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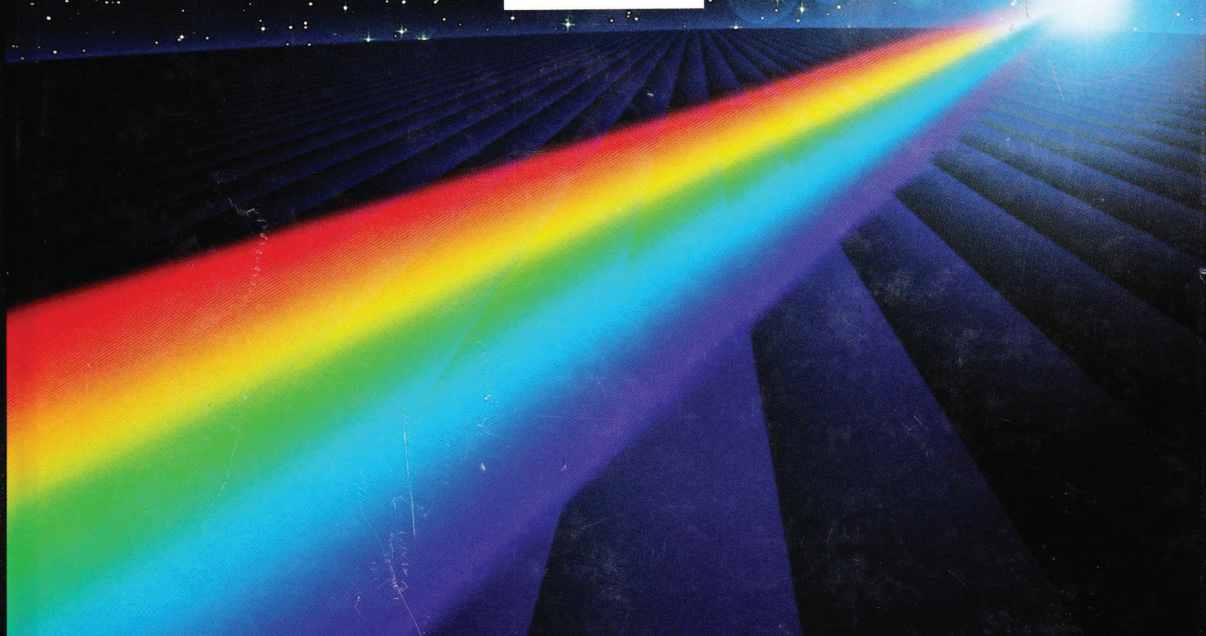
# HANDBOOK OF OPTICS

## DEVICES, MEASUREMENTS, & PROPERTIES

• SECOND EDITION •

VOLUME II



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**McGRAW-HILL, INC.**
New York San Francisco Washington, D.C. Auckland Bogotá
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

**Library of Congress Cataloging-in-Publication Data**

Handbook of optics / sponsored by the Optical Society of America ;
Michael Bass, editor in chief. — 2nd ed.
p. cm.
Includes bibliographical references and index.
Contents: — 2. Devices, measurement, and properties.
ISBN 0-07-047974-7
1. Optics—Handbooks, manuals, etc. 2. Optical instruments—
Handbooks, manuals, etc. I. Bass, Michael. II. Optical Society
of America.
QC369.H35 1995
535—dc20 94-19339
CIP



2 3 4 5 6 7 8 9 DOC/DOC 9 0 9 8 7 6 5

ISBN 0-07-047974-7

The sponsoring editor for this book was Stephen S. Chapman, the editing supervisor was Paul R. Sobel, and the production supervisor was Suzanne W. Babeuf. It was set in Times Roman by The Universities Press (Belfast) Ltd.

Printed and bound by R.R. Donnelly & Sons Company.

This book is printed on acid-free paper.

the total market for a given resin formulation, and since these materials are sold at prices ranging from less than two dollars to a few dollars per pound, the market opportunity represented by optical applications seems minuscule to most polymer vendors.

## 34.5 OPTICAL PROPERTIES

### Variations

It is only a fortuitous accident that some of the polymers exhibit useful optical behavior, since most all of these materials were originally developed for other end uses. The possible exceptions are the materials used for eyeglass applications (poly-diallylglycol), and the materials for optical information storage (specially formulated polycarbonate). Citation of optical properties for any polymeric material must be done with some caution and qualification, as different melt flow grades (having different molecular weight distribution) may exhibit slightly different refractive index properties. Additives to regulate lubricity, color, and so on can also produce subtle alterations in the spectral transmission properties.

### Spectral Transmission

In general, the carbon-based optical polymers are visible-wavelength materials, absorbing fairly strongly in the ultraviolet and throughout the infrared.[12,13,14] This is not readily apparent from the absorption spectra published in numerous references, though. Such data are normally generated by spectroscopists for the purpose of identifying chemical structure, and are representative of very thin samples. One can easily develop the impression from this information that the polymers transmit well over a wide spectral range. Parenthetically, most of these polymers, while they have been characterized in the laboratory, are not commercially available. What is needed for optical design purposes is transmission data (for available polymers) taken from samples having sufficient thickness to be useful for imaging purposes.

