Refractive Index of Cesium Bromide for Ultraviolet, Visible, and Infrared Wavelengths

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The index of refraction of cesium bromide was measured at 37 wavelengths from 0.365 to 39.22 microns. The minimum deviation method was used, and the entire range was covered with a single instrument. The index changes approximately two units in the first decimal place over the wavelength range. The dispersion compares favorably with that of KRS–5 beyond 20 microns; and when the effects of inhomogeneity and reflection losses are considered, the resolving power of CsBr is probably better.

1. Introduction

Large crystals of cesium bromide of reasonably good optical quality have recently been successfully grown, providing a new material for infrared studies in the range beyond the 25-micron (μ) limit of KBr and out to about 40 μ, wherein lie many of the fundamental modes of vibrations of molecules. A mixed crystal of thallium bromide-iodide, known as KRS–5, was previously the only material available for use in this region.

In order to utilize fully any dispersive medium, spectroscopists must have a knowledge of the indices of refraction and dispersion for all wavelengths transmitted by the medium. Such data are also useful to physicists for evaluating theoretical dispersion equations and for studying the forces between the constituents of the crystal. The alkali-halides, having the cubic structure, are favorable subjects for such studies.

The authors are fortunate in having access to two samples of cesium bromide whose faces are about 4 sq in. One of these samples was grown by the Harshaw Chemical Co. of Cleveland, Ohio, and the other was grown at the National Bureau of Standards by Francis P. Phelps of the Mineral Products Division. The refractive indices of each of these samples were determined for 37 wavelengths ranging from 0.365 to 39.22 μ, the latter being near the infrared transmission limit of cesium bromide.

2. Instrument

The instrument (fig. 1) used in these experiments is a Gaertner precision spectrometer adapted for measuring indices of refraction for nonvisible radiation. The telescope and collimator objectives have been replaced by mirrors of the same focal length. The telescope eyepiece is replaced by a second, or exit, slit. The radiation is focussed on the exit slit by the telescope mirror, and the image of the slit or the prism face is formed on the detector by use of another mirror or a lens of KRS–5.

The infrared detectors employed are the lead sulfide photoconducting cell for the near ultraviolet, the visible, and the infrared to about 2.5 μ; and the Golay pneumatic detector beyond 2.5 μ to the limit of transmission of the window employed with this cell, which in this case is about 40 μ. The signal, chopped at the rate of 10 times a second, is amplified by a gated amplifier controlled by a photocell in the chopper unit. The amplified signal is recorded on a recording potentiometer.

The spectrometer is equipped with a set of gears, also shown in figure 1, in such ratio that when engaged the prism table rotates at one-half the rotation rate of the telescope and microscope ring. The gears may be readily engaged at will, and they maintain a condition of minimum deviation once it has been established for any line. The method of minimum deviation provides desirable features of high accuracy and simplicity of calculation as compared, for example, with methods where a constant angle of incidence is employed.
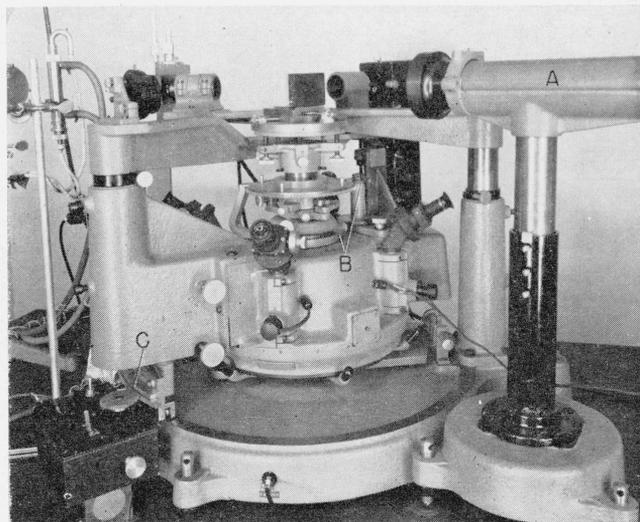

FIGURE 1.   *Gaertner precision spectrometer.*

A, Auxiliary telescope is used to level and center the prism; B, gear system is used to maintain minimum deviation; C, driving mechanism for scanning. Entrance slit is partially hidden by telescope mirror directly above driving mechanism. Collimator mirror is hidden by the auxiliary telescope. Exit slit is seen between prism and auxilary telescope.

