Better refractometer results with the Bright Line technique

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Abstract: *Grazing incidence illumination of gemstones on the gemmologist's refractometer is now little used, but offers some significant advantages. The authors review the history of such use, give detailed explanations of how it is accomplished, and provide suggestions for its application to practical problems. There are three principal applications of grazing incidence illumination that can aid the gemmologist in practical discrimination between gems. One is in easier and better determination of the refractive index, or indices for birefringent stones. The second is in estimation of relative dispersion, and the third is in being able to observe polarized absorption spectra of gems.*

Keywords: *bright line technique; grazing incidence; polarized spectra; refractive index; refractometer*

Introduction

"It is a wise precaution in a doubtful case to study the effect when the stone is illuminated from above and not below."

G. F. Herbert Smith (1940, 31) in discussing use of the refractometer.

Many gemmologists may not be aware of the 'bright line' technique (Anderson, 1959) for obtaining refractive index (RI) readings with the common, critical angle refractometer or if aware, do not make use of it. This is not surprising due to the limited discussion of the technique in modern gemmological texts and the design of modern instruments, which can make it awkward to properly position the light source. The authors have taken a new look at the bright line method, which is an old variation of stone illumination, and have found that it has distinct advantages that are not currently utilized. This paper examines the technique and explains how to get more from your standard gemmological refractometer.

History

Most readers will be familiar with the workings of the standard gemmologist's critical angle refractometer, where light enters a dense glass prism from behind and below, and is reflected at the glass/gem interface, so that a shadow edge defines

 ISSN: xxxxxxxx

Figure 1: *A critical angle refractometer with the light shield removed and illuminated for grazing incidence using a torch.*

Figure 2: *Modern style refractometer with small LED light directed at grazing incidence.*

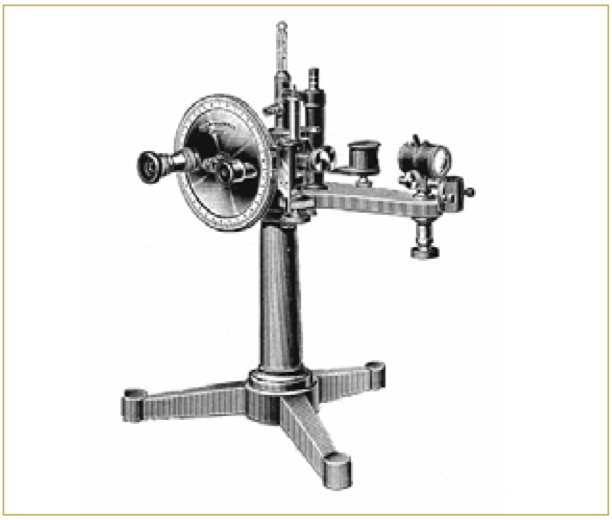

Figure 3: *Pulfrich refractometer, catalog scan taken from Arthur H. Thomas Co. Laboratory Apparatus and Reagents. Philadelphia (1921).*

the critical angle of reflection on a scale within the instrument. In using the bright line technique, the normal light port of the instrument is not used, and light enters the gem directly, so that some of the light is at grazing incidence to the glass/gem interface (*Figures 1* and *2*). With this technique, the light and dark parts of the refractometer scale are reversed, and importantly, a very bright spectrum is seen at the boundary, hence the term 'bright line'. The authors believe that the dramatic difference in the appearance of the readings between the two illumination methods, shown in *Figure 8*, has not been adequately noted in the literature. Traditional illumination with white light produces a diffuse shadow edge with hints of blue on the low side and red on the high side, but monochromatic light or a polarizing filter can make the reading more distinct. Grazing incidence produces one or two very bright, clear spectra that show the absorption spectrum of the gem. In pleochroic stones, the differing spectra can be observed side by side. This means of comparison is a valuable educational and identification tool. Anderson (1959, 1980) indicates that C. J. Payne used this method when it was difficult to obtain readings by traditional means. The light hood of the instrument was removed and Anderson (1959, 33) says that the light was "… so adjusted as to provide light at grazing incidence on the stone …". No other lighting details are given. He goes on to note that it may be necessary to rotate the stone to see the effect clearly, again without further explanation.

