Use of the polarizing filter on the refractometer

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Abstract: *Use of the refractometer is summarized and a new comprehensive method to obtain reliable refractive indices is described. A single table contains all possible combinations of RI data and should be kept with the gemmological refractometer for practical use by both beginners and expert gemmologists.*

Introduction

The refractometer is one of the most used instruments in gemmology. Unfortunately, very few gemmologists feel confident that they can properly interpret all of the data that can be observed. Most can accurately measure the range of refractive indices (RIs) but few can differentiate between uniaxial or biaxial (in special orientation) or determine the optic sign from observations on the shadow edges.

It is not because they were not willing to invest their time and effort. Interpretation of the observations on the refractometer is a part of many gemmology courses. The problem lies in the instructions for use of the refractometer – they are complex and are often difficult to understand. Many students learn just enough to pass an examination and later they do not apply the method fully in practice. In many practical identifications, determination of the range of the RIs is all that is needed. In some cases, however, proper interpretation of the observed data can save time and the cost of an additional test.

Previous methods

One of the best descriptions of the use of the refractometer is, also, one of the oldest. At the beginning of the 20th century Herbert Smith developed a modern refractometer. An excellent description of the use of the polarizing filter is found in Smith (1972). This method requires a good understanding of optical mineralogy theory and use of the indicatrix. At Smith's time many gemmologists were also excellent optical mineralogists and could easily follow his instructions.

Later, in the second half of the 20th century, gemmologists became more and more involved in the detection of synthetic materials and various enhancement or alteration processes. The techniques used did not require such a sound understanding of optical mineralogy theory. Consequently, some attempts to simplify refractometer use have produced complex, confusing and sometimes simply wrong instructions.

Present practice

It is very difficult to evaluate the present teaching of refractometer use. Many schools or institutions have their own course manuals (notes) and do not rely exclusively on the text books. The level of instruction varies a great deal.

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Table I: Optical properties which can be determined on the refractometer.

	Isotropic	Anisotropic			
		Uniaxial		Biaxial	
Crystal system	amorphous and cubic	tetragonal and hexagonal		orthorhombic, monoclinic and triclinic	
RIs	N	N_o N_e		N_z N_y N_x	
Optic sign		Positive $N_e > N_o$	Negative $N_o > N_e$	Positive N_y closer to N_x	Negative N_y closer to N_z
Optical angle				$2V_z = 0 - 90°$	$2V_x = 0 - 90°$
Maximum birefringence		$N_e - N_o$	$N_o - N_e$	$N_z - N_x$	

NB: Other symbols used include:
Uniaxial gems = $N_o = \omega$, $N_e = \varepsilon$; lower case n is also used.
Biaxial gems = $N_x = \alpha$, $N_y = \beta$, $N_z = \gamma$; $2V_z = 2V(+)$, $2V_x = 2V(-)$.

In fact, the only safe statement that can be made is that the use of the polarizing filter is a minor (and difficult) part of many courses and rarely used later. This should not be so. A new approach to the teaching of refractometer use is proposed whereby a student, a jeweller or an experienced gemmologist can become familiar with the new method in about an hour. This new graphical approach does not require an extensive background in optical mineralogy and very little needs to be memorized. All that is required for the practical use of the refractometer is presented in a single table.

With mastery of this procedure, a lot of time and effort can be saved, leaving more time for the ever increasing number of new methods needed for the identification of enhancements and alteration processes. Most of all, the confidence that they can use this basic instrument to its fullest, stays with gemmologists or jewellers for life.

New approach

The new approach comprises graphical presentation and step-by-step instructions in a single table. Every new method combines old and new ideas and experiences. Here, diagrams similar to those in Hurlbut and Kammerling (1991) are used in order to describe six basic patterns. However, the vertical scale is reversed so that it corresponds to the image seen in the refractometer (the highest value is at the bottom) as is shown in the diagrams by Read (1999).

The new approach is characterized by the following features:

1. There is no recording of the rotation angles and corresponding RIs, or plotting of this information on diagrams.
2. All possible combinations of optical data and the orientation of the gem table are presented in six patterns and the interpretation of each pattern is described separately.
3. A single table describes step-by-step interpretation of the observed data. Nothing needs to be memorized. A table kept next to the refractometer is all that is needed (the table is downloadable from the Gem-A website at www.gem-a.info).
4. The use of an optic angle diagram for biaxial gemstones makes determination of the optic sign very simple.