3. Procedure

To begin a series of measurements the refracting angle of the prism and the deviation angles at minimum deviation for several visible lines are measured on a Watts precision spectrometer by the usual methods and described in a previous paper [1].[1] Index of refraction values accurate to $\pm 1 \times 10^{-5}$ are easily attainable by this method [2]. Then an auxiliary telescope, figure 1, is used to level and center the prism with respect to the optical axis of the mirror system on the Gaertner spectrometer. Another auxiliary telescope is used to set a given line, usually the 0.6438 μ line of cadmium, at its minimum deviation position. The table is now clamped in this position. The mirror, acting as the telescope objective, is brought into the beam so that an image of this line falls on the exit slit, causing a deflection of the potentiometer pen. The scale position corresponding to maximum deflection of the pen is observed with the microscopes. This is repeated several times, and the microscope is set at the average of these readings and clamped. The gears are now engaged and the telescope and prism-table clamps released. A condition of minimum deviation will then prevail for other spectral lines.

Unfortunately, with this mirror system, one cannot directly observe the position of an undeviated beam or measure twice the minimum deviation, as is feasible in visual measurements. It is therefore necessary to compute the average reading for an undeviated beam by applying a few deviations, as observed visually on the Watts instrument, to the scale readings on the Gaertner spectrometer for the corresponding lines of the visual spectrum as determined by the use of the detector.

The spectra are now scanned by using a driving mechanism consisting of a synchronous motor and a gear segment attached to the telescope assembly. The spectra used are the emission lines of mercury and cadmium for the ultraviolet, visible, and infrared to about 2.3 μ, the absorption bands of polystyrene from approximately 3 to 15 μ [3], 1,2,4-trichlorobenzene from approximately 15 to 20 μ [3], and water-vapor bands for the rest of the range [4]. The bands of carbon dioxide at 4.2 and 14.9 μ are also used. The scanning serves to identify and locate the approximate scale position corresponding to these lines and bands. The actual measurements are made by the method used to determine precisely the scale position for the 0.6438 μ line. For some broad bands and for the region of low intensity, scale positions may be read from the graphs. This is done by using a relay to mark the graph at intervals varying from 1 min of arc to 15 sec of arc, depending on the speed at which the telescope is being driven.

4. Data

The refractive indices of the two crystals of cesium bromide were measured at room temperatures near 24° and 31° C. The temperature was determined

by placing a calibrated mercury thermometer directly over the sample and observing the temperature at 1-min intervals with a telescope and averaging. This procedure was repeated several times each day, and the variations between these averages did not exceed ± 0.2 deg C. Indices were determined for 37 wavelengths, ranging from 0.365 to 39.22 μ, at each temperature. Temperature coefficients of refractive index were determined, and the indices at 24° and 31° C were adjusted to 27° and averaged for each sample. These average values were again averaged, giving the average for both samples. The average temperature coefficient for both samples is $7.9 \times 10^{-5}/\text{deg C}$.

Table 1 lists the indices at this temperature as obtained from the observations and as computed by means of eq 1.

$$n^2 = a^2 - k\lambda^2 + \frac{p}{\lambda^2} + \frac{M}{\lambda^2 - L^2} + \frac{m}{\lambda^2 - l^2}, \qquad (1)$$

where

λ = wavelength, microns	$M = 41110.49$
$a^2 = 5.640752$	$L^2 = (119.96)^2 = 14390.4$
$k = 0.000003338$	$m = 0.0290764$
$p = 0.0018612$	$l^2 = (0.15800)^2 = 0.024964.$

Although this equation has 7 constants, only 5 of them were determined by means of a simultaneous solution. The constants appearing in the denom-