G. F. Herbert Smith, the father of the gemmologist's refractometer, was certainly aware of the utility of grazing incidence illumination, as shown by the quotation given at the introduction above. His 1913 text Gemstones does not include instruction on grazing incidence illumination, but by his 9th edition (1940) he includes it. Smith even shows a photograph of a Zeiss pocket refractometer designed for jewellers, that provides for illumination to either the glass hemisphere or the stone. A schematic drawing of this instrument is shown by Diniz Gonsalves (1949), clearly showing that an adjustable mirror is moved to provide either type of illumination and indicating that the grazing illumination is directed along the plane of the prism/gem interface. Diniz Gonsalves notes that it is one of the instruments most often used by the experts.

Critical angle refractometers used in other industries may use either type of illumination. The Pulfrich refractometer (*Figure 3*), designed for grazing incident light, provides much needed information on the use and limitations of such refractometers. A sketch of the principal optics of this instrument when measuring a solid is shown in *Figure 4*. In order to obtain good results, the material being tested must have an optically flat surface (for example, a polished facet surface) with an adjacent surface intersecting at a clean, 90-degree angle (Cooper, 1946). These two factors are critical in obtaining accurate results with the instrument. Light entering the solid at grazing incidence will exit into the dense glass at the critical angle. Light entering the solid at angles less than grazing will be refracted into the dense glass at angles less than the critical angle, lightening the lower part of the refractive index scale. In other respects it is the same as a gemmologist's refractometer. This explains the reversal of the dark and light parts of the scale.

The technique is mentioned in the 3rd edition of Webster's Gems (1975), but was dropped by the 5th edition (1994). Webster (1975) emphasizes that the technique is sometimes useful for those difficult cases when an RI cannot be obtained by normal means, adding that best results are for trap-cut [rectangular step-cut] gems, without explanation. He makes another comment regarding colour fringes seen when using white light for RI determinations in the traditional manner that will be important for our story later. Webster (1975, 627) says: "The sharpness or otherwise of the coloured fringe of the shadow edge in white light will give some idea of the dispersive power of the stone … and this may give useful confirmatory information." Bright line gives a strong indication of relative dispersion, not easily available by other testing methods. Hoover and Linton (2000, 2001), and Linton (2005) are the only authors we know of who have recently made much use of the 'bright line' technique, as noted in their papers on dispersion measurement. There are few other references to the technique in the current literature, other than Liddicoat (1989), who makes passing mention of it. Liddicoat states that the light source should be directed from above and behind the stone, not mentioning grazing incidence. We shall address this aspect later. Liddicoat (1989) notes the reversal of the bright and dim parts of the scale, and further states that the spectrum when using the bright line scheme is predominantly red, as opposed to the blue-green seen in normal operation.

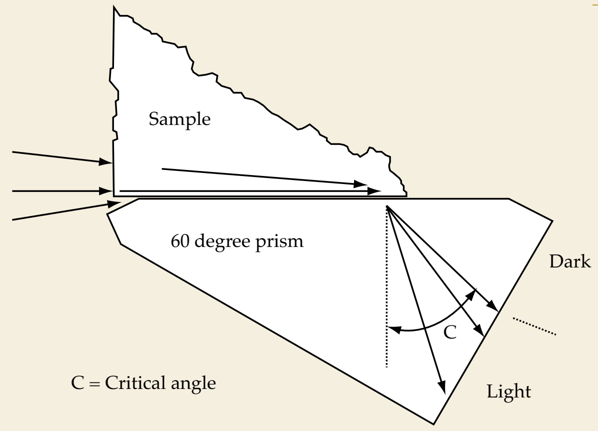

Figure 4: Sketch of the light path in the sample and prism of a Pulfrich refractometer when solids are measured.

The authors suspect that the principal reasons for the lack of interest in the 'bright line' technique are the lack of instruction in its use and the redesign of modern instruments, limiting the size of light source that can be used to obtain grazing incidence. Many gemmologists may have tried it but have become discouraged in their attempts to get proper lighting. Understanding the illumination requirements permits one to adjust the measuring technique so that, with practice, useful measurements can be quickly and easily obtained.

