NOTES
· AND ·
NEW TECHNIQUES

A CUBIC ZIRCONIA REFRACTOMETER

By C. S. Hurlbut, Jr.

With the development by C. D. West of practical high-refractive-index liquids, the major barrier to extending the range and durability of the refractometer has been the need for an isotropic substance with an index of refraction higher than that of the glass commonly used. On the basis of the author's experiments with a cubic zirconia refractometer, CZ–with its relatively low cost, high refractive index, and hardness–shows great promise for meeting this need.

Since the development of a direct-reading jeweler's refractometer by G. F. Herbert Smith (1907), numerous changes have been incorporated into the design of such instruments. However, the basic principle on which they operate remains the same: that is, the refractive index (R.I.) of the gemstone is determined by means of the stone's total reflection and critical angle. Light entering the instrument passes through a dense glass, impinges on the gemstone, and, at the critical angle, is totally reflected back through the glass. The dense, highly refractive glass may be in the form of a hemisphere, as in early models, or a hemicylinder or prism.The glass and the liquid that is interposed between it and the gemstone must both have a refractive index higher than that of the gemstone. Thus, these two items (but usually the liquid) set the upper limit to R.I. determinations.

The liquid most commonly used today has a refractive index of about 1.81. While glass continues to be the most common isotropic substance used, some refractometers have been constructed using diamond, sphalerite, and, most recently, strontium titanate and cubic zirconia (CZ) in place of glass. The ready availability, high refractive index, and hardness of cubic zirconia, together with other properties, suggest that it may be particularly well suited for use in the refractometer.

REFRACTOMETERS WITH HIGH REFRACTIVE INDEX READINGS

The two basic requirements for increasing the range of a refractometer are: (1) an isotropic substance with an index of refraction higher than that of available glass, and (2) a liquid with a refractive index above that of commonly encountered gemstones. When C. D. West (1936) developed practical liquids in the refractive index range of 1.78–2.06, one of these problems was overcome. But what highly refractive, transparent, isotropic mineral could be used in place of glass? B. W. Anderson and C. J. Payne (1939) found two answers to this question: diamond and sphalerite (blende).

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Diamond, with its optical purity, high hardness, and high refractive index (2.417) was a logical candidate, but its cost seemed prohibitive. Anderson and Payne felt that sphalerite, with a refractive index of 2.37, might serve in spite of its low hardness (3½–4). But clear crystals of sphalerite large enough to be cut into hemispheres were difficult to find. Employing the principle suggested by Wollaston in 1802, however, Anderson and Payne designed an instrument that uses a small, 60° *prism* of sphalerite. With it, and with West's liquids as contact media, they obtained refractive index readings of over 2.00. Using the same principle, they then had constructed a diamond refractometer with a 2.505-carat prism cut from 6.632 carats of rough. Because of an inadequate supply of sphalerite and the high cost of diamond, neither instrument has been widely used. However, Anderson and Payne's successful design pointed the way for the use of a glass prism in the Rayner refractometer in the early 1940s.

Forty years were to elapse before the development of another refractometer giving high refractive index readings: the Krüss refractometer (Read 1980). This instrument uses a prism of strontium titanate (R.I. 2.41, hardness 5½), and its scale is calibrated from 1.75 to 2.21. The contact "liquid" is a paste (R.I. 2.22) that must be heated to 120°F (49°C) to become fluid enough to serve as a contact medium. The prism, therefore, is heated to keep the paste liquid while a measurement is being made. The high dispersion of strontium titanate (0.190) requires that a sodium light source be used.

CUBIC ZIRCONIA REFRACTOMETER

When cubic zirconia (CZ) became available in 1976, it immediately suggested itself as a substance to replace highly refractive glass and extend the range of the refractometer. It has all the attributes of an ideal material: it is isotropic, has a high refractive index (2.16), has high hardness (8½), and is optically clear and chemically inert. In comparison, the glass in common use has a refractive index of about 1.90 and a hardness of less than 5, is yellow, and reacts with liquids of R.I. greater than 1.81.

The GIA refractometer is designed around a glass hemicylinder with a 0.5-inch (1.3 cm) radius and a refractive index of 1.90. The greater amount of material required to cut a hemicylinder rather than a prism is more than offset by the simplicity of the accompanying optical system. In 1978, a cubic zirconia hemicylinder of 1-cm radius was substituted for the glass of an old GIA Duplex refractometer, the instrument in which the mirror could be rotated to bring successively different parts of the scale into the field of view. The results were most encouraging and refractive indices as great as 2.08 could be determined. A year later, a similar CZ hemicylinder was adapted to the GIA Duplex II refractometer. This instrument, with its fixed mirror, functioned equally as well and gave very satisfactory readings as high as 2.06.

It must be noted that a change in either the refractive index or the radius of the hemicylinder necessitates a change in scale. The spacings between calibrated intervals increase with increasing radius but decrease with increasing refractive index. Since the scale must be at the focal line of the hemicylinder, it is positioned differently for each set of conditions. Thus the adaptation of the 1-cm-radius cubic zirconia to the GIA refractometers required not only a different scale but also changes in the radius of the scale holder and its position in the instrument. If a cubic zirconia hemicylinder were used with a focal length equal to that of the glass hemicylinder, however, these design changes could be avoided. This has been done in the most recent adaptation of CZ to the Duplex II refractometer. The scale is calibrated from 1.40 to 2.10, and readings can be obtained from 1.44 to 2.06.