Review of optical properties determined on a refractometer

All of the optical properties that can be determined on a gemmological refractometer are listed in *Table I*. the term 'gemstone' in this context includes minerals and synthetic materials.

Isotropic gemstones

Isotropic gemstones crystallize in the cubic system or are amorphous (e.g. opal, glass). They show the same refractive index (RI) regardless of the direction of light rays moving through them. This produces a single and constant shadow edge during the rotation of the gemstone on the refractometer (*Table II*, Pattern I).

Anisotropic gemstones

In general, a light ray entering an anisotropic gemstone is divided into two rays that:

1. move at different speeds and have different RIs (birefringence);
2. are polarized and have vibration directions perpendicular to each other;
3. may have different absorption – resulting in different colours for each ray (pleochroism);
4. may move in slightly different directions – resulting in the doubling of images.

It is important to remember that there are exceptions to the above and when, for example, the light moves in special directions (called optic axes), it continues as a single ray.

The rotation of an anisotropic gemstone on the refractometer can bring it into a position where the light rays are moving in the direction of an optic axis. In this case, a single shadow edge is observed as in isotropic gemstones. However, further rotation brings into view two shadow edges – representing RIs of the two rays. This allows for the easy distinction between anisotropic and isotropic gemstones.

Anisotropic gemstones can have either one or two optic axes and on this basis are divided into two groups: uniaxial and biaxial.

Anisotropic uniaxial gemstones have one optic axis and crystallize in either the tetragonal or hexagonal crystal systems. One ray – called the ordinary ray – has a constant RI regardless of the direction of light through the gemstone and is designated N_o. During rotation of a uniaxial gemstone, one shadow edge remains constant, indicating the constant RI (N_o) of the ordinary ray.

In most orientations of a gem, the other shadow edge – representing the extraordinary ray – varies during the rotation. We refer to this shadow edge as variable and it is designated N_e. Uniaxial gemstones are characterized by two principal RIs N_o and N_e.

During the rotation, the variable shadow edge can show any RI - N_e' – between the two extremes of N_o and N_e. Patterns II, III and IV in *Table II* show the range of relationships between the shadow edges representing ordinary and extraordinary rays.

The RI of the ordinary ray (N_o) is read on the constant shadow edge. The RI of the extraordinary ray (N_e) is read on the variable shadow edge in the position where the constant and variable shadow edges are at maximum separation.

Two special cases (shown in patterns II and III) are more common than one might think, because many uniaxial gem crystals have prominent faces perpendicular or parallel to the optic axis. The table facet of a zircon is commonly cut perpendicular to the optic axis, while that of a tourmaline is commonly parallel – producing these special patterns II and III.

Anisotropic biaxial gemstones have two optic axes and crystallize in either the orthorhombic, monoclinic or triclinic crystal systems. They are defined by three principal RIs and three principal vibration directions, Z, Y and X. N_x is the smallest RI and is observed when light vibrates parallel to the principal vibration direction X, N_y is the intermediate RI for light vibrating parallel to the principal vibration direction Y, and N_z is the largest RI for light vibrating parallel to the principal vibration direction Z. It is important to note that N_y can be any value between N_z and N_x – generally it is not exactly halfway between the two.

RIs of the two rays formed in biaxial gemstones depend on the direction of light through a gemstone. In general, when a biaxial gemstone is rotated on a refractometer, two variable shadow edges are observed (pattern VI). One ray has RI (N_x') that varies between N_x and N_y, and the other ray's index (N_z') varies between N_y and N_z. On rotation on the refractometer, the direction of light in the gemstone changes and so do the RIs (N_z' and N_x') of the two rays.

Special orientations of the optical elements and the gem table – when any of the principal vibration directions Z, Y and X is perpendicular to the gem table – are characterized by one constant and one variable shadow edge (patterns IV and V). As in uniaxial gemstones, these special orientations can be fairly common, because the principal vibration directions Z, Y and X are often perpendicular to the prominent faces chosen and fashioned as the table facet.

Determination of the optic sign

The optic sign depends on the relationship between the principal RIs (N_o/ N_e and N_z /N_y/N_x). In order to avoid complex descriptions of the behaviour of the shadow edges during the rotation of a gemstone - in this method, the principal RIs are determined first and then two simple rules are used to identify the optic sign.