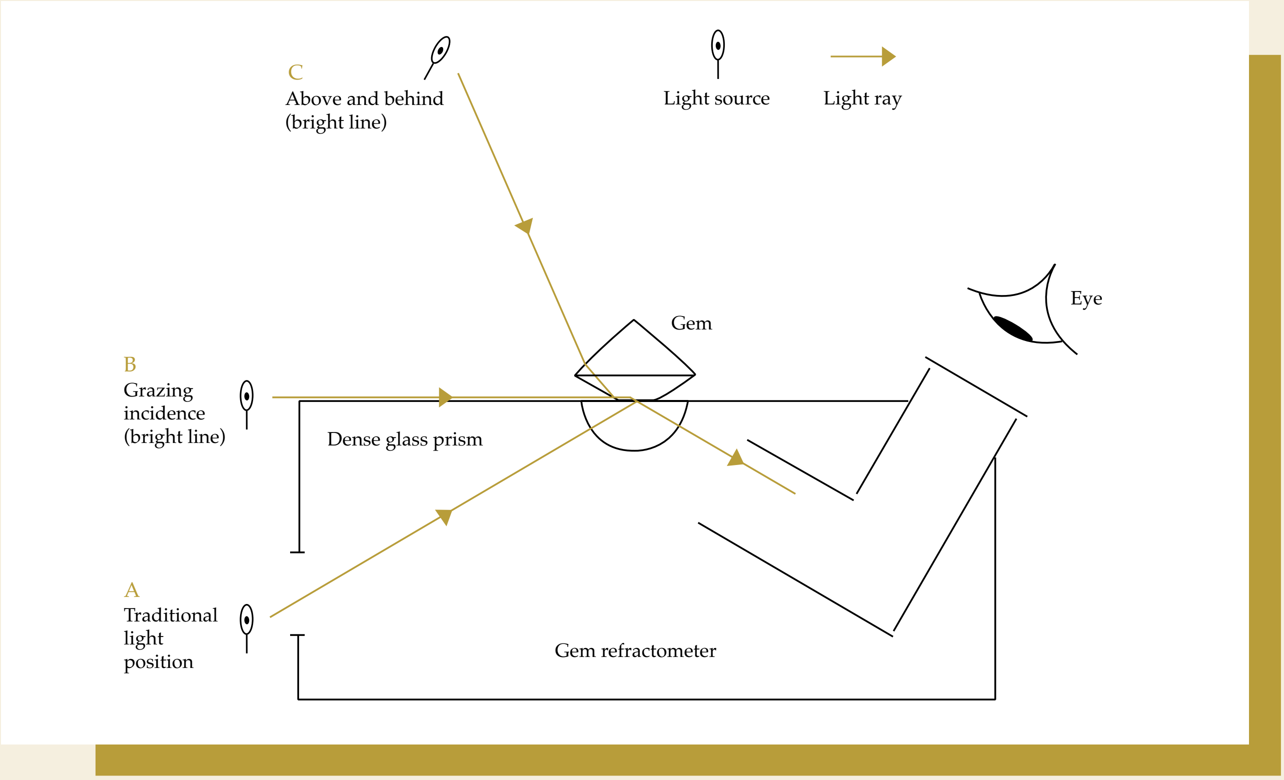

Figure 5: Diagram of a refractometer showing the positions a, b and c of a light source for traditional illumination, and for grazing incidence.