CONTACT LIQUIDS

West's high-refractive-index liquids are mixtures of phosphorus, sulfur, and methylene iodide. They are difficult to use for they must be stored under water to prevent spontaneous combustion of the phosphorus. In common use today in mineralogical laboratories are liquids in the R.I. range of 1.82–2.00 developed by Meyrowitz and Larsen (1951) and manufactured by Cargille Laboratories (Cedar Grove, NJ). They have a yellow to brown color, are reasonably fluid, and are easy to handle. Cargille also supplies liquids in the R.I. range 2.01–2.10. These contain selenium, which gives them a darker color and higher viscosity, thus requiring that the gemstone be pressed into the liquid to exclude all but a thin film. After a determination has been made, the liquid remaining on the hemicylinder and the gemstone can be removed easily with methylene iodide. All the Cargille liquids with refractive indices above 1.82 must be used with caution for they are toxic and corrosive. However, the author has used them (usually 2.00) with the cubic zirconia refractometer for two years with no difficulties. Nevertheless, unless it is suspected that the gemstone in question has a refractive index above 1.80, the 1.81 liquid should be used.

ADVANTAGES AND DISADVANTAGES OF THE CZ REFRACTOMETER

The principal advantage of the CZ refractometer is that its range, 1.44–2.06, permits R.I. readings on all commonly encountered gems with the exception of diamond. Of gem simulants, only strontium titanate, rutile, and, of course, cubic zirconia itself are beyond its reach. Of these, only the R.I. of cubic zirconia lies within the range of the Krüss refractometer. In addition to broadening the refractometer's range, cubic zirconia has other desirable features. Because of its high hardness, CZ not only takes an excellent polish but retains it as well. As with any instrument, the cubic zirconia refractometer should be treated with respect; but because it is harder than most gemstones, CZ does not require the extreme caution necessary with glass or strontium titanate to avoid scratching. Moreover, because CZ is chemically inert, its polished surface does not become clouded even if a liquid is left on it a long time.

Among the disadvantages is the fact that the more highly refractive the hemicylinder of a refractometer is, the smaller the critical angle of a given R.I. reading will be. For example, the critical angle of the 1.70 reading using glass (R.I. 1.90) is 63.47°, and using CZ (R.I. 2.16) it is 51.91°. The scale used with a glass hemicylinder is thus more open than the scale of the same radius used with a CZ hemicylinder. This makes interpolation between calibrated marks, particularly in low R.I. readings, less accurate with CZ than with glass. Figure 1 compares the scale used with a glass hemicylinder in the Duplex II refractometer to the scale used when CZ replaces the glass.

Cubic zirconia has a dispersion of 0.060, less than one-third that of strontium titanate. Nevertheless, when CZ is used in a refractometer with white light, the dispersion gives rise to color fringes on the shadow edge. To obtain precise readings, a monochromatic light source, such as sodium light or the yellow light of the GIA utility lamp, should be used.

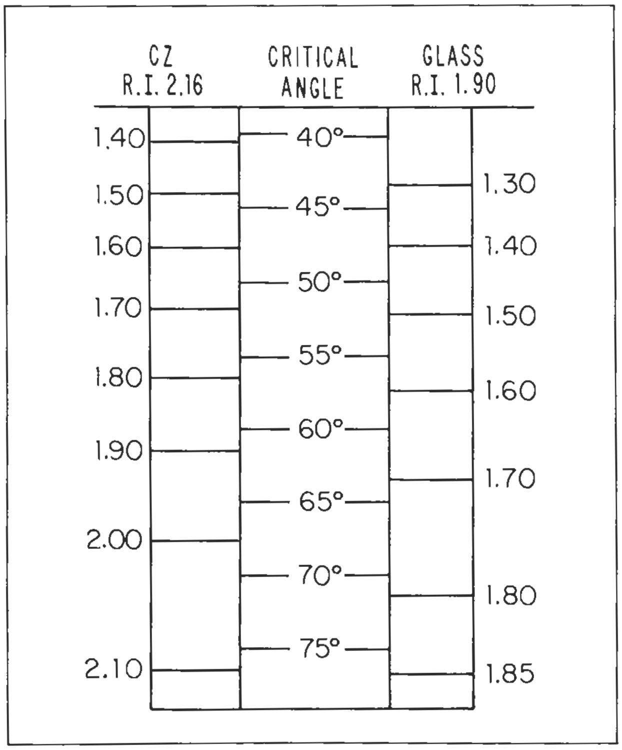

Figure 1. The higher the R.I. of the hemicylinder, the smaller the critical angle for a given reading. This is shown by a comparison of the scale of the GIA Duplex II refractometer (glass) with the scale used when CZ replaces the glass.

CONCLUSION

In summary, it appears that cubic zirconia shows considerable promise as a substance to replace glass and extend the range of the refractometer when used with high-refractive-index liquids. The hardness of CZ, in particular, provides for less damage of the optical finish and thus better readings and fewer repairs. The commercial feasibility of a CZ refractometer is currently under study.

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