Uniaxial gemstones: The optic sign of an anisotropic uniaxial gemstone is

Positive if $N_o < N_e$

Negative if $N_o > N_e$

Biaxial gemstones: The optic sign of an anisotropic biaxial gemstone is

Positive if N_y is closer to N_x

Negative if N_y is closer to N_z

The optic sign and angle between the optic axes depends on the three principal RIs (N_z /N_y/ N_x) and can be found using the Optic Angle Diagram in *Figure 1*. The use of the diagram is shown in the following example illustrated in *Figure* 2.

First, the three RIs of a gemstone were determined as:

$N_z = 1.625$

$N_y = 1.610$

$N_x = 1.600$

Second, $N_z - N_y$ and $N_y - N_x$ were calculated as:

$N_z - N_y = 0.015$

$N_y - N_x = 0.010$

Third, these values were plotted on the Optic Angle Diagram and indicate that the gemstone is biaxial - positive with a 2V angle about 80°.

The Optic Angle Diagram can also be used to show how errors in the observed RIs can

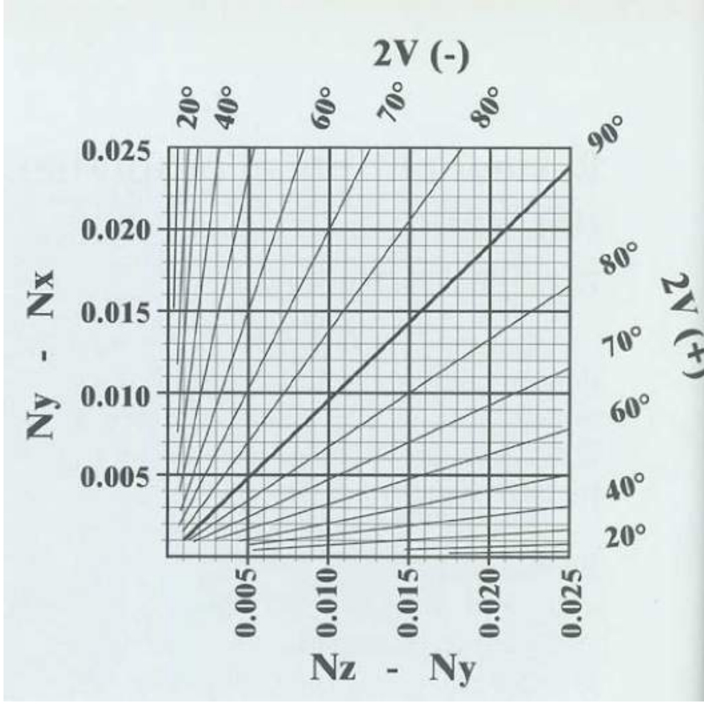


Figure 1: Diagram for determination of the optic sign and the optic angle of anisotropic biaxial gemstones.

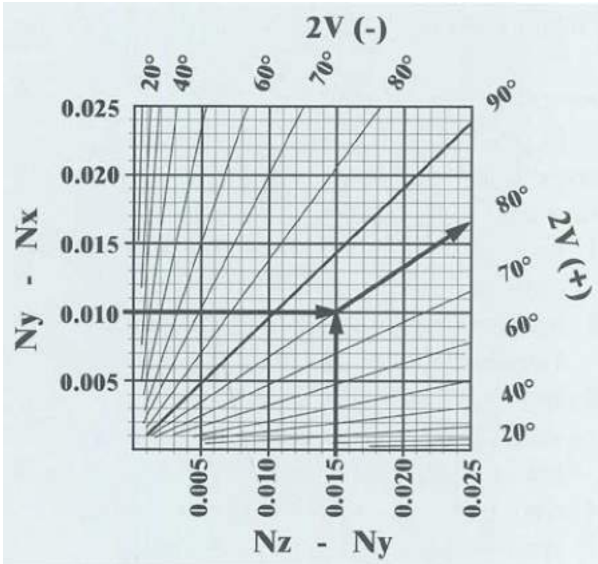


Figure 2: The optic angle diagram showing values plotted for $N_y - N_x$ and $N_z - N_y$ as discussed in the text.

have a significant bearing on determination of the optic sign.