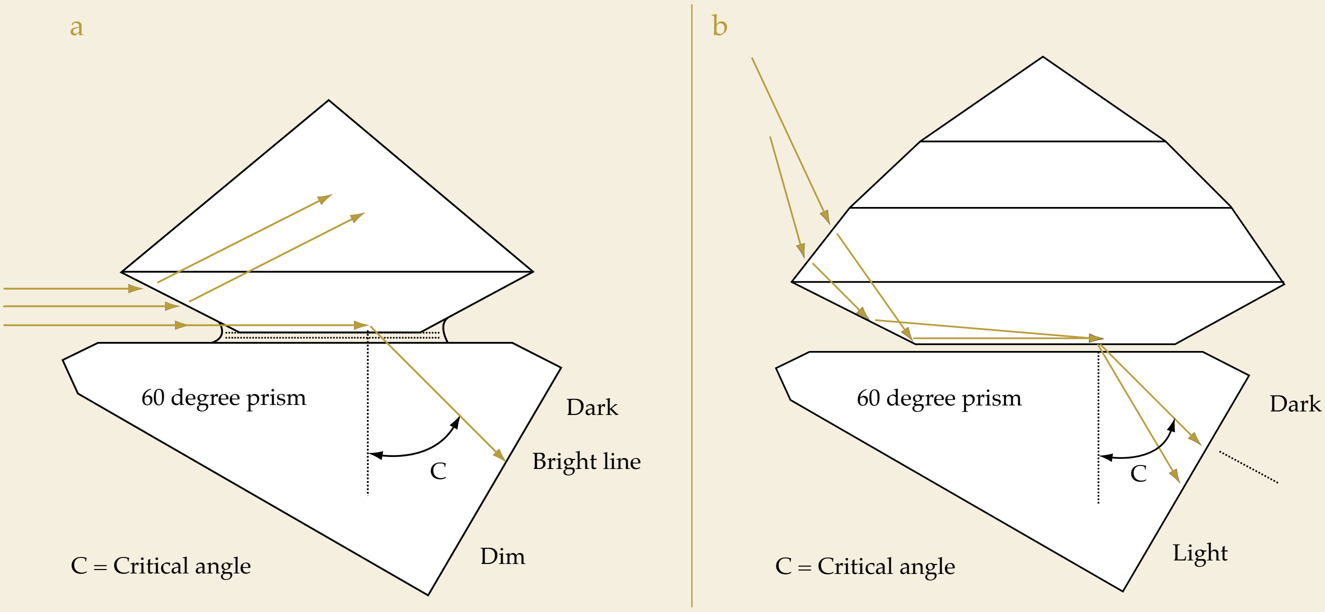

Figure 6: Sketch of the light paths in the prism of a gemmologist's refractometer when grazing incidence is used. In position (a) light is directed in the plane of the prism surface. In position (b), light is directed into a pavilion facet from above and behind.

Obtaining grazing illumination

The review above shows that for the bright line technique to be practised; a simple, reversible alteration to the standard gemmologists' refractometer is required to allow for grazing incidence mode (*Figure 1*). The light shield must be removed. Alternatively, a small light source can be used, as in *Figure 2*. We prefer to remove the cover. *Figure 5* shows a conventional refractometer with the dense glass prism, and a 90-degree telescope with scale for viewing the critical angle. Three possible positions (a, b and c) for the light source are also indicated. In this diagram the plane of the paper is the optical plane of the instrument. Position a is the traditional mode of illumination from below. Position b may be easier to obtain with the light shield removed (*Figures 1* and *2*). Position c will vary depending on the RI and facet angles of the stone under test.

Figure 6 shows details of two ways in which grazing light may be introduced into a gem placed table-down on a refractometer with the light shield removed. *Figure 6a* shows a light beam travelling at grazing incidence along the instrument path, and parallel to the gem/prism interface. The thickness of the contact fluid layer is exaggerated in this figure for clarity, and we only consider the facets adjacent to the table. This mimics the light path in the Pulfrich instrument, except that when using a faceted gem, having the adjacent facet at 90 degrees to the table is generally not possible, nor is it necessary. The adjacent facet must still be oriented at 90 degrees to the plane of the refractometer, as shown in the diagram (*Figure 7*). Within a small range, the light can also be oriented at 90 degrees to any facet adjacent to the table, as long as the light path still roughly follows the light path of the refractometer. This explains Anderson's statement that a stone may have to be rotated in order to obtain a reading, and Webster's comment on trap-cut stones being best. Certainly, rectangular step cut stones are best for learning the technique. Light directly entering crown facets will refract light away from grazing incidence (*Figure 6a*). Light entering the contact fluid film between the gemstone and the instrument table will be refracted at the critical angle of the fluid, or upward into the stone, and lost (not shown). It is only if there is a sufficient bead of contact liquid on the adjacent crown facet (*Figure 6a*) that light at grazing incidence will be able to enter the stone. Therefore, it is key that one should use sufficient RI fluid so that a small bead of fluid forms at the facet edge. A consequence of using the small 'window' of liquid rather than a facet at 90 degrees is that the lower part of the refractometer scale will not be so brightly lit as with a 90 degree face due to the lower quality of light at appropriate angles entering the gem. The scale in this case remains quite dark, with only the one (or two if birefringent) bright spectrum clearly seen; a shadow edge(s) will be seen if monochromatic light is used.

