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Standard Guide for
Choosing a Method for Determining the Index of Refraction and Dispersion of Glass[1]

This standard is issued under the fixed designation C1648; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide identifies and describes seven test methods for measuring the index of refraction of glass, with comments relevant to their uses such that an appropriate choice of method can be made. Four additional methods are mentioned by name, and brief descriptive information is given in Annex A1. The choice of a test method will depend upon the accuracy required, the nature of the test specimen that can be provided, the instrumentation available, and (perhaps) the time required for, or the cost of, the analysis. Refractive index is a function of the wavelength of light; therefore, its measurement is made with narrow-bandwidth light. Dispersion is the physical phenomenon of the variation of refractive index with wavelength. The nature of the test-specimen refers to its size, form, and quality of finish, as described in each of the methods herein. The test methods described are mostly for the visible range of wavelengths (approximately 400 to 780μm); however, some methods can be extended to the ultraviolet and near infrared, using radiation detectors other than the human eye.

1.1.1 List of test methods included in this guide:

1.1.1.1 Becke line (method of central illumination),

1.1.1.2 Apparent depth of microscope focus (the method of the Duc de Chaulnes),

1.1.1.3 Critical Angle Refractometers (Abbe type and Pulfrich type),

1.1.1.4 Metricon[2] system,

1.1.1.5 Vee-block refractometers,

1.1.1.6 Prism spectrometer, and

1.1.1.7 Specular reflectance.

1.1.2 Test methods presented by name only (see Annex A1):

1.1.2.1 Immersion refractometers,

1.1.2.2 Interferometry,

1.1.2.3 Ellipsometry, and

1.1.2.4 Method of oblique illumination.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 **Warning**—Refractive index liquids are used in several of the following test methods. Cleaning with organic liquid solvents also is specified. Degrees of hazard associated with the use of these materials vary with the chemical nature, volatility, and quantity used. See manufacturer's literature and general information on hazardous chemicals.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E167 Practice for Goniophotometry of Objects and Materials (Withdrawn 2005)[4]

E456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 *Definitions:*

3.1.1 *dispersion, n*—the physical phenomenon of the variation of refractive index with wavelength.

3.1.1.1 *Discussion*—The term, "dispersion," is commonly used in lieu of the more complete expression, "reciprocal relative partial dispersion." A dispersion-number can be defined to represent the refractive index as a function of wavelength over a selected wavelength-range; that is, it is a combined measure of both the amount that the index changes and the non-linearity of the index versus wavelength relationship.

3.1.2 *resolution, n—as expressed in power of 10*, a commonly used term used to express the accuracy of a test method in terms of the decimal place of the last reliably measured digit of the refractive index which is expressed as the negative power of 10. As an example, if the last reliably measured digit is in the fifth decimal place, the method would be designated a 10^{-5} method.

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[2] Metricon is a trademark of Metricon Corporation 12 North Main Street, P.O. Box 63, Pennington, New Jersey 08534.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

TABLE 1 Spectral Lines for Measurement of Refractive Index[A]

Fraunhofer Line	A'	C	C'	D	d	e	F	F'	g	G'	h
Element	K	H	Cd	Na	He	Hg	H	Cd	Hg	H	Hg
Wavelength Nanometers	786.2[B]	656.3[C]	643.8[D]	589.3	587.6	546.1	486.1	480.0[D]	435.8	434.0	404.7

[A] From Ref **(1)**.

[B] A later reference (identification not available) lists 789.9 nm for the potassium A' line, although referring to Ref **(1)**. The Handbook of Chemistry and Physics lists 789.9 nm as a very strong line, and it does not list a line at 786.2 nm at all.

[C] The wavelength of the corresponding deuterium line is 656.0 nm.

[D] The two cadmium lines have been recognized for refractometry since Ref **(1)** was published.