TABLE 1. *Observed and computed data on index of refraction of CsBr (27° C)*

Wavelength (microns)	Observed index, n_0	Computed index, n_c	$(n_0 - n_c)$
0.365015	1.75118	1.75113	$+5 \times 10^5$
.366288	1.75050	1.75045	+5
.404656	1.73344	1.73343	+1
.435835	1.72333	1.72335	−2
.546074	1.70189	1.70193	−4
.643847	1.69202	1.69204	−2
1.01398	1.67766	1.67766	0
1.12866	1.67584	1.67584	0
1.52952	1.67237	1.67238	−1
1.7011	1.67158	1.67157	+1
3.3610	1.66866	1.66866	0
4.258	1.66794	1.66793	+1
6.465	1.66587	1.66620	−33
9.724	1.66283	1.66285	−2
11.035	1.66118	1.66115	+3
14.29	1.65594	1.65599	−5
14.98	1.65474	1.65472	+2
15.48	1.65375	1.65375	0
17.40	1.64967	1.64974	−7
18.16	1.64795	1.64801	−6
20.57	1.64184	1.64197	−13
21.80	1.63846	1.63856	−10
22.76	1.63565	1.63573	−8
23.86	1.63234	1.63231	+3
25.16	1.62817	1.62802	+15
25.97	1.62521	1.62520	+1
26.63	1.62284	1.62282	+2
29.81	1.61034	1.61028	+6
30.54	1.60749	1.60713	+36
30.91	1.60591	1.60550	+41
31.70	1.60198	1.60192	+6
33.00	1.59584	1.59576	+8
34.48	1.58835	1.58831	+4
35.45	1.58284	1.58317	−33
35.90	1.58069	1.58071	−2
37.52	1.57183	1.57147	+36
39.22	1.55990	1.56106	−116

inators of two terms represent the infrared and ultraviolet absorption bands. The ultraviolet term, l^2, was determined by taking a weighted mean of several measured bands. The infrared term, L^2, is an estimate based on the measured and computed values of the infrared absorption bands of cesium chloride and is probably low.

Some obvious anomalies occur in the residuals, for instance, at wavelengths 6.465 and 35.45 μ. It is known that the first of these bands consists of several unresolved bands, indicating that the anomalous residual may be due to an inaccurate value for the wavelength. A value of 6.695 μ arrived at by taking a differently weighted average gives a more consistent value of n. The bands at 35.45 and 39.22 μ are quite broad, causing considerable difficulty in locating their minima.

Index of refraction as a function of wavelength is plotted in figure 2. This graph is particularly interesting as it shows the smoothness that results from taking data over a large range on a single instrument for a single sample and under the same conditions. It is hoped that consistent data such as these will lend themselves more readily to theoretical analysis. The total change in index amounts to approximately 2 units in the first decimal place over the wavelength range considered. The values plotted are the indices at 27° C. Differences between samples are small.
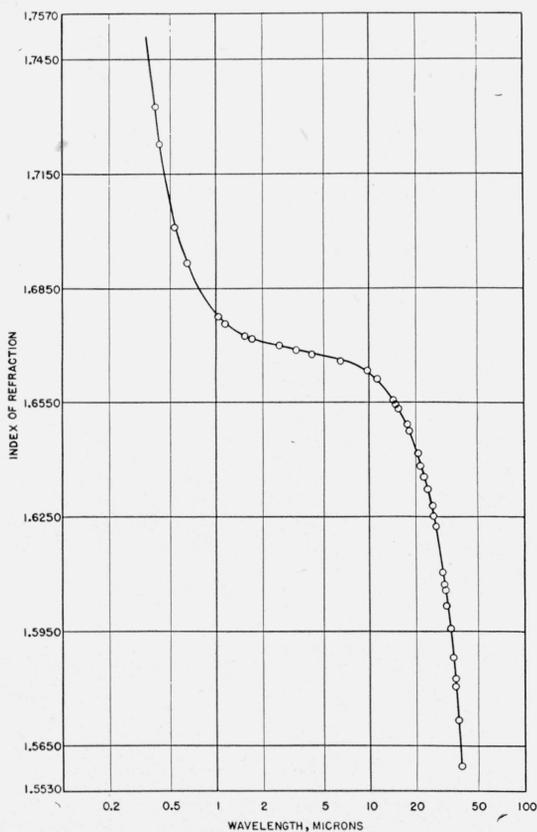
The index values of the Phelps crystal are lower by several units in the fifth decimal than corresponding values for the Harshaw crystal. The only prior data available are 3 values in the visible spectral region given by Sprockoff [5] to only 4 decimal places at an unspecified temperature.

The preliminary values published by the authors [6] for only one of the crystals are in substantial agreement with values published in this paper. There are some changes and additions beyond 30 μ, and in many cases another significant figure has been added.