Figure 6b shows another method of getting light into a faceted gem at grazing incidence.

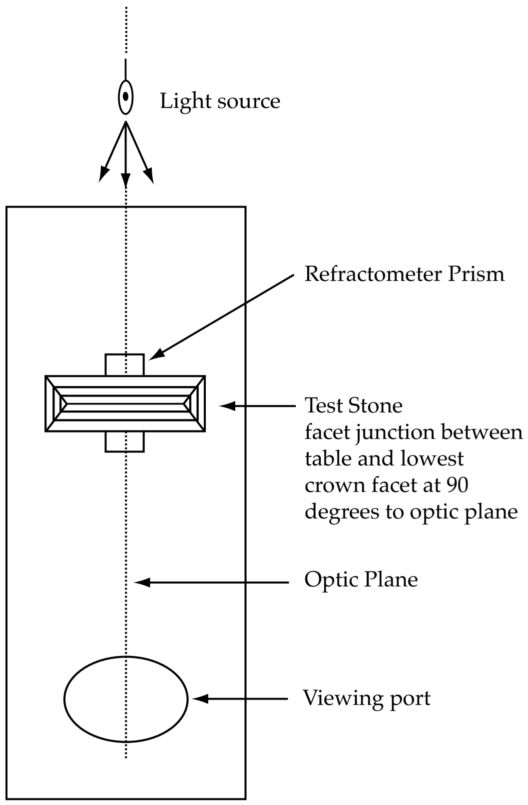

Figure 7: Diagram of a refractometer showing the placement of a gem with respect to the optic plane of the refractometer.

By holding the light source above and slightly behind the stone, the light entering the pavilion is internally reflected off of a crown facet at its intersection with the table. The optimum position of the light source will vary depending on the RI and facet angles of the stone. With normal faceting angles, as in most stones, the reflection within the gem at the crown facet will be at or above the critical angle providing good light intensity at grazing incidence. Placing the stone so that the facet junction between the table and crown facet is perpendicular to the optical plane of the refractometer remains crucial. Tracing this light path back within the stone and out, one sees that generally the light source should be above the stone, and away from the viewer. This explains Liddicoat's suggestion (op. cit.) that the source be "from above and behind".

It is most important to note that there are a number of possible light paths which may produce line or spectral images on the scale at other than the critical angle. These false readings can cause some confusion to the novice, but are simple to detect. Smith (1940) gives us the clue; one should check the gem with illumination from both above and below (traditional refractometer testing). If illumination is correct, then shadow edges and spectra will be at the same positions. Continue to adjust the light position until the readings match and are consistent. What none of the quoted writers have said is that when using white light and traditional illumination, both the boundary and the spectrum seen at the boundary are very weak, while with grazing illumination the spectrum is bright and well defined (*Figure 8*).

This aspect will turn out to be a major asset, especially in cases where it is difficult to get clear readings by the traditional method. In these cases, the bright line technique is ideal for confirming both R.I. and birefringence. This supports what C. J. Payne found many years ago. Two bright spectra would be seen for a birefringent gem. Pleochroic stones may show two slightly different spectra due to the variation in absorbance along different polarization directions. If one uses monochromatic illumination, then for grazing incidence the 'shadow edge' is not really a shadow edge, but one sees the edge defined by a very bright sharp spectral line that marks the RI for that wavelength, against a generally dark background. In essence one has a prism spectroscope with a birefringent prism. It is these bright, sharp lines that make it much easier to read the scale of the instrument at any particular colour.

