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IN THIS ISSUE

A Test of the Ceres Diamond Probe

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Abstract:

Tests are reported of a new instrument, the Ceres Diamond Probe, which has been developed to distinguish diamond from all of its limitations. The magnitude of the thermal conductivity, where diamond has a uniquely high value, is tested by a copper-tipped probe which is pressed against the stone to be tested. Within about three seconds, the response on the dial of the instrument, as well as flashing lights, indicates whether or not the material is a diamond. Stones as small as three points (three hundredths of a carat), are readily checked, and the only transparent materials which could produce confusion are bromellite (soft and poisonous), silicon carbide (usually deep colored, birefringent, etc.), and, of course, a diamond-topped doublet.

Introduction

Man-made diamond imitations have improved steadily over the years. Starting with the rather dull synthetic sapphire, spinel, and the overly brilliant but yellowish rutile, there was a large improvement in going to the colorless and overly dispersive or fiery brilliant, but still soft strontium titanate. With YAG and GGG, the hardness improved greatly, and the most recent material, cubic zirconia(1,2), is extremely close to diamond in appearance and presents identification problems.

To make easier the distinction of such imitations from diamond, there have been developed a series of new test instruments based on reflectivity, including the Gemeter(3) and the Gemeter '75(4) (made by Sarasota Instrument, Inc., Sarasota, Florida); the Jeweler's Eye(5,7), lustermeter(6,8) and Diamond Eye(7)(Hanneman Lapidary Specialities, Castro Valley, California); and the Martin Gem Analyser(9) (Martin Precision Instrument, Inc., Saratoga, California). Techniques which are based on surface wetting, such as the measurement of the contact angle of water(10,11) or of certain inks(11), have also been perfected.

The most recent development is the arrival of an entirely new instrument, the Ceres Diamond Probe. The author is grateful to the manufacturer (Mr. J.F. Wenckus, Ceres Corp., Waltham, Massachusetts) for permission to test a prototype of this instrument, which is reported to be scheduled for production later this year. (Marketing is being arranged through MSB Industries, New York City.)

The Thermal Conductivity Probe

The observation that gems are cold to the touch is well known. It was recognized long ago that diamond has one of the highest of thermal conductivities.(12,13) In fact, diamonds of Type 2a conduct heat so very much better than the best of metals that they are used as heat sinks to dissipate heat from high power transistors.

The scientific basis for the conduction of heat is extremely complex.(13) Experimental values taken from a variety of sources are shown in *Table 1.* It can be seen that there is an astonishingly precise division into three groupings. In Group A, there are conductivities above 10 watts per cm per degree K, and here there are only diamond and a special form of carbon, black pyrolytic graphite (even so only when measured in one specific direction).

In Group B are listed the four best thermal conductivity metals. All other metals have lower conductivities and are omitted. In Group C are the majority of gem and mineral substances. It will be noted that the highest value for any of the diamond simulants, which range from less than 0.1 to 0.3 watts per cm per degree K, is far from the lowest value reported for diamond, 10 watts per cm per degree K.

A precise thermal conductivity measurement usually involves elaborate equipment(13) and requires a carefully shaped slab of the material to be tested. Several systems of units are used and conversion factors are as follows:

> to convert thermal conductivity data to watts per cm per degree K, multiply by
>
> for BTU per hour per foot per degree F, use 0.0173
> for Cals per sec per cm per degree K, use 4.184
> for Joules per sec per cm per degree K, use 1.0.

With the modern availability of transistors and integrated circuits, compact and relatively simple devices are now possible for semi-quantitative measurements.

The Ceres Diamond Probe uses a thermistor at the tip of a pen-like probe. When a short pulse of a very small electric current is passed through the thermistor, it heats up a little. The speed with which its temperature falls when the current stops is next measured by elaborate electronic circuitry, and this process of heat pulse and temperature measurement is automatically repeated at a rate of once a second.

The output from the circuitry is displayed on a scale which is divided into three zones: green (go, for diamond) on the right, yellow in the center, and red (for danger, simulant) on the left. There are also three lights: green, yellow and red. The appearance of the instrument will be close to the mock-up shown in *Figure 1.* Although the prototype examined was slightly different, the functioning is stated to be exactly the same.

After switching on the instrument, its operation is first checked by touching the tip of the probe to a test point (apparently aluminum) which should move the needle into the central yellow region and turns on the yellow light (a calibration knob is used if the reading is off, e.g., from dropping the unit!).

The spring-loaded probe is next pushed against the material to be tested. The needle fluctuates for the first pulse or two, but then settles down to give a steady reading in the green, yellow or red sections of the scale visible in *Figure 1.* At the same time, flashing lights, either green alternating with yellow, yellow only or yellow and red, are also activated.

If the tip of the probe touches a material of high thermal conductivity, the heat will be conducted away efficiently, and a rapid drop in the temperature occurs. For a low conductivity, the drop in temperature is more gradual.

The actual temperature change of the probe is so small that it cannot be felt by touch, and there should be no danger on testing even the most heat sensitive of materials. The tip is made of copper and should present no scratching problem. The unit is powered by an internal battery, which can be recharged by means of a plug-in 110-volt recharge unit supplied with the instrument. Some probe failure

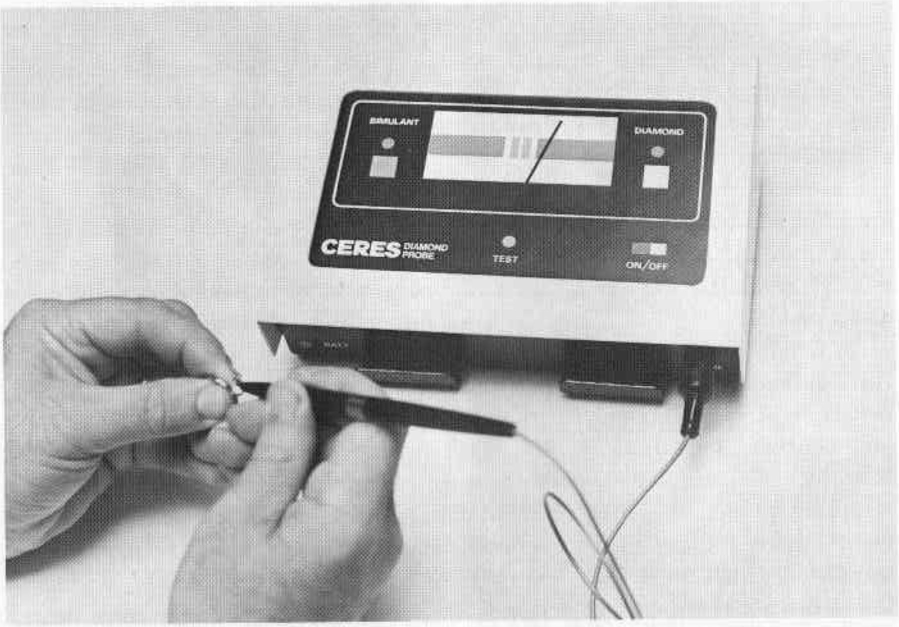

Figure 1. The Ceres Diamond Probe in use.

was encountered with the prototype and this survey was completed with a replacement probe.