Equation (1) has been used for computing values of $n-1$ for cesium bromide that are listed in table 2. They are considered as the best values obtainable from the measurements here described and are probably accurate to within ± 1 or 2×10^{-5}, except for wavelengths longer than about 30 μ.

The dispersion $\Delta n/\Delta \lambda$ of CsBr is shown in figure 3. Both abscissa and ordinate are logarithmically graduated. The dispersion in the far infrared increases but remains less than in the visible region by a factor of 10. The values of $\Delta n/\Delta \lambda$ are plotted at the midpoint of the $\Delta \lambda$ increment.

Values for the dispersion of KBr and KRS–5 [7, 8] were also computed at various wavelengths and plotted for comparison purposes. We see that KRS–5 has a higher dispersion than CsBr throughout the spectral range considered. KBr has a higher dispersion than either from 10 to 25 μ, where it becomes opaque. This result would lead to the conclusion that KRS–5 is better than CsBr as a dispersive material, if the effects of its optical inhomogeneity and larger index could be ignored.
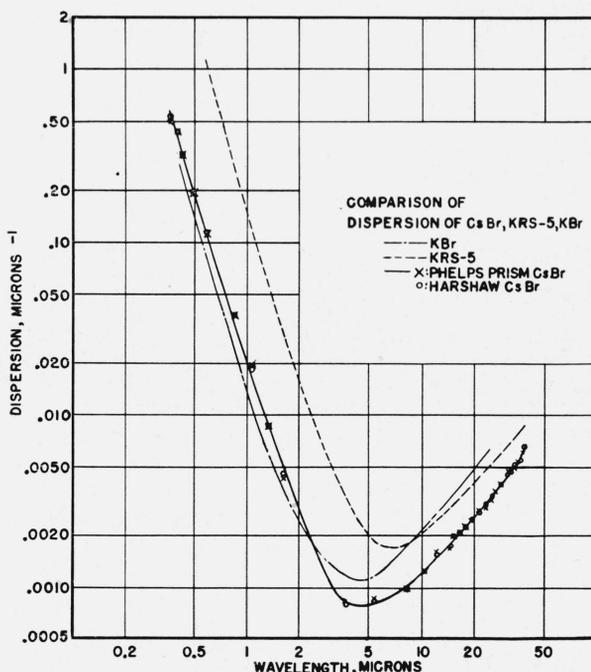

FIGURE 2. *Index of refraction of* CsBr *as a function of wavelength.*

Wavelength scale is logarithmically graduated.

FIGURE 3. *Dispersion as a function of wavelength.*

Both abscissa and ordinate are logarithmically graduated.

TABLE 2. *Refractivity, $(n-1) \times 10^5$, of CsBr at 27° C*

This table gives the average refractivity of two samples of CsBr, one grown at the Harshaw Chemical Co. and one grown at the National Bureau of Standards.