3.2 *Symbols:*

n = index of refraction

ν = Abbe-number; a representation of particular relative partial dispersions

ν_D = Abbe-number determined with spectral lines *D*, *C*, and *F*

ν_e = Abbe-number determined with spectral lines *e*, *C'*, and *F'*

D = the spectral emission line of the sodium doublet at nominally 589.3 nm (which is the mid-point of the doublet that has lines at 589.0 nm and 589.6 nm)

C = the spectral emission line of hydrogen at 656.3 nm

F = the spectral emission line of hydrogen at 486.1 nm

e = the spectral emission line of mercury at 546.1 nm

C' = the spectral emission line of cadmium at 643.8 nm

F' = the spectral emission line of cadmium at 480.0 nm

4. Significance and Use

4.1 *Measurement*—The refractive index at any wavelength of a piece of homogeneous glass is a function, primarily, of its composition, and secondarily, of its state of annealing. The index of a glass can be altered over a range of up to 1×10^{-4} (that is, 1 in the fourth decimal place) by the changing of an annealing schedule. This is a critical consideration for optical glasses, that is, glasses intended for use in high performance optical instruments where the required value of an index can be as exact as 1×10^{-6}. Compensation for minor variations of composition are made by controlled rates of annealing for such optical glasses; therefore, the ability to measure index to six decimal places can be a necessity; however, for most commercial and experimental glasses, standard annealing schedules appropriate to each are used to limit internal stress and less rigorous methods of test for refractive index are usually adequate. The refractive indices of glass ophthalmic lens pressings are held to 5×10^{-4} because the tools used for generating the figures of ophthalmic lenses are made to produce curvatures that are related to specific indices of refraction of the lens materials.

4.2 *Dispersion*—Dispersion-values aid optical designers in their selection of glasses (Note 1). Each relative partial dispersion-number is calculated for a particular set of three wavelengths, and several such numbers, representing different parts of the spectrum might be used when designing more complex optical systems. For most glasses, dispersion increases with increasing refractive index. For the purposes of this standard, it is sufficient to describe only two reciprocal relative partial dispersions that are commonly used for characterizing glasses. The longest established practice has been to cite the Abbe-number (or Abbe ν-value), calculated by:

$$\nu_D = (n_D - 1)/(n_F - n_C) \tag{1}$$

where ν_D is defined in 3.2 and n_D, n_F, and n_C are the indices of refraction at the emission lines defined in 3.2.

4.2.1 Some modern usage specifies the use of the mercury e-line, and the cadmium *C'* and *F'* lines. These three lines are obtained with a single spectral lamp.

$$\nu_e = (n_e - 1)/(n_{F'} - n_{C'}) \tag{2}$$

where ν_e is defined in 3.2 and n_e, $n_{F'}$, and $n_{C'}$ are the indices of refraction at the emission lines defined in 3.2.

4.2.2 A consequence of the defining equations (Eq 1 and 2) is that smaller ν-values correspond to larger dispersions. For ν-values accurate to 1 to 4 %, index measurements must be accurate to 1×10^{-4}; therefore, citing ν-values from less accurate test methods might not be useful.

NOTE 1—For lens-design, some computer ray-tracing programs use data directly from the tabulation of refractive indices over the full wavelength range of measurement.

NOTE 2—Because smaller ν-values represent larger physical dispersions, the term constringence is used in some texts instead of dispersion.

5. Precision, Bias, and Accuracy (see Terminology E456)

5.1 *Precision*—The precision of a method is affected by several of its aspects which vary among methods. One aspect is the ability of the operator to repeat a setting on the observed optical indicator that is characteristic of the method. Another aspect is the repeatability of the coincidence of the measurement scale of the instrument and the optical indicator (magnitude of dead-band or backlash); this, too, varies among methods. A third aspect is the repeatability of the operator's reading of the measurement scale. Usually, determinations for a single test specimen and for the reference piece should be repeated several times and the resulting scale readings averaged after discarding any obvious outliers.

5.2 *Bias (Systematic Error):*

5.2.1 *Absolute Methods*—Two of the test methods are absolute; the others are comparison methods. The absolute methods are the prism spectrometer and the apparent depth of microscope focus. These yield measures of refractive index of the specimen in air. In the case of the prism spectrometer, when used for determinations of 1×10^{-6}, correction to the index in vacuum (the intrinsic property of the material) can be calculated from the known index of air, given its temperature, pressure, and relative humidity. The accuracy of the apparent depth method is too poor for correction to vacuum to be meaningful. Bias of the prism spectrometer depends upon the accuracy of its divided circle. The bias of an index determination must not be greater than one-half of the least count of