Results

A series of some hundreds of rough specimens and faceted gemstones, both loose and mounted, were tested. The diamonds included a full range of the four types; 1a, 1b, 2a and 2b (some kindly loaned by Lazare Kaplan and Sons, Inc., New York City), as well as man-made diamonds and all the major diamond simulants. Of the items of *Table 1*, only the graphite and borazon were not available for testing, but these are not transparent and, therefore, not potential diamond simulants.

TABLE 1.
Literature Values of Thermal Conductivities at Room Temperature in Watts per cm per degree K

Group A:	Diamond Type 1	10-20*
	Diamond Type 2a	26
	Diamond Type 2b	15
	Graphite (pyrolytic, parallel)	20
Group B:	Silver	4.3
	Copper	4.0
	Gold	3.2
	Aluminum	2.4
Group C:	Bromellite (BeO)	3.7
	Borazon (cubic BN)	1-4
	Moissanite (SiC)	0.9**
	Corundum (Al_2O_3), Zincite (ZnO), Sphalerite (ZnS)	about 0.3
	Topaz, Kyanite	about 0.2
	Spinel, YAG, Rutile, Cubic Zirconia, Quartz, Zircon, Beryl, Halite, Sylvite, Glass, etc.	0.1 or less

*The purer, the higher the value.
**Somewhat variable depending on the ploytype structure.

Each test takes about three seconds, and repeated testing on various parts of the same specimen gave identical results, as long as the probe was held squarely against a flat part of the specimen and adequate pressure was used to partially depress the spring-loaded probe so as to provide good contact. Stones as small as three points were readily checked, even if deeply recessed within a mounting.

It was noted that the smaller the stone, the weaker the response, as is pointed out in the operating instructions. Using the numbering of the scale of *Figure 2* for reference, the diamonds tested over 1/3 carat all gave a response in the 7 region, while a number of 3 pointers measured at the low end of 5, i.e., almost in the yellow region. The results are summarized in *Table 2*. Interestingly enough, some black man-made carbonado also measured in the green region. The moissanite (silicon carbide) thermal conductivity value of *Table 1* is obviously inadequate.

It is clear from *Table 2* that diamond can be distinguished unambiguously from all practical simulants. The bromellite and moissanite (silicon carbide) results should present no problems; the former is a very poisonous technological material of low refractive index (1.73), only produced experimentally in small crystals; the latter is seen in transparent

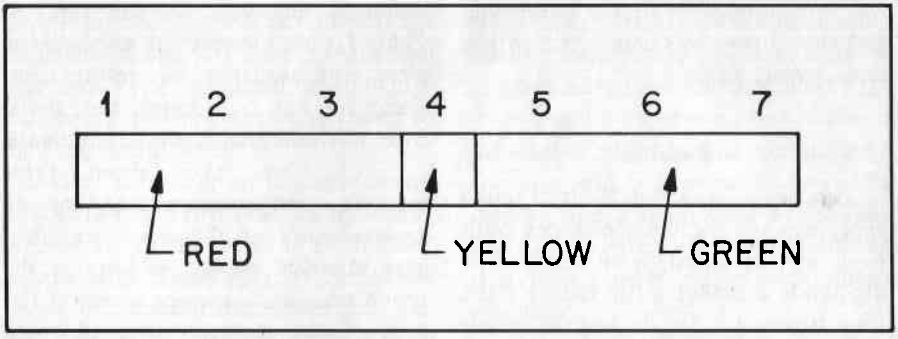

Figure 2. Drawing of the scale with numbers added for ease of describing the test data.

crystal form only rarely and then only in very small sizes, usually deeply colored, and shows birefringence, a distinct dichroism, with both the refractive index and the dispersion being higher than the diamond values.

TABLE 2.
Ceres Diamond Probe Test Results
(Red is 1, 2, 3: Yellow is 4;
Green is 5, 6, 7; see Fig. 2)

Non-Metals (transparent)	
All diamonds (natural and man-made)	5-7*
All diamond simulants**	1
Moissanite crystals	1-7*
Bromellite crystals	4-7*
All other transparent gems and minerals tested	1
Metals	
Yellow & White Gold, 14K and 18K; Platinum	1
Gold-plated sterling; 1/20 gold-filled metal	3-5
Sterling; rhodium-plated sterling	5-7
Pure Gold (24K)	7

*Depending on size and impurity content.

**Including cubic zirconia, GGG, YAG, strontium titanate, rutile, spinel, sapphire, zircon, quartz, glass, plastic.

The probe might actually also be of some use in distinguishing among the metals as seen in *Table 2.* Thin platings should have little effect and the base metal might be so identifiable. This was not further investigated.

Discussion and Comparison with Other Techniques

Allowing for the fact that very small stones will give lower readings, the Ceres Diamond Probe was found to give accurate results on both large and small, loose and mounted, stones. Since the property being monitored, the thermal conductivity, is a bulk property, thin surface coatings will not interfere. Only a coating so thick and/or rough that the probe never touches the stone could affect the reading, and such a coating would be easily seen by the unaided eye. The only problem might arise from a doublet with a diamond top, and even here, a test on the back of the stone would reveal such a combination. Nevertheless, this last possibility points up that an eye at least partly trained is always necessary and will probably never be completely displaced by any instrument in gemological testing.

The surface tension tests referred to in the introduction need some experience and, since a surface property is involved, can be foiled by quite invisible surface coatings as has already been reported.(14)

The reflectometer instrument also referred to in the introduction can probably serve a useful function. However, mounted stones which do not protrude from their mounting cannot be measured and the surface must be well polished and very clean or low values will be obtained. Since internal reflections can give high values, several readings must be taken.(7) Finally, since a surface property is being measured, it may unfortunately be only a matter of time until someone will come up with a coating which will give a reflectometer "diamond" reading on any gemstone!