Some specially formulated variants of poly-methylmethacrylate have useful transmission down to 300 nm.[15] Most optical polymers, however, begin to absorb in the blue portion of the visible spectrum, and have additional absorption regions at about 900 nm, 1150 nm, 1350 nm, finally becoming totally opaque at about 2100 nm. The chemical structure which results in these absorption regions is common to almost all carbon-based polymers, thus the internal transmittance characteristics of these materials are remarkably similar, with the possible exception of the blue and near-UV regions. A scant few polymers do exhibit some spotty narrowband transmission leakage in the far-infrared portion of the spectrum, but in thicknesses suitable only for use in filter applications.

### Refractive Index

The chemistry of carbon-based polymers is markedly different from that of silicate glasses and inorganic crystals in common use as optical materials. Consequently, the refractive properties differ significantly. In general, the refractive indices are lower, extending to about 1.73 on the high end, and down to a lower limit of about 1.3. In practice, those materials which are readily available for purchase exhibit a more limited index range—from about 1.42 to 1.65. The Abbe values for these materials vary considerably, though, from about 100 to something less than 20. Refractive index data for a few of these polymers, compiled from a number of sources, is displayed in Table 2. In the chart,

**TABLE 2** Refractive Index of Some Optical Polymers

| Line ID | Wavl., nm | PMMA | P-styr | P-carb | SAN | PEI | PCHMA |
|---|---|---|---|---|---|---|---|
| | 1014.0 | 1.4831 | 1.5726 | 1.5672 | 1.5519 | | |
| s | 852.1 | 1.4850 | 1.5762 | 1.5710 | 1.5551 | | |
| r | 706.5 | 1.4878 | 1.5820 | 1.5768 | 1.5601 | | |
| C | 656.3 | 1.4892 | 1.5849 | 1.5799 | 1.5627 | | 1.502 |
| C′ | 643.9 | 1.4896 | 1.5858 | 1.5807 | 1.5634 | 1.651 | |
| D | 589.3 | 1.4917 | 1.5903 | 1.5853 | 1.5673 | | |
| d | 587.6 | 1.4918 | 1.5905 | 1.5855 | 1.5674 | 1.660 | 1.505 |
| e | 546.1 | 1.4938 | 1.5950 | 1.5901 | 1.5713 | 1.668 | |
| F | 486.1 | 1.4978 | 1.6041 | 1.5994 | 1.5790 | | 1.511 |
| F′ | 480.0 | 1.4983 | 1.6052 | 1.6007 | 1.5800 | 1.687 | |
| g | 435.8 | 1.5026 | 1.6154 | 1.6115 | 1.5886 | | |
| h | 404.7 | 1.5066 | 1.6253 | 1.6224 | 1.5971 | | |
| i | 365.0 | 1.5136 | 1.6431 | 1.6432 | 1.6125 | | |
| Abbe number | | 57.4 | 30.9 | 29.9 | 34.8 | 18.3 | 56.1 |
| $dn/dT \times 10^{-4}/°C$ | | −1.05 | −1.4 | −1.07 | −1.1 | | |

PMMA signifies polymethylmethacrylate; P = styr, polystyrene; p = care, polycarbonate; san, styrene acrylonitrile; PEI, polyetherimide; PCHMA, polycyclohexylmethacrylate. The thermo-optic coefficients at room temperature (change in refractive index with temperature) are also listed. Note that these materials, unlike most glasses, experience a reduction in refractive index with increasing temperature. Figure 1, a simplified rendition

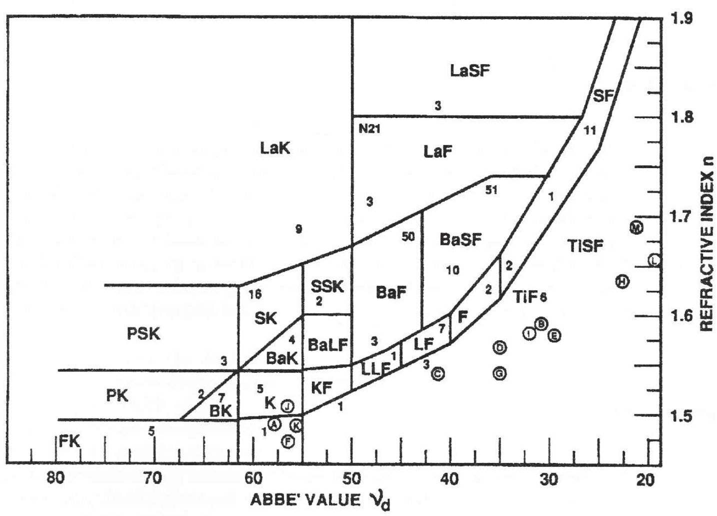


**FIGURE 1** Optical glasses and polymers: (*a*) polymethylmethacrylate; (*b*) polystyrene; (*c*) NAS; (*d*) styrene acrylonitrile; (*e*) polycarbonate; (*f*) polymethyl pentene; (*g*) acrylonitrile-butadiene styrene (ABS); (*h*) polysulfone; (*i*) polystyrene co-maleic anhydride; (*j*) polycyclo-hexylmethacrylate (PCHMA); (*k*) polyallyl diglycol carbonte; (*l*) polyetherimide (PEI); (*m*) polyvinyl naphthalene.

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