The use of Table II

The determination of the optical properties of a gemstone on the refractometer is divided into several stages in this new approach. *Table II* summarizes the patterns obtainable from a refractometer, indicates which patterns yield further information with use of a polarizing filter, gives step-by-step instructions on how to obtain this information, and indicates the relevant orientation of the gem under measurement.

There are six possible pattern types, represented in six rows in *Table II*. The **Initial observation** column (column 2) charts the patterns of shadow edges obtainable if one rotates the gemstones through 180°. At this stage, the polarizing filter is not used.

For patterns I and II, the shadow edges are constant and the orientation of the gem when rotation is started is not significant, but for patterns III, IV and V, 0° on the pattern diagram indicates the point of maximum separation of the shadow edges. Pattern VI starts where the largest RI (N_z) is observed.

Patterns I, III and V yield the maximum optical information obtainable from the refractometer but patterns II, IV or VI, require detailed observations.

Detailed observation is done with the polarizing filter set into one of the two positions (north-south or east-west). The gemstone is first rotated to the position indicated by a red dot in *Table II* and the polarizing filter is set on the eye-piece. Identification is then based on the disappearance of a particular shadow edge.

A polarizing filter is supplied with most modern refractometers. Its vibration direction is indicated by a dot. If this dot is erased, a very simple procedure can be used to accurately determine the filter's vibration direction. A quartz crystal (with enough faces to indicate the crystallographic axis *c*) is set in the horizontal position on the refractometer table. The crystal is rotated in the position where the *c*-axis is perpendicular to the long axis of the refractometer. Two shadow edges are observed. The one with the RI of 1.544 represents the ordinary ray with its vibration direction being north-south. The polarizing filter is set on the eye-piece and rotated until this shadow edge (N = 1.544) disappears. The vibration direction of the polarizing filter is now exactly east-west (parallel to the refractometer table) and this direction should be marked on the polarizing filter. This test can be done with any uniaxial crystal where the *c*-axis and the shadow edge representing the ordinary ray can be identified.

Isotropic gemstones produce *pattern I* and this is characterized by a single shadow edge that stays constant during rotation. The rotation test is very important because, in particular positions, anisotropic gemstones can also show a single shadow edge (see patterns III and V).

Pattern II is a special case of a uniaxial gemstone where the optic axis is perpendicular to the gem table. The two shadow edges representing ordinary and extraordinary rays stay constant during rotation of the gem. The polarizing filter is used to identify the ordinary and extraordinary ray shadow edges in *Table II*.

Pattern III is the other special case where the optic axis of a uniaxial gemstone is parallel to the gem table. It is characterized by the variable shadow edge touching the constant shadow edge at one position during the rotation. The polarizing filter is not needed for determination of the optic sign. Read N_o on the constant shadow edge and read N_e on the variable shadow edge in the position where the two shadow edges are at maximum separation.

Pattern IV can be generated by both uniaxial and biaxial gemstones. In both cases we observe one constant shadow edge and one variable shadow edge which do not touch at any position of the gem during rotation.

The polarizing filter is used to determine whether the gemstone producing this pattern is uniaxial or biaxial. With the filter set in the north-south position on the eye-piece, if the constant shadow edge disappears the stone is