Summary

The Ceres Diamond Probe appears to be a well-build, rugged instrument which admirably meets its aim – to distinguish diamond from the various diamond imitations by testing their thermal conductivity. The writer cannot, in fact, understand why it took so long for someone to take advantage of this unique property of diamond for a testing approach. The only reservation is based on the fragility of the probe tip, with which some difficulties were experienced. The manufacturer states that a re-design under way should eliminate this problem.

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Sapphire-Blue Euclase, A New Collector's Gem

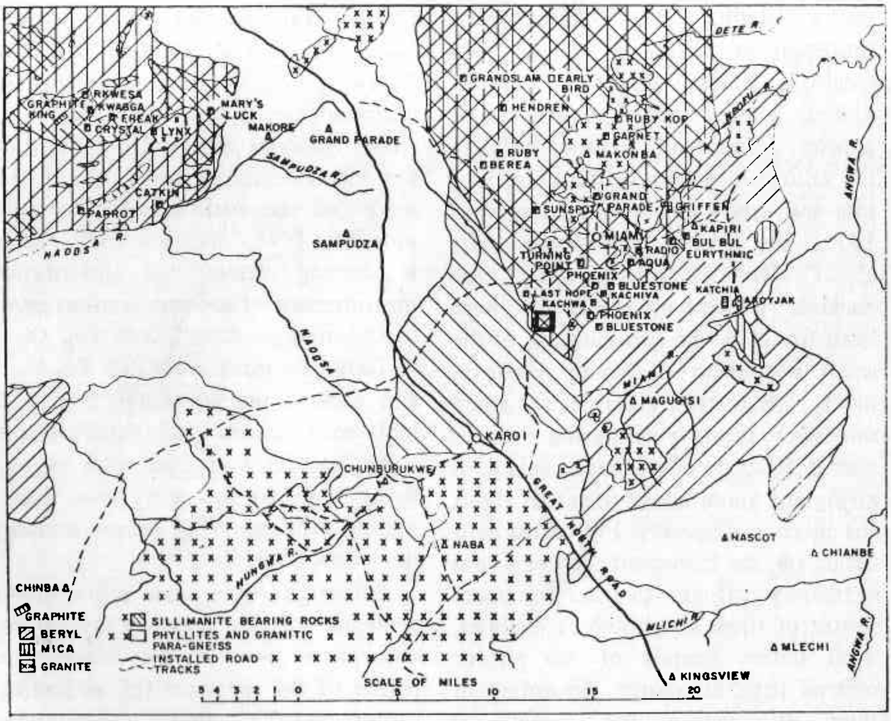
By E.J. GÜBELIN, Ph.D., CG, FGA
Lucerne, Switzerland

The discovery of a new gemstone, or even just a new color variety of an already known gemstone, is always a joyful event for the world of experts. In the course of the past 10 years Africa has yielded several such surprises, with an apparent preference for blue novelties. Thus the Dark Continent bestowed on us blue zoisite (tanzanite) in 1967, jeremejevite from Cape Cross, near Swakopmund in South-West Africa, in 1973, scorodite from Tsumeb in South-West Africa, in 1975, and now just in the past winter a sapphire-blue euclase from Miami in Rhodesia.

Till now, euclase has been known only in pale shades, ranging from colorless through light blue and light green to deep yellowish-green or greenish-blue. The colors are due to the various states of oxidation of the iron which is present in very small quantities.

Euclase ($AlBe[OH|SiO_4]$), the epigone of beryl, is an exemplary secondary product of the pegmatitic phase; it could hardly have developed during the climax of this phase (700°-600°C) but rather at the time of transition to lower temperatures (600°-400°C), by disintegration of the abundant beryl then present – i.e. at the beginning of the pneumatolytic or even the hydrothermal phase. The pegmatites of Miami have a geological age of ca. 500-600 million years. Radiometric age determinations with radioactive columbite/tantalite gave an age of 550 million years, whilst muscovite from the Catkin and Esquire mines measured by the K/Ar method indicated an age of 520-530 million years respectively. These investigations proved that the Miami pegmatites originated in two clearly distinct generations. The older group is homogeneous and of little or no economic value. The most important mineral components are plagioclase and quartz with some tourmaline. These rocks obviously belong to the earlier soda metasomatism, that is, they represent alterations.

The pegmatites of the younger and economically more important group may easily be recognized by their wealth of microcline, which simultaneously shows that they belong to the later potash-rich phase. A simplified idealized pegmatite of this group exhibits an obviously zoned structure. The zones form shells which succeed one another around an inner core. They consist of varying amounts of quartz with microcline, albite or plagioclase, as well as mica (mostly muscovite), beryl, and tourmaline, and in most favorable cases they are accompanied by rarer but typical pegmatite minerals whose larger and more transparent specimens can be used as



Geological map of the gemiferous region, the so-called Miami gneiss shield, north of Karoi. The black square indicates the exact locality, five miles southwest of Miami where sapphire-blue euclase is found.

gemstones. It is not therefore surprising that in the extensive gneiss shield of Miami, with its numerous pegmatite intrusions and widespread beryl occurrences, euclase should develop in a later process of recrystallization.

So far, the euclases originating in the Miami district used to display the pale colors (i.e. colorless, pale blue and light green as well as mixtures of the latter two) well known heretofore, and it came as an unexpected surprise when a few months ago *sapphire-blue* specimens appeared on the market. The light-colored varieties had been coming from limited occurrences between "Radio" and "Bul-Bul" east-southeast of Miami as well as from localities called "Bluestone" almost directly south of Miami at distances of approx. 2 and 4 miles, respectively. In the course of an inspection of various pits and mines in the Miami region in 1971, the author had heard hints about "very beautiful dark blue euclases" which were rumored to have been found in the surroundings of the small settlement of Miami. Unfortunately, his further enquiries remained unanswered; and even during a repeat visit in 1973 no one seemed capable of giving any more accurate details about the place of discovery. Even after their debut on the European market it was extremely difficult to trace the exact source of these sapphire-blue euclases, until native friends of the author offered their assistance. According to their information the locality is situated west-southwest of Miami very near the southwestern rim of the beryl and muscovite bearing gneiss shield, approximately 8 to 10 miles northeast of Karoi as the crow flies (see map).

