer over the range from 460 mμ toward shorter wavelengths into the ultraviolet as far as there was measurable transmission. The transmittance values obtained on the GE spectrophotometer were taken as a reference and the Beckman values adjusted to them when necessary in accordance with the following procedure: [5] (1) The GE transmittance values were used from 460 to 1,000 mμ, subject to an occasional smoothing not exceeding 0.001; (2) from 410 to 460 mμ the GE data were used to compute an adjustment factor to apply to all of the Beckman data. This adjustment factor was the average of the ratios (T_{GE}/T_{BQ}) at each of the six wavelengths from 410 to 460 mμ. In this range the adopted values were then based on both the GE data and the adjusted Beckman data; (3) from 400 mμ toward shorter wavelengths the adopted values were based on these adjusted Beckman data.

All the values by the Beckman spectrophotometer were obtained with the samples at 25° C.[6] Values by the GE spectrophotometer (visible and infrared) were obtained at a room temperature close to 25° C, and should be valid also at 25° C.

3. Spectrophotometric Results

Curves of the transmittances for 1-mm thickness for four glasses are shown in figure 1 (numbered 1 to 4), together with the transmittance curve for the 5-mm thickness of the rare-earth glass 1.673, numbered 5 in the figure.

Curves for the internal transmittances for 4- and 100-mm thicknesses of the same four glasses are shown in figure 2, together with the internal transmittance curve for the 100-mm thickness of the rare-earth glass 1.673.

The values of transmittance and internal transmittance are given in table 1. All are subject to slight uncertainty in the last figure. Examination of the values of T_i for 100 mm for the rare-earth glass 1.673 shows traces of the absorption bands near 580 and 740 mμ commonly found in didymium glasses.

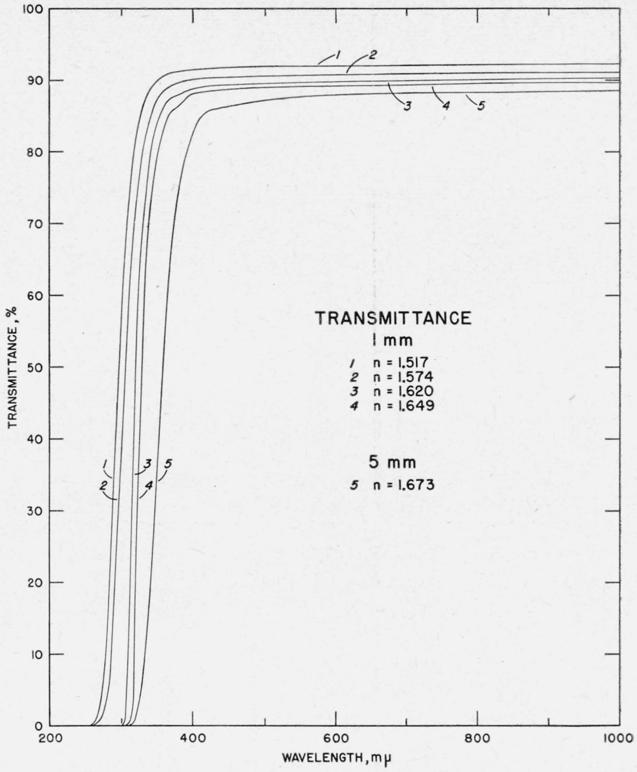

FIGURE 1. *Spectral transmittance of five selected optical glasses made at NBS for the ultraviolet, visible, and near-infrared spectrum.*

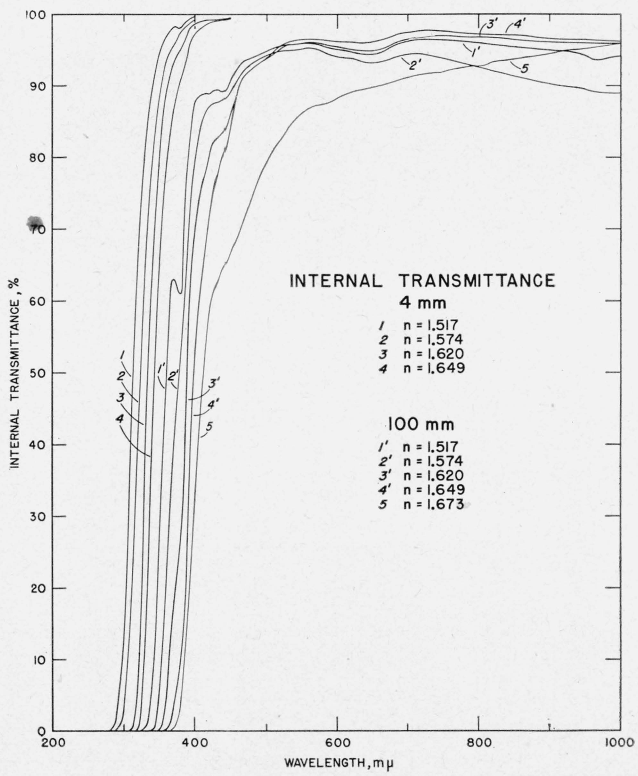

FIGURE 2. *Spectral internal transmittance of five selected optical glasses made at NBS for the ultraviolet, visible, and near-infrared spectrum.*

[5] This indicated procedure was followed for 4 of the 5 glasses. For rare-earth glass 1.673, a slightly different procedure was used.