PATTERN NUMBER	INITIAL OBSERVATION	POLARIZING FILTER	DETAILED OBSERVATION For observation with the POLARIZING FILTER rotate the gemstone in the position indicated by the RED dot. For determination of the REFRACTIVE INDEX rotate the gemstone in the position indicated by the GREEN dot.	ORIENTATION AND OPTICAL PROPERTIES	RESULTS
I	(0°, 90°, 180°; 1.500, 1.600, 1.700) Single CONSTANT shadow edge	Not used	**Detailed Observation not needed.** Make sure that the **SINGLE** Shadow edge stays **CONSTANT** during the rotation of the gemstone. (0°, 90°, 180°; 1.500, 1.600, 1.700; N)	**Isotropic**	Record N
II	(0°, 90°, 180°; 1.500, 1.600, 1.700) Two CONSTANT and PARALLEL shadow edges	Set in the North – South position (NORTH, SOUTH)	1. Observation can be made in any position during the rotation of a gemstone. 2. Insert the polarizing filter. (Shadow edge of the ordinary ray (N_o) disappears.) 3. Read N_e on the shadow edge that stays visible. 4. Remove the polarizing filter. Read N_o on the shadow edge that is now visible. (0°, 90°, 180°; 1.500, 1.600, 1.700; N_o, N_e) (0°, 90°, 180°; 1.500, 1.600, 1.700; N_e, N_o)	**Uniaxial** Optic axis is perpendicular to the gem table (Optic Axis)	Record N_e, N_o Determine the **optic sign** Calculate the **maximum birefringence**
III	(0°, 90°, 180°; 1.500, 1.600, 1.700) Or (0°, 90°, 180°; 1.500, 1.600, 1.700) One CONSTANT and one VARIABLE shadow edge **TOUCHING**	Not used	**Detailed Observation not needed.** 1. Read N_o on the constant shadow edge. 2. Read N_e on the variable shadow edge **when two shadow edges are separated the most.** (as shown by the green dots). (0°, 90°, 180°; 1.500, 1.600, 1.700; N_o, N_e) (0°, 90°, 180°; 1.500, 1.600, 1.700; N_e, N_o)	**Uniaxial** Optic axis is parallel to the gem table (Optic Axis)	
IV	(0°, 90°, 180°; 1.500, 1.600, 1.700) Or	Set in the North – South position (NORTH, SOUTH)	1. Rotate gemstone in the position indicated by the red dot (where shadow edges are the closest). 2. Insert the polarizing filter **Observe which shadow edge disappears.** CONSTANT shadow edge **DISAPPEARS** (0°, 90°, 180°; 1.500, 1.600, 1.700; N_o, N_e) (0°, 90°, 180°; 1.500, 1.600, 1.700; N_e, N_o)	**Uniaxial** Random orienation (Optic Axis)	

The use of the polarizing filter on the refractometer

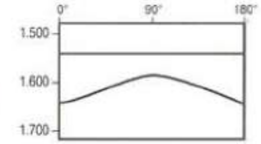
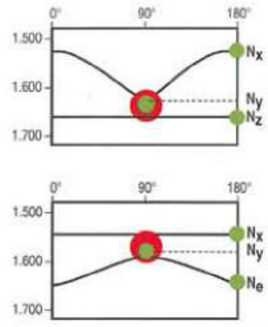
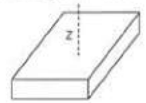
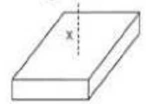
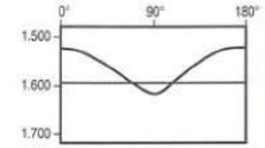
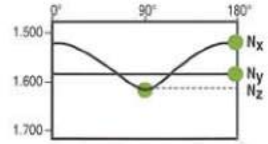
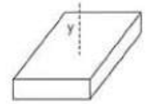
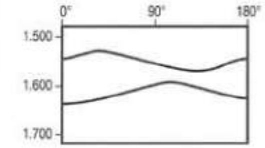
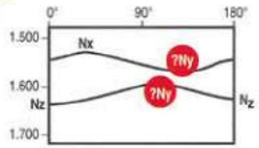
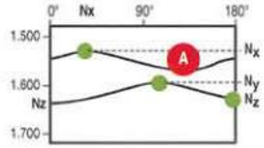
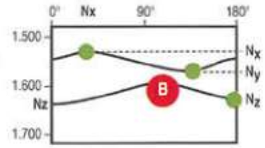
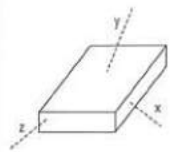
IV	 One CONSTANT and one VARIABLE shadow edge **NOT TOUCHING**		**Observe which shadow edge disappears.** Identify gemstone as uniaxial or biaxial. 3. Remove the polarizing filter. Read principal refractive indices in positions shown by green dots. VARIABLE shadow edge **DISAPPEARS** 	**Biaxial** Z perpendicular to the gem table  X perpendicular to the gem table 	Record N_Z, N_y and N_x. Calculate the **maximum birefringence**. Use 2V diagram to determine the 1. **optic sign** 2. **optic angle (2V)**
V	 One CONSTANT and one VARIABLE shadow edge **INTERSECTING**	Not used	**Detailed Observation not needed.** Read N_Z, N_y and N_x as indicated by green dots 	**Biaxial** Y perpendicular to the gem table 	
VI	 Two VARIABLE shadow edges **NOT TOUCHING**	Set in the East – West position 	N_Z AND N_X ARE DETERMINED AS THE LARGEST AND THE SMALLEST REFRACTIVE INDEX OBSERVED DURING THE ROTATION. N_y CAN BE READ EITHER ON THE UPPER OR ON THE LOWER SHADOW EDGE  *Each shadow edge must be observed separately to determine N_y* Rotate gemstone in the position A indicated by the red dot. Insert the polarizing filter in the East-West position. If the shadow edge containing N_x disappears - read N_y and N_z on the other shadow edge.  *If the shadow edge containing N_x does not disappear, test the other shadow edge.* Rotate gemstone in the position B indicated by the red dot. Insert the polarizing filter in the East-West position. If the shadow edge containing N_z disappears - read N_y and N_x on the other shadow edge. 	**Biaxial** Random Orientation 	