Colour

The euclases described below were certainly correctly offered as euclases; but the completely new dark blue color seemed to call for a detailed investigation. In a fairly large parcel totalling 33 rectangular and square faceted euclases only a few were uniformly dark blue; most individuals were bi-colored, i.e. dark blue sections alternated with colorless parts. The dark blue color on average corresponded to color numbers 17 : 4 : 5, and in better qualities to 18 : 5 : 3 (with corresponding color values X_c 5, 8; Y_c 5, 7; Z_c 13, 4 and X_c 12, 0; Y_c 14, 1; Z_c 31, 0 respectively), in accordance with the DIN color chart 6164. Analyses achieved by means of the electron micro-probe traced the origin of the dark coloring to iron, moreover ONLY iron was indicated as a coloring element. A quantitative measurement of the iron content gave:

Colorless portions 0.06% Fe_2O_3

Dark blue portions 0.12% Fe_2O_3

and showed unequivocally that trivalent iron causes the sapphire-blue color, natural voids and color centers being likely to also exert their determining influence. The copper content lies below 0.005%.

Although ferric iron often shows evidence of its presence in strong absorption lines in the lower blue region of the spectrum (cf. andradite, chrysoberyl, epidote, corundum, orthoclase, etc.), absolutely no absorption lines in the blue sector could be observed with the optical spectroscope

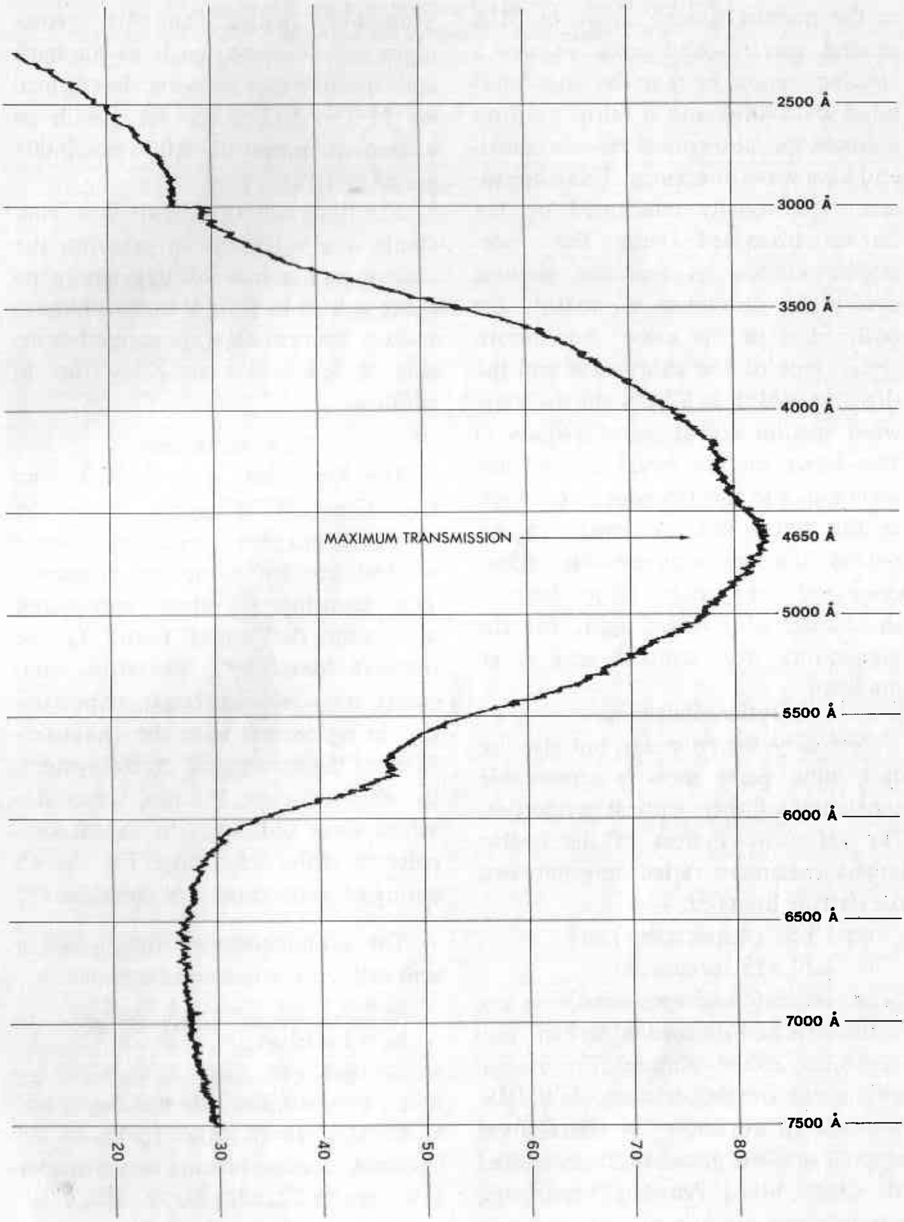

2500 Å
3000 Å
3500 Å
4000 Å
MAXIMUM TRANSMISSION
4650 Å
5000 Å
5500 Å
6000 Å
6500 Å
7000 Å
7500 Å
20
30
40
50
60
70
80

Figure 1.

in the material under discussion. The general spectroscope image showed a striking transparency in the neighbourhood of 4500Å and a fairly uniform increase of absorption in the short-and-long-wave directions. This observation was equally confirmed by the curve obtained with the spectrophotometer, as was the obvious absorption minimum at 4650Å. On both sides of the curve the smooth clean trace of the short-wave and the slight shoulder at 5702Å on the long-wave section are apparent. *(Figure 1)* The latter feature could not be discerned in the spectroscope – not even as the finest line. As might be expected, the new sapphire-blue euclase does not react under either long or short-wave ultra-violet light, for the pigmenting iron content acts as an inhibitor.

Optical Behaviour

Not only the colorless, but also the dark blue parts show a remarkable constancy of their optical properties. The refractive indices of the twelve largest specimens varied only between the narrow limits of: –

$n\alpha$ 1.652 (4 specimens) and
1.653 (8 specimens)
$n\beta$ 1.656 (all 12 specimens)
$n\delta$ 1.671 (4 specimens) and
1.672 (8 specimens)

with a birefringence value of +0.019 (for all 12 euclases). In the dichroscope a marked pleochroism was seen, of azure blue, Prussian blue, and greenish-blue.