Making a measurement

At first the user may have difficulty obtaining clear readings by grazing illumination, but practice will quickly bring proficiency. Unfortunately, it is not entirely without problems. Poorly cut stones and included stones will give significant problems, scattering or distorting the light beam in its passage through the stone. Such defects prevent greater application of the technique. Mounted stones have obvious limitations in orientation, but many will still yield good results with bright line if an RI reading is possible. It is suggested that the beginner start with a well-cut, clean, rectangular step-

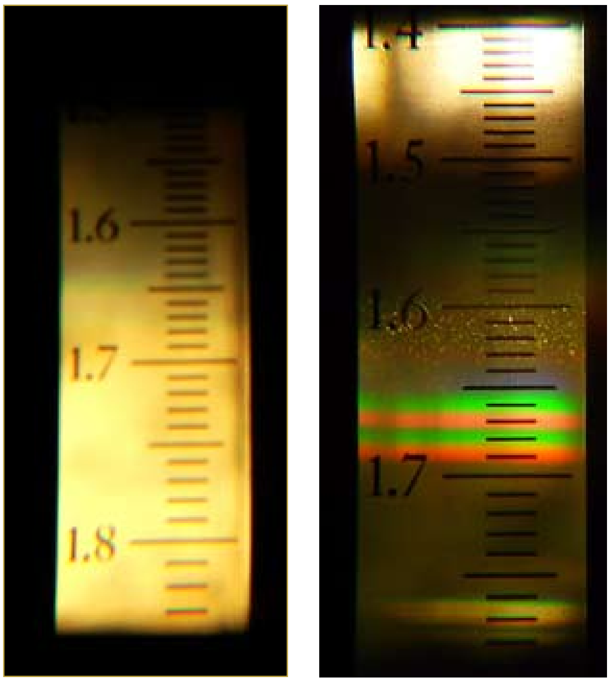

Figure 8: Refractometer readings for a peridot when illuminated by white light with (a) traditional illumination, and with (b) grazing illumination.

cut quartz and use white light. For some refractometers, it will be helpful to remove the top cover. Use a light source that is easily moved so comparisons can be made quickly between the a, b and c illumination positions shown in *Figure 5*. A small key-chain white LED source is ideal.

Remember to use sufficient contact liquid, and to orient the stone so that one of the facet junctions with the table will be perpendicular to the refractometer axis. This is illustrated in *Figure 7*, which shows a step-cut stone on a refractometer. *Figure 9* illustrates the direction that the optic plane of the refractometer should take with respect to three different cuts. With a stone on the refractometer, find the shadow edge using traditional illumination methods. Look carefully and you will find a very faint spectrum at the shadow edge. With your head held in this viewing position, take your light source and raise it slowly to shine on the stone in the b position shown in *Figure 5*. As the light is raised, a very bright spectrum should suddenly appear in the same position as the shadow edge under traditional illumination. Note that there may be additional spectra at other positions on the scale. These are to be ignored. Practise until you can easily find the bright spectrum. Next, raise the source to be above the stone in the c position of *Figure 5*, and move it up and down to find the bright spectrum from light reflecting within the stone. If you have difficulty, practise with other clean, well-cut stones.

Various light sources can be used with this technique, and a small LED light is one example, as shown in *Figure 2*. If using white LED, it is important to note that it is not a true, full-spectrum light; and while it will produce accurate RI readings, the spectrum may not be accurate enough for positive identifications. Today's well-stocked lab should have several white and monochromatic LED lights. Yellow LEDs are ideal for traditional RI readings when a monochromatic filter is not available. It should be obvious how much brighter and sharper the readings are with grazing incidence. If the room is very dimly lit, the refractometer scale may be difficult to read; it will help to introduce some diffuse light into the rear light port in order to light the scale. Once seen, the bright line effect is quite impressive. But remember, poorly cut and/or included stones can give poor results.