Wavelength	Refractivity at wavelength (microns)—									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	------	------	------	------	73,519	70,896	69,583	68,825	68,345	68,022
1	67,793	67,624	67,496	67,397	67,318	67,254	67,201	67,157	67,120	67,088
2	67,061	67,036	67,015	66,996	66,979	66,963	66,948	66,935	66,923	66,911
3	66,901	66,890	66,881	66,871	66,862	66,853	66,845	66,837	66,829	66,821
4	66,813	66,805	66,798	66,790	66,782	66,775	66,767	66,760	66,752	66,745
5	66,737	66,730	66,722	66,715	66,707	66,699	66,691	66,683	66,675	66,667
6	66,659	66,651	66,643	66,634	66,626	66,617	66,609	66,600	66,591	66,582
7	66,573	66,564	66,555	66,545	66,536	66,526	66,517	66,507	66,497	66,487
8	66,477	66,467	66,457	66,446	66,436	66,425	66,414	66,403	66,392	66,381
9	66,370	66,359	66,347	66,335	66,324	66,312	66,300	66,288	66,276	66,263
10	66,251	66,238	66,226	66,213	66,200	66,187	66,174	66,160	66,147	66,134
11	66,120	66,106	66,092	66,078	66,064	66,050	66,035	66,021	66,006	65,991
12	65,976	65,961	65,946	65,931	65,915	65,900	65,884	65,868	65,852	65,836
13	65,820	65,804	65,787	65,770	65,754	65,737	65,720	65,703	65,685	65,668
14	65,651	65,633	65,615	65,597	65,579	65,561	65,543	65,524	65,505	65,487
15	65,468	65,449	65,430	65,411	65,391	65,372	65,352	65,332	65,312	65,292
16	65,272	65,251	65,231	65,210	65,190	65,169	65,148	65,126	65,105	65,084
17	65,062	65,040	65,018	64,996	64,974	64,952	64,929	64,907	64,884	64,861
18	64,838	64,815	64,792	64,768	64,745	64,721	64,697	64,673	64,649	64,625
19	64,600	64,576	64,551	64,526	64,501	64,476	64,450	64,425	64,399	64,374
20	64,348	64,322	64,295	64,269	64,243	64,216	64,189	64,162	64,135	64,108
21	64,080	64,053	64,025	63,997	63,969	63,941	63,913	63,884	63,856	63,827
22	63,798	63,769	63,739	63,710	63,681	63,651	63,621	63,591	63,561	63,530
23	63,500	63,469	63,438	63,407	63,376	63,345	63,313	63,282	63,250	63,218
24	63,186	63,154	63,121	63,089	63,056	63,023	62,990	62,957	62,923	62,890
25	62,856	62,822	62,788	62,754	62,719	62,685	62,650	62,615	62,580	62,545
26	62,509	62,474	62,438	62,402	62,366	62,330	62,293	62,256	62,220	62,183
27	62,146	62,108	62,071	62,033	61,995	61,957	61,919	61,881	61,842	61,803
28	61,764	61,725	61,686	61,646	61,607	61,567	61,527	61,487	61,446	61,406
29	61,365	61,324	61,283	61,242	61,200	61,158	61,116	61,074	61,032	60,990
30	60,947	60,904	60,861	60,818	60,775	60,731	60,687	60,643	60,599	60,555
31	60,510	60,465	60,420	60,375	60,330	60,284	60,238	60,192	60,146	60,100
32	60,053	60,007	59,960	59,912	59,865	59,817	59,770	59,722	59,673	59,625
33	59,576	59,527	59,478	59,429	59,380	59,330	59,280	59,230	59,179	59,129
34	59,078	59,027	58,976	58,924	58,873	58,821	58,769	58,717	58,664	58,611
35	58,558	58,505	58,452	58,398	58,344	58,290	58,236	58,181	58,126	58,071
36	58,016	57,960	57,905	57,849	57,792	57,736	57,679	57,622	57,565	57,508
37	57,450	57,392	57,334	57,276	57,217	57,158	57,099	57,040	56,980	56,920
38	56,860	56,800	56,739	56,678	56,617	56,556	56,494	56,432	56,370	56,308
39	56,245	56,182	56,119	------	------	------	------	------	------	------

The results of practical tests on these materials [9] indicate that CcBr prisms gives better resolving power. This better resolving power could, largely, be due to better optical homogeneity of CsBr. The effects of higher index of KRS–5 also deserve some consideration because there are practical limits to the size of the crystals grown.

5. References

[1] R. J. Spindler and W. S. Rodney, J. Research NBS **49**, 253 (1952) RP2361.
[2] L. W. Tilton, BS J. Research **2**, 909 (1929) RP64.
[3] E. K. Plyler and C. Wilbur Peters, J. Research NBS **45**, 6 (1950) RP2159.
[4] Randal, Dennison, Ginsburg, and Weber, Phys. Rev. **52**, 160 (1937).
[5] M. Sprockhoff, Neues Jahr Mineral Geol., Beilage Bd. **18**, 117–154 (1904).
[6] W. S. Rodney and R. J. Spindler, J. Opt. Soc. Am. **42**, 431 (1952).
[7] R. E. Stephens, Earle K. Plyler, W. S. Rodney, and R. J. Spindler, J. Opt. Soc. Am. **43**, 110 (1953).
[8] L. W. Tilton, E. K. Plyler, and R. E. Stephens, J. Research NBS **43**, 81 (1949) RP2008.
[9] E. K. Plyler and Nicola Acquista, J. Research NBS **49**, 61 (1952) RP2343.

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