The axial angle amounted to 2V =48°; the axial plane lay in the (010) plane, and the extinction position measured 41°+. The remaining properties which can be gemologically measured, such as hardness and specific gravity were determined as: H=7½; S.G.=3.06 - 3.13, with an arithmetic mean of 3.096 ± 10.001 g/cm³/4°C.

The determination of all these constants was sufficient to establish the variety and nature of this new gemstone and to identify it undubitably as euclase. Nevertheless, it seemed desirable to carry out an X-ray test in addition.

X-ray Behaviour

The X-ray data were derived from five Gandolfi diagrams, and the crystallographic constants were worked out by computer programs. The resulting d - values correspond well with the values found in the relevant literature*; the lattice constants are somewhat larger, expecially C_0. In agreement with the characteristics of the monoclinic crystal system, to which euclase belongs, many d - values were obtained. In the accompanying table only those for the 45 strongest reflections are mentioned*:

The aforementioned data yield a unit cell with lattice constants of:

$a_o = 4.77_5$Å $(a_o = 4.76_3$Å);
$b_o = 14.29_8$Å $(b_o = 14.29$ Å);
$c_o = 4.65_5$Å $(c_o = 4.61_8$Å).
$a : b : c = 0.334 : 1 : 0.325$
$\beta = 100° 18'$ $(\beta = 100°15')$*
$Z = 4$. Euclase belongs to the space group C^5_{2h}- $P2_1/c$.

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*The values in brackets correspond to data after M.E. Mrose et al. *Zeitschrift f. Krist. 112*, 285-287. 1959. (See also McKie, D. (1955) Notes on some minerals from Tanganyika. *Rec.Geol.Surv. Tanganyika 5*, 81-94)

X-ray and Crystallographic Data for Sapphire-Blue Euclase from Miami, Rhodesia

Gandolfi camera, CuKα -irradiation

I (estimated)	d (measured)	hkl	I (estimated)	d (measured)
100	7.07	020	10	1.948
20	4.576	010	20	1.881
20	4.468	110	10	1.806
50	3.845	021	30	1.784
15	3.578	040	5	1.729
10	3.506	$\bar{1}11$	10	1.669
10	3.298	031	10	1.627
70	3.223	$\bar{1}21$	5	1.565
10	2.962	111	5	1.543
20	2.893	$\bar{1}31$	5	1.512
10	2.836	041	20	1.497
80	2.785	121	10	1.441
40	2.546	131	10	1.409
30	2.449	150	5	1.391
20	2.353	200	10	1.378
20	2.256	$\bar{2}01$	20	1.368
5	2.229	220	10	1.337
10	2.193	$\bar{1}12$	10	1.316
5	2.111	061	20	1.311
10	2.069	151	5	1.286
10	2.042	$\bar{2}31$	10	1.270
5	2.015	$\bar{1}32$	5	1.247
20	1.995		+ further lines	

Microscopic Observations

When seen under the microscope the apparently uniform blue color seen by macroscopic observation exhibits an obviously cloudy (but not streaky) or zonal distribution, and in this respect resembles many blue sapphires.

Unexpectedly the colorless sectors are almost completely clear, while by contrast the blue parts, as well as the completely blue euclases, are more or less rich in inclusions, thus revealing that they experienced a more eventful history of formation than the colorless sectors or crystals. The inclusions consist mainly of cracks, with random trends, which transect the host in any direction. Some of them consist of syngenetic, pseudo-secondary inclusions, i.e. they are partially healed cracks, which are easily recognized as bizarrely shaped "undigested" liquid droplets and hoses. Neither the pattern exhibited by these liquid droplets, nor the shape and arrangement of the "feathers" show specific, diagnostically significant characteristics; no conclusions can therefore be drawn from these inclusions as to the classification or origin of this gemstone. The other kind of cracks could be of epigenetic origin, for they are dry and filled with air – and hence, not healed. They reflect the incident light in certain places, so that when the stone is moved bright reflections flash out. No mineral inclusions have so far been observed. In any case, the inclusions act as a definite proof of genuineness and – when they are not too dense – pleasantly enliven the appearance of these dark blue euclases.

The surprising occurrence of this new sapphire-blue gemstone once more confirms that gemstones can never be certainly identified by their color alone, for who would have suspected 10 years ago that sapphire-blue euclase would one day be found?

The author wishes to thank Professor Dr. M. Weibel, Dr. R. Oberholzer, and G. Brunner of the Institute of Crystallography and Petrography of the Federal Highschool for Technology in Zürich, CH., for their valuable and decisive assistance.

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The Adiel Steacy Memorial Scholarship in Gemology

A very generous scholarship in gemology for Canadians is being offered through the Queen's University in Kingston, Ontario, Canada. The Adiel Steacy Memorial Scholarship will be awarded according to the following conditions:

> "This is an annual scholarship open to a resident of the city of Brockville or the surrounding area who is in need of assistance to enable him to pursue the study of gemology. The scholarship provides actual costs up to a maximum of $2,500 to enable the recipient to attend the Gemological Institute of America or any institute in Canada of equivalent status. If there is no applicant from the city of Brockville or the surrounding area, the scholarship may be awarded to a person ordinarily resident in Ontario. It is a condition of the scholarship that the recipient must seek employment in the jewelry industry in Canada. Applications should be submitted to the Assistant Registrar (Student Awards), Queen's University, Kingston, Ontario, prior to July 1 of the year of application."

Please contact the Queen's University for further details.

Distinguishing Diamond From Cubic Zirconia:

Old and new tests for the identification of diamond

By K. NASSAU, Ph.D.
Bernardsville, N. J.

Abstract

With the arrival of ever better diamond imitations, culminating in cubic zirconia, even the expert may no longer be able to trust his trained eye. Most of the classical gemological properties (hardness, density, refractive index, dispersion, etc.) either cannot usually be used or have severe limitations.

Three new approaches are the reflectometers, the recent surface wetting behavior (with water or with ink), and the very recent thermal conductivity probe. The uses and limitations of these, as well as the older techniques, are described.