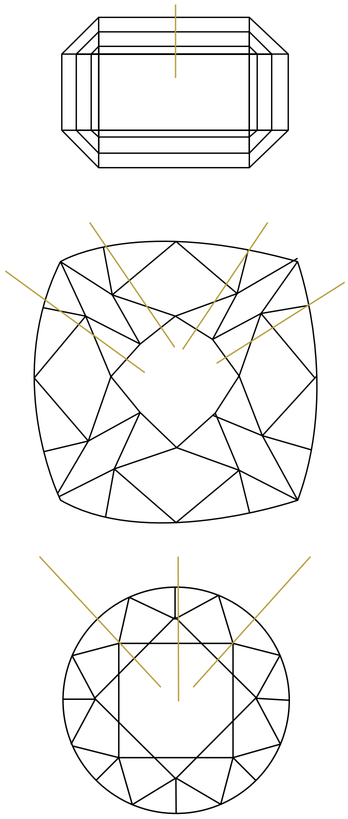

Figure 9: Diagrams of emerald-, cushion- and brilliant-cut gems, showing the orientation of the gem facets to the light path /optical plane of the refractometer (as in Figure 7) for grazing illumination.

Summary of steps to obtain a bright line reading

1. Obtain RI reading through traditional lighting method (*Figure 5*, position a).
2. Remove light cover from refractometer (*Figure 1*). (Optional)
3. Apply sufficient RI fluid to create a small bead along table/facet edge interface (*Figure 6*).
4. Align a facet (chosen facet must be adjacent to the table) at ninety degrees to light path/optic plane (*Figures 7* and *9*).
5. Direct light along grazing incidence (*Figure 5*, position b).
6. Observe bright line spectrum (*Figure 8*).
7. Direct light from above and behind (*Figure 5*, position c).
8. Confirm reading by comparison with position a (*Figure 5*, position a and b).

Utilization of grazing incidence

There are three key areas where grazing incidence will be of benefit to gemmologists in facilitating gem identification. The first is in better and easier reading of refractive index or indices, for birefringent stones. The second is in estimation of dispersion, and lastly as a simple prism spectroscope.

Refractive index or indices measurements

Gemmologists will occasionally come across a specimen that gives vague or unclear readings on the refractometer by traditional methods. The bright line technique is ideal for obtaining RI measurements on such stones, as grazing incidence gives much better definition of the shadow edge(s). Even for clear and simple RI measurements, the authors recommend that Smith's (1940) advice be heeded, and that both illumination techniques be used whenever possible. It is quick and simple, and provides much greater confidence.

Orienting a stone for maximum birefringence readings may be difficult due to the requirement that the facet through which the light enters the stone must be at 90-degrees to the light path, limiting the number of positions for gem. Accurate birefringence readings should be taken using traditional illumination, and then confirmed with bright line technique if the facets allow. Displacing the light source slightly to one side or the other when using bright line (*Figure 5* positions b and c) can still provide good readings within a given range, depending on the facet arrangement.

Dispersion estimation

If a white light source is used for grazing incidence a clear, bright spectrum should be visible, including its absorption features. Because these spectral colours may cover a wide span on the refractometer scale, it might be tempting to assume this would provide a good measure of dispersion, by simply taking the difference in readings at either end. This is not the case. The spread of the spectrum across the scale is an apparent dispersion, not a true dispersion; and its width is inversely proportional to the dispersion of the gem. If the refractometer reading indicates a large apparent dispersion, then that gemstone will have a low actual dispersion. For example quartz will show a wide, spread spectrum across the refractometer scale, whereas a spinel will show a narrower spectrum. Imitation gems of glass typically have high dispersions and show relatively low apparent dispersion on the refractometer. These glass imitations have become more sophisticated and more prevalent in the market, with their optical and physical properties often overlapping with known natural materials. While intense colours may mask the observed dispersion, the apparent dispersion in the bright line method can be a strong indicator of their true nature.

The amount of apparent dispersion a gem may show depends on the type of refractometer, prism or hemisphere, and the nature of the dense glass used (see Hoover and Linton, 2000, 2001 for details). In order to qualitatively estimate dispersion, one needs to become familiar with an instrument by checking known materials and standards representing a range of dispersion. Once familiar, then relative dispersions may be estimated, based on the width in RI units of the colour spectrum relative to known gems.