[6] At the steep portions of the curves (figs. 1 and 2), the transmittance and internal transmittance vary importantly with temperature, in these cases in the ultraviolet region of the spectrum [7].

TABLE 1. *Spectral transmittance and internal transmittance data of five selected optical glasses made at NBS for the indicated thicknesses and for the wavelength range 200 to 1,000 millimicrons*

Wave-length	Glass BSC $n=1.517$ $\nu=64.5$			Glass LBC $n=1.574$ $\nu=57.7$			Glass F $n=1.620$ $\nu=36.2$			Glass DF $n=1.649$ $\nu=33.8$			Rare-earth glass $n=1.673$ $\nu=56.2$	
	1 mm	4 mm	100 mm	1 mm	4 mm	100 mm	1 mm	4 mm	100 mm	1 mm	4 mm	100 mm	5 mm	100 mm
	T	T_i	T_i	T	T_i	T_i	T	T_i	T_i	T	T_i	T_i	T	T_i
mμ														
250	0.000													
260	.002	------	------	0.000										
270	.026	0.000	------	.008										
280	.12	.001	------	.054	0.000	------	------	------	------	------	------	------	0.000	
290	.33	.019	------	.17	.003	------	------	------	------	------	------	------	.001	
300	.56	.14	------	.37	.030	------	0.000	0.000	------	0.000	------	------	.002	
310	.72	.39	------	.56	.16	------	.10	.002	------	.003	0.000	------	.004	
320	.813	.64	0.000	.71	.39	------	.46	.072	------	.17	.003	------	.014	
330	.862	.802	.004	.80	.62	0.000	.69	.36	------	.51	.11	------	.063	
340	.887	.896	.065	.847	.79	.002	.79	.63	0.000	.70	.39	------	.18	
350	.900	.945	.24	.873	.884	.046	.840	.79	.003	.79	.63	0.000	.36	
360	.907	.972	.48	.886	.939	.21	.864	.885	.047	.832	.78	.002	.53	0.000
370	.910	.982	.63	.893	.966	.42	.876	.934	.18	.857	.867	.030	.66	.004
380	.911	.981	.61	.896	.975	.53	.879	.949	.26	.864	.905	.09	.74	.042
390	.913	.992	.79	.899	.985	.66	.885	.974	.49	.874	.946	.26	.795	.15
400	.915	.996	.875	.901	.992	.80	.888	.987	.694	.881	.971	.50	.825	.32
410	.915	------	.889	.902	------	.856	.890	.990	.765	.882	.981	.633	.847	.47
420	.916	------	.889	.902	------	.869	.891	.991	.794	.883	.986	.705	.856	.575
430	.916	------	.895	.903	------	.878	.892	.993	.827	.884	.990	.775	.860	.625
440	.916	------	.892	.903	------	.880	.892	.993	.835	.885	.992	.804	.862	.645
450	.917	------	.910	.904	------	.892	.893	.995	.864	.887	.993	.842	.864	.667
460	------	------	.929	------	------	.912	------	------	.899	------	------	.900	------	.696
470	------	------	.936	------	------	.925	------	------	.916	------	------	.913	------	.723
480	------	------	.940	------	------	.932	------	------	.923	------	------	.923	------	.748
490	------	------	.944	------	------	.938	------	------	.931	------	------	.932	------	.773
500	.918	------	.949	.905	------	.942	.895	------	.938	.889	------	.940	.873	.794
510	------	------	.953	------	------	.946	------	------	.947	------	------	.948	------	.811
520	------	------	.956	------	------	.948	------	------	.952	------	------	.955	------	.826
530	------	------	.957	------	------	.949	------	------	.956	------	------	.959	------	.840
540	------	------	.958	------	------	.950	------	------	.958	------	------	.962	------	.852
550	.919	------	.959	.906	------	.952	.896	------	.959	.890	------	.964	.877	.862
560	------	------	.960	------	------	.953	------	------	.961	------	------	.965	------	.869
570	------	------	.958	------	------	.951	------	------	.960	------	------	.965	------	.873
580	------	------	.955	------	------	.947	------	------	.958	------	------	.964	------	.874
590	------	------	.952	------	------	.943	------	------	.956	------	------	.962	------	.878
600	.919	------	.951	.907	------	.941	.897	------	.955	.891	------	.961	.879	.883
610	------	------	.950	------	------	.939	------	------	.953	------	------	.961	------	.887
620	------	------	.947	------	------	.938	------	------	.951	------	------	.961	------	.890
630	------	------	.945	------	------	.935	------	------	.949	------	------	.960	------	.893
640	------	------	.944	------	------	.933	------	------	.949	------	------	.960	------	.895
650	.920	------	.944	.908	------	.932	.898	------	.949	.892	------	.961	.881	.898
660	------	------	.946	------	------	.933	------	------	.950	------	------	.962	------	.901
670	------	------	.951	------	------	.935	------	------	.954	------	------	.966	------	.903
680	------	------	.956	------	------	.940	------	------	.959	------	------	.969	------	.906
690	------	------	.960	------	------	.943	------	------	.962	------	------	.973	------	.909
700	.920	------	.962	.908	------	.945	.899	------	.965	.893	------	.974	.882	.911
710	------	------	.963	------	------	.945	------	------	.966	------	------	.976	------	.913
720	------	------	.963	------	------	.944	------	------	.967	------	------	.977	------	.916
730	------	------	.964	------	------	.942	------	------	.969	------	------	.977	------	.917
740	------	------	.964	------	------	.940	------	------	.969	------	------	.976	------	.918
750	.921	------	.963	.909	------	.938	.900	------	.969	.894	------	.976	.882	.919
760	------	------	.963	------	------	.936	------	------	.969	------	------	.975	------	.923
770	------	------	.963	------	------	.934	------	------	.969	------	------	.975	------	.924
780	------	------	.962	------	------	.931	------	------	.968	------	------	.974	------	.926
790	------	------	.961	------	------	.929	------	------	.968	------	------	.974	------	.927
800	.921	------	.960	.909	------	.926	.900	------	.968	.895	------	.973	.882	.927
810	------	------	.959	------	------	.923	------	------	.967	------	------	.972	------	.928
820	------	------	.958	------	------	.920	------	------	.966	------	------	.972	------	.932
830	------	------	.957	------	------	.918	------	------	.966	------	------	.972	------	.934
840	------	------	.956	------	------	.916	------	------	.965	------	------	.971	------	.936
850	.922	------	.955	.909	------	.913	.901	------	.965	.896	------	.971	.883	.937
860	------	------	.954	------	------	.911	------	------	.964	------	------	.970	------	.939
870	------	------	.953	------	------	.909	------	------	.963	------	------	.969	------	.940
880	------	------	.952	------	------	.907	------	------	.963	------	------	.968	------	.941
890	------	------	.951	------	------	.905	------	------	.962	------	------	.967	------	.943
900	.922	------	.950	.909	------	.903	.901	------	.962	.896	------	.966	.884	.945
910	------	------	.949	------	------	.901	------	------	.961	------	------	.966	------	.947
920	------	------	.948	------	------	.900	------	------	.961	------	------	.965	------	.948
930	------	------	.947	------	------	.898	------	------	.961	------	------	.965	------	.950
940	------	------	.946	------	------	.897	------	------	.960	------	------	.964	------	.952
950	.922	------	.942	.909	------	.895	.901	------	.960	.896	------	.964	.884	.953
960	------	------	.937	------	------	.891	------	------	.959	------	------	.963	------	.954
970	------	------	.936	------	------	.890	------	------	.959	------	------	.962	------	.956
980	------	------	.938	------	------	.890	------	------	.959	------	------	.962	------	.957
990	------	------	.940	------	------	.890	------	------	.959	------	------	.962	------	.958
1000	.922	------	.941	.909	------	.890	.902	------	.959	.896	------	.962	.885	.960