A. Introduction

Once upon a time it was easy to tell an *imitation* diamond from a *real* diamond. The low refractive index and dispersion materials, such as colorless sapphire and spinel, just lacked any real "life," and the high refractive index and dispersion of strontium titanate (e.g. "fabulite") and rutile (e.g. "titania") had so much "fire" that anyone with the least experience could never mistake them for diamond.

When the synthetic garnets YAG and GGG came on the scene(1), the distinction became more difficult. Yet with a little practice both of these materials, as well as the rather similar colorless natural zircon, could be distinguished from diamond. One would, for example, look at the faceted stone from the side, or immerse it in water, and the difference would become obvious.

With the recent arrival of cubic zirconia(2), however, the situation has changed drastically. Even the professional can no longer just glance at the stone and say: *"yes, a diamond"* or *"no, an imitation."* He has to take his loupe, examine the stone closely, and then his highly trained eye should give him the answer. *Figure 1* is an attempt to show this close likeness between a $5000. diamond and a $50. cubic zirconia.

Even though cubic zirconia has been available only for a short time, there have been many reports of jewelers being deceived by them. In several instances a "customer" viewing a batch of loose diamonds has successfully substituted a cubic zirconia for one of the diamonds. There have also been jewelry items sold to jewelers in which just one or two of a number of diamonds in the setting were cubic zirconias; even ballerina settings have contained some cubic zirconias mixed in with the diamonds.

In most other gem materials, the

measurement of the refractive index is the test which will almost always give a unique answer. However, the better diamond imitations have a refractive index above the range of conventional refractometers, and other testing techniques are needed.

Cubic zirconia is too recent to be found in the gem testing books, but textbooks, such as the Liddicoat(3) and Anderson(4) volumes, should be consulted for the conventional gemological tests discussed below.

This article reviews the different properties of diamond and examines how some of these can be used for identification. Recent new approaches to this problem will be discussed, including the reflectometers, the contact angle and wetting tests, and the thermal conductivity probe. Although the distinction between diamond and cubic zirconia is the most difficult problem, other imitations such as YAG, GGG, strontium titanate, rutile, and zircon will also be briefly covered.

Of utmost value to the trained eye is the appearance of the facets, edges, and the girdle: with its supreme hardness, diamond yields extremely flat facets meeting at razor-sharp edges. Such perfection is almost unknown in the softer gem materials where different faceting techniques are used and where much less care is taken in the shaping. To the expert, the bruted girdle of the diamond, sometimes "bearded" from too rapid bruting, is quite characteristic. The presence of "naturals" on or close to the girdle, these being portions of the original diamond faces and frequently showing "trigon" growth or solution features, are diagnostic for diamond. Note, however, that an unpolished facet recently seen next to the girdle of a cubic zirconia looked just like a "natural" at a quick glance.

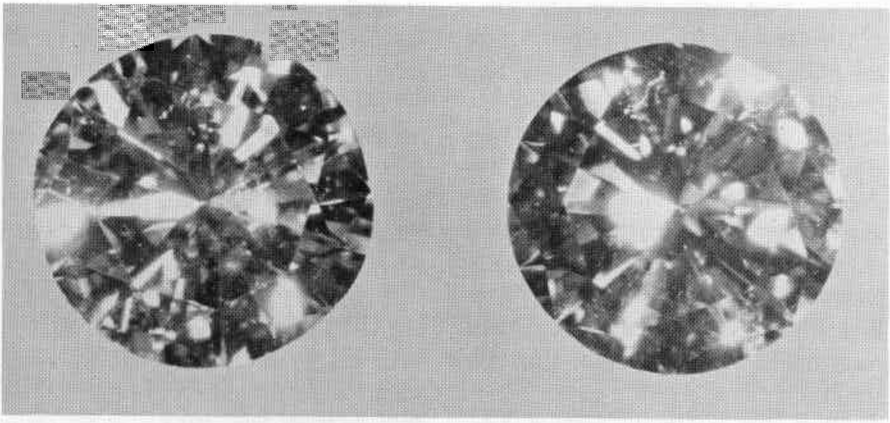

Figure 1. Which is the $5000. diamond and which the $50. cubic zirconia? If you just guess, you have a 50:50 chance of hitting it right. If you think you can see a real difference, it probably lies in the problem of photographig and reproducing in color such gemstones. (The answer is given at the end of the article). Courtesy of A. Israel Diamond, Inc., and MSB Industries, both of New York City).

The adamantine luster is shared by diamond, cubic zirconia, strontium titanate, and rutile. The "fire" from the dispersion is shared by diamond with cubic zirconia and zircon; strontium titanate and rutile are excessive in this respect and therefore easily spotted. Strong birefringence shown by apparent doubling of the back or side facets is present in rutile, is weaker in zircon, and any material can have some weak strain birefringence (anomalous double refraction).

Observing the apparent loss of brilliance when the gem is viewed from the side or immersed in water or a higher refractive index liquid will reveal the lower refractive index materials such as zircon, YAG, and GGG.

Characteristic inclusions seen under magnification can be diagnostic, but only to the knowledgeable; in clean stones this is, of course, not very helpful!

C. Optical and Related Characteristics

None of the convincing diamond imitations has a refractive index lower than 1.81, and therefore cannot be measured on the conventional refractometers. This also eliminates the possibility of a measurement of the birefringence which was discussed in the previous section, and the dispersion is never easily measured. Pleochroism does not occur in these colorless materials. There is always the technique of measuring the actual depth of a stone and dividing it by the apparent depth, as read on a scale attached to a microscope, to obtain the refractive index, but this is a difficult test to perform accurately, particularly in a mounted stone, and does not give satisfactory values on small stones.

The recently developed reflectometers indirectly evaluate the refractive index by measuring the amount of light reflected from the polished surface. Several instruments have been placed on the market in recent years, including the Gemeter(5), the Gemeter '75(6) (made by Sarasota Instrument, Inc., Sarasota, FL); the Jeweler's Eye(7-9), Lustermeter(8-10), and Diamond Eye(9) (Hanneman Lapidary Specialities, Castro Valley, CA); and the Martin Gem Analyser(11) (Martin Precision Instrument Inc., Saratoga, CA). All appear to use a battery powered semi-conductor light-emitting diode operating in the infrared. These are very stable devices, and the use of the infrared permits an improved distinction of diamond from the imitations, since the refractive index variation with the wavelength of light is different in different materials. Full descriptions may be found in the cited references, particularly reference 7.