Table II: Patterns of shadow edges and use of polarizing filter to determine the optical properties of gems. (The Table may be downloaded from the Gem-A website at www.gem-a.info.)

uniaxial; if the variable shadow edge disappears it is biaxial.

Uniaxial in random orientation - where the optic axis is inclined at an angle to the gem table which is not 0° or 90°. The gemstone is rotated to the position of maximum separation of the two shadow edges and N_e is determined (with polarizing filter removed). N_o is read on the constant shadow edge.

Biaxial in special orientations – where the principal vibration directions X or Z are perpendicular to the gem table. N_y is read on the variable shadow edge when the two shadow edges are as close as possible. If the two shadow edges are almost touching it may be difficult to read N_y accurately, so the polarizing filter should be placed over the eyepiece and rotated until the constant shadow edge disappears; this should make it easier to measure N_y. N_z and N_x are read in the position where the constant and variable shadow edges are at maximum separation (with polarizing filter removed).

Pattern V represents the third special case of the biaxial gemstone - where the principal vibration direction Y is perpendicular to the gem table. The polarizing filter is not used. N_y is read on the constant shadow edge and N_z and N_x on the variable shadow edge in the positions where the two shadow edges are at maximum separation.

Pattern VI is the general case of a biaxial gemstone – where none of the principal vibration directions X, Y or Z is perpendicular to the gem table. It is characterized by two variable shadow edges. N_y is read on only one of them, and the polarizing filter must be used to identify which shadow edge contains N_y.

Each shadow edge must be observed in the separate position indicated in *Table II*. For the shadow edge showing N_x, this is a position with the highest RI reading. For the shadow edge showing N_z, this is the position with the lowest RI reading. To obtain the value of N_y and determine the optic sign of the gemstone, place the polarizing filter on the eyepiece in the east-west orientation and follow the procedure in *Table II*.

Sometimes bringing the gemstone to the required maximum or minimum position may be difficult if the shadow edge moves little during the rotation (shows almost the same RI). In such cases a rotation of the polarizing filter 10-15° off the proper position may help. If not, possible readings of N_y from both the N_x and N_z shadow edges must be considered in assessing which is the best value to use when attempting to identify the stone.

Conclusions

The refractometer is one of the most used gemmological tools. Its use including observation with the polarizing filter is a part of many courses and study programmes. However, many instructions concerning the filter are descriptive with very few drawings, making them complex and sometimes confusing for students. The new approach enables one to learn the use of the polarizing filter on the refractometer in a fraction of the time needed previously. This leaves more time for the study of the new techniques and methods used in identification of alteration or enhancement processes.

Any jeweller or gemmologist can become familiar with the use of the polarizing filter in about one hour. After that, *Table II* kept next to the refractometer will give them the confidence that they can properly interpret any observation made on the refractometer.

A set of standards representing the six patterns can easily be prepared. These could be combined with a set of drawings on CD showing vibration directions and RIs during the rotation.

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References

Hurlbut Jr, C.S., and Kammerling, R., 1991. *Gemology*. John Wiley & Sons Inc., New York

Read, P.G., 1999. *Gemmology*. 2nd Edn. Butterworth Heinemann, Oxford

Smith, G.F.H., 1972. *Gemstones*. Chapman and Hall, London

Note: Table II may be downloaded From the Gem-A website at www.gem-a.info