It should be emphasized that the above discussion concerns relative dispersion. True dispersion is difficult to measure, but Hoover and Linton (2000, 2001) have given details of the problem using a critical angle refractometer; they show that it is only practical for those instruments with a hemispherical or hemicylindrical dense glass element.

In general, dispersion follows closely the refractive index of a material, so is not expected to be a simple means of discrimination except for glasses and liquids, which tend to have higher dispersions than crystalline solids. Care also needs to be taken if estimates are made from the spectrum produced from white light: absorptions in the gem at the red or blue end of the spectrum may make the apparent dispersion appear less than it really is (e.g. selenium glass).

Absorption spectra definition

When trying the bright line technique with a ruby and white light, it will become immediately apparent that the coloured fringe shows the absorption spectrum of the ruby, and appears similar to that seen using the ‘Visual Optics’ method (Hodgkinson, 1995). Other strongly absorbing gems also show typical spectra, e.g. almandine; emerald; gold, cobalt, and selenium glass imitations; and cobalt coloured synthetic spinels. Thus, for some stones, the spectroscope may be avoided simply by resorting to grazing incidence illumination. We believe this significantly adds to the importance of the refractometer as a determinative instrument for gemmologists.

Another advantage is that for anisotropic gems, both polarized spectra are visible at the same time, a feature not previously available to most gemmologists. This can yield additional information, which may help to identify a gem such as alexandrite or tourmaline. The polarized spectra of anisotropic gems commonly overlap, especially in those with relatively low birefringence and/or dispersion, so that use of a polarizing filter may be needed to clearly separate them. The difference in absorption spectra of strongly pleochroic stones can be observed and easily compared. Of course, it helps if the stone is oriented for maximum birefringence, although this may not be possible if facet geometry is unfavourable. As with traditional RI measurement, if the c-axis is perpendicular to the facet under test, only one spectrum will be seen. With ruby the difference in the red end of the spectrum is easily seen by the shift from red to orange-red. With green and blue tourmaline the distinct differences in absorption along the ordinary and extraordinary rays across the entire spectrum can be seen. The spectrum of the ordinary ray in most tourmalines will be much weaker than that of the extraordinary ray. Distinct differences in the polarized spectra of properly oriented dark emeralds may also be seen by this method. In alexandrite, distinct differences in the spectra of each ray are visible and easily compared, side-by-side. The low-index ray passes much of the yellow, while the high index ray has an absorption in the yellow easily seen by its absence. Liddicoat (1989) shows examples of such polarized spectra.

Although the spectra produced by grazing incidence illumination are quite clear, minor or very narrow absorption lines may not be easily visible, especially at the blue end. The width or spread of the spectrum will also be an inverse function of the gem’s dispersion. For the serious gemmologist, a simple addition can be used to spread the spectrum a little. If a small 45-90 degree prism is made of low dispersion glass (or better fluorite which has very low dispersion) then the apparent dispersion will cover a range of about 0.05 units on the refractometer. The prism is placed on the refractometer, similar to that for a Pulfrich refractometer as illustrated in *Figure 4*. It can then act as a ‘poor man’s’ spectroscope, but without the capacity to produce polarized spectra. Light simply has to be introduced to the vertical end of the prism after passing through a gem whose spectrum is to be observed.

Summary

The authors believe that use of the long neglected ‘bright line’ technique to measure refractive indices can be a significant aid to gemmologists. This tool can significantly increase the confidence in measurements of refractive indices, especially for difficult cases. Further, it may assist in identifying glass or paste by providing estimates of relative dispersion, or provide polarized absorption spectra without resorting to other instrumentation. The authors suggest that students of gemmology should also be exposed to the technique, as an aid in learning how to measure refractive indices, and for better understanding of refractometers. Renewed use of the Bright Line method will hopefully inspire equipment manufacturers to build refractometers that enable easier implementation of this valuable technique.

Acknowledgements

We extend thanks to Bear Williams of Stone Group Labs for the use of their photographic and gemmological equipment, and to an anonymous reviewer for their valuable suggestions.

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