There are some limitations to these reflectometer type instruments. The surface must be flat, clean and free of imperfection. Several readings must be taken in different spots on the gem, since scratches will give low readings, and internal reflections can give high readings. Although satisfactory for the main stone protruding from a setting, other stones (or even the main stone if it does not protrude) cannot be measured. Curiously enough, a modification employing a narrow elevated tube for the positioning of the stone could avoid much of this limitation, but none of the reflectometer instruments have such a feature.

The spectroscope can identify the cape series of diamonds (the yellow and darker tinted stones), but this is a very limited test. The exceptional transparency of diamond to X-rays is diagnostic but similarly not of general utility. Fluorescence, whether stimulated by ultraviolet, X-rays, etc., can be of value in the hands of an expert, but most materials can be so variable in their reaction that this is of little value by itself. An exception occurs with those diamond stones giving a strong blue fluorescence under long wave ultraviolet light if they also give a yellow phosphorescence (afterglow) when removed from the excitation; this appears to be diagnostic.

D. Mechanical Properties and Related Tests

No other material even approaches the hardness of diamond, and this certainly provides a unique test. However, it cannot be generally recommended since there are dangers. In one form of testing, a tungsten carbide point is applied to the stone. If it turns out to be not a diamond, the stone may be disfigured; even a diamond may, however, be damaged if a hidden weakness, a strained region at a cleavage plane, or an area close to a thin girdle is handled too carelessly. Alternatively, the girdle can be applied to a piece of sapphire to see if it will scratch it. Either of these or related tests should only be used by an experienced tester and with the recognition of the risk involved.

The density (specific gravity) gives a very satisfactory distinction if a loose stone is involved; indeed merely hefting in the hand will readily separate a diamond from a cubic zirconia of similar size. With a set stone this test is, unfortunately, not applicable. The determination of structure by X-ray diffraction is a test that is not very practical. The characteristic octahedral cleavage of diamond can be seen in the rough material, but only rarely in the faceted stone.

The electrical conductivity is diagnostic only for the rare and valuable blue type 2b diamonds.

The fact that diamond is not wetted by water but preferentially attaches itself to grease is well known and is used in its separation from rock on the "grease tables" in South African diamond mines. In a recent report by Nassau and Schonhorn(12) an account has been given of how this can give a satisfactory distinction between diamond and its major imitations which are even less easily wetted! Here again, some experience and, in particular, a meticulous cleanliness and measurement technique are necessary. As described there(12), an adherent film left by irradition can give erroneous measurement, but can be removed by a mild abrasive (see below).

In previous attempts to use such a wetting test by Tjwan(13) and Hanneman(14), lack of an adequate cleaning technique appears to have produced haphazard results and conclusion that cannot be accepted as valid(12).

More recently, an "ink test" seems

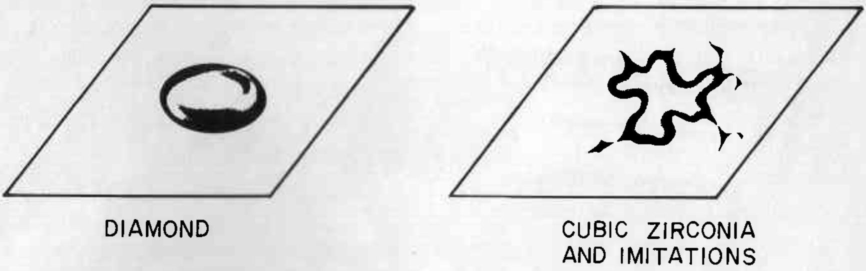

Figure 2. Drawing of an ink test on Diamond (left) and Cubic Zirconia (right).

to have arisen almost spontaneously in the diamond industry. The stone is cleaned (merely wiping with a clean cloth appears to be adequate), and a spot of ink from the right type of felt-tip pen or marker is applied on the surface of the gemstone. Under these conditions the ink wets the diamond and forms a spot with smooth edges; on cubic zirconia and the other major imitations the ink does not wet but beads up and withdraws from much of the area covered with ink as does water on a greasy surface, as shown in *Figure 2.* The spot must be examined before the ink dries up.

A survey by the author of a number of felt tip pens showed that the response is variable, presumably dependent on the specific nature of the chemicals used in the ink formulation. Interestingly enough, manufacturers who market several different pens and markers each, such as Sanford and Esterbrook, appear to use different formulations in their different lines, as shown by the results of *Table 1.* The results of *Table 1* can be used as a guide for choosing a pen but any specific pen should still be checked before use, since the ink formulation could always have been changed by the manufacturer in the meantime.

Unfortunately, the validity of this test has already been compromised, since some cubic zirconias have been reported by Crowningshield(16) to have been coated so as to give the diamond response to the ink test. It has been found, however, that a light rubbing with a mild abrasive will remove such a coating or an irradiation-induced coating (see Appendix), and a set of a special ink pen together with an abrasive is being marketed by the Gem Instruments Corp., as listed in *Table 1.*

Lastly, there is the use of the uniquely large room-temperature thermal conductivity of diamond. This is much larger than that of any diamond imitation, and the Ceres Diamond probe (manufactured by the Ceres Corp., of Waltham, MA) is scheduled for marketing by the end of 1978. *(Figure 3)*

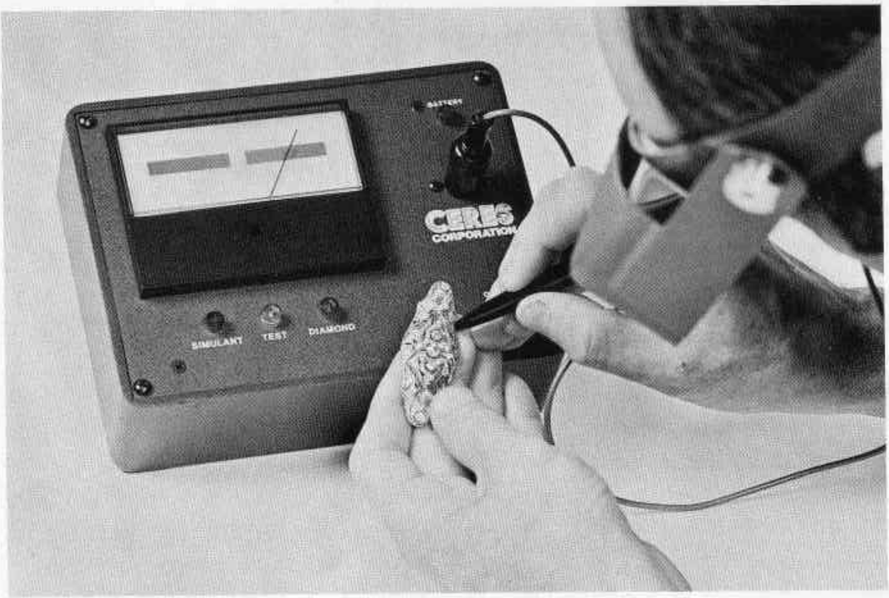

Figure 3. A brooch containing 39 diamonds being tested with the Ceres Diamond Probe. All stones, down to 0.03 carats in size, were checked out in less than three minutes.