Values of T_i for 4 mm are not tabulated above 400 or 450 mμ where the values exceed 0.995. As there is uncertainty of 0.001 or 0.002 in such values, it would be preferable, where the absorption is so slight, to compute the values of T_i for 4 mm (or for any other small thickness) from the values of T_i for 100 mm than to measure them directly.

The slight error in T_i resulting from the multiple reflections through different thicknesses of glass [8] is ignored in these results. For either high or low transmittance the error is of the order of 0.001. In view of the equal or greater uncertainties indicated above, computation of such corrections was considered unwarranted.

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4. References

[1] A. C. Hardy, History of the design of the recording spectrophotometer, J. Opt. Soc. Am. **28,** 360 (1938).

[2] J. L. Michaelson, Construction of the General Electric recording spectrophotometer, J. Opt. Soc. Am. **28,** 365 (1938).

[3] K. S. Gibson and H. J. Keegan, Calibration and operation of the General Electric recording spectrophotometer of the National Bureau of Standards, J. Opt. Soc. Am. **28,** 372 (1938).

[4] H. J. McNicholas, Equipment for routine spectral transmission and reflection measurements, BS J. Research **1,** 793 (1928) RP30.

[5] H. H. Cary and A. O. Beckman, A quartz photoelectric spectrophotometer, J. Opt. Soc. Am. **31,** 682 (1941).

[6] K. S. Gibson and M. M. Balcom, Transmission measurements on the Beckman quarts spectrophotometer, J. Research NBS **38,** 601 (1947) RP1798; also J. Opt. Soc. Am. **37,** 593 (1947).

[7] K. S. Gibson, Spectrophotometry, NBS Circular 484 (1949). See figures 29 and 30.

[8] T. Smith, Note on measurements of glass absorption, Proc. Phys. Soc. **58,** 473 (1946).

[9] K. S. Gibson, Direct-reading photoelectric measurement of spectral transmission, J. Opt. Soc. Am. and Rev. Sci. Instr. **7,** 693 (1923).

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