TABLE 1.
PENS TRIED FOR DISTINGUISHING DIAMOND FROM CUBIC ZIRCONIA AND OTHER IMITATIONS

A. Specially manufactured for the purpose:
   GEM Diamond Pen (Gem Instrument Corp., Santa Monica, CA; includes an abrasive for removing coatings.)

B. Suitable
   (Diamond is wetted)
   Banana (Bic)
   Feltwriter (Esterbrook)
   Liquid Crayon (Magic Marker)
   Pilot
   Scripto
   Skinny Tip (Magic Marker)
   Vis-a'-Vis (Sanford)
   Wearever

C. Not Suitable
   (Diamond and Cubic Zirconia are both wetted)
   El Marko (Flair)
   Lab Pen (Nalgene)
   Marker De Luxe (Sanford)
   Sharpie (Sanford)
   Vega (Farber-Castell)
   Vu Thru (Esterbrook)

D. Not Suitable
   (Neither Diamond nor Cubic Zirconia is wetted)
   Expresso (Sanford)

E. Not Suitable
   (Dries too rapidly)
   Liquid Tip (Blaisdell)

The point of a pen-like probe is applied to a stone and the deflection of a meter needle and a flashing light gives a reading in two to three seconds. The brooch shown being tested in *Figure 3* contains 39 diamonds ranging down to about 3-pointers (three hundredth of a carat), and all 39 stones were checked (and found genuine) in less than three minutes. With its slender probe point, the nature of the mounting does not interfere, as it can with the reflectometers, and surface coatings do not appear to affect the reading.

An interesting low priced version of this test is the "breath test." If one breathes on a diamond and an imitation of about the same size, so that a little moisture from the diamond will evaporate much more rapidly than from the imitation, again because of its much larger thermal conductivity. Obviously some practice is advised, and surface coating can have a significant effect on this test.

E. Summary

With a loose stone, the high density is a give-away for cubic zirconia. The major stone in a mounting, if it protrudes from the setting, can be checked on a reflectometer type instrument such as the "Diamond Eye." All stones can be checked rapidly and precisely by a thermal conductivity probe instrument such as the "Ceres Diamond Probe." In the absence of these instruments, an ink wetting test and the "breath" test can be tried, but coatings could conceivably interfere.

A doublet consisting of a thin natural diamond top and a cubic zirconia base would, of course, pass as a diamond by any test which is applied only to the diamond table facet of such a stone. Examination by the trained eye, looking for general features as well as characteristic defects, "naturals" on the girdle, etc., could of course identify such a stone and is a necessary part of any gemological examination.

NOTE: In *Figure 1,* the diamond (with a dagger-shaped reflection) is at the left.

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Transparent Bluish-Green Kornerupine From East Africa (Kenya and Tanzania)

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Since 1972 bluish-green and blue kornerupines (Bank & Berdesinski 1974, 1975; Webster 1974) from Kenya and Tanzania have arrived at gemological laboratories.

These stones are distinctly different in their optical features from the green kornerupine crystals from the Kwale District, Kenya (Schmetzer et al. 1974; Girgis et al. 1976). The samples which are described here are mainly cut stones which could be partly detected in lots of other minerals (green tourmalines or green garnets). Partly they had been offered as single stones under other names (e.g. sillimanite).

In the last few months, we have been able to obtain bigger lots of rough cuttable material of these

TABLE 1:
PLEOCHROISM OF KORNERUPINE FROM DIFFERENT LOCALITIES.

Ceylon and Madagascar	Kwale District Kenya	Kenya and Tanzania, various localities somewhat different due to contents of trace elements		
X yellowish-brown	intensively green	emerald green	emerald green	
Y brown	slightly green	bluish grey	reddish purple	Y and Z show only small differences
Z green	greenish-yellow	reddish purple	bluish grey	

bluish-green kornerupines for investigations. Therefore, we will publish here some of our results though we have not yet been able to comprehensively clarify the especially interesting correlation between their crystal chemistry and colour.

The kornerupines mentioned above differ especially in their expressive pleochroism *(Table 1)* from those of the Kwale District, Kenya, and also from the brown-green crystals of the historic occurrences in Ceylon and Madagascar. They show, on observation in polarized light parallel to the crystallographic c-axis, an intense emerald-green colour.

Perpendicular to the c-axis, there can be seen a slightly weaker blue colour which may differ from crystal to crystal (sometimes more reddish-purple, sometimes more bluish-grey). The color itself varies in natural, unpolarized light in various stones from green over bluish-green to blue and purple. This colour corresponds to the colours along the detections of X, Y and Z (colours parallel to the crystallographic axis a, b, and c of the orthorhombic mineral kornerupine) and eventually a mixture of these three colours appears on viewing at any angle other than these directions. A similar pleochroism is present for different colours of all varieties of optically anisotropic minerals but only in very few minerals are they distinctive. It has been described by Rösch 1971) for blue zoisite as an example.

Though polarized absorption spectra of the kornerupine crystals from Kenya and Tanzania could not yet be interpreted in detail, it can be stated with certainty, as result of chemical and spectroscopical investigations, that the colour is caused by traces of the elements iron, chromium and vanadium *(Table 2).* In the case of blue samples, it was possible to determine distinctive contents of Cr_2O_3 analytically, whereas chromium-free

TABLE 2:
CHEMICAL ANALYSIS OF KORNERUPINE (ELECTRON PROBE ANALYSIS).

Locality	Colour	Fe	Cr	V
Madagascar	brownish-green	0.83	0.02	0.01
Ceylon		3.82	*	0.02
Burma		1.05	0.02	0.01
Kwale District, Kenya	green	0.03	0.03	0.15
Kenya and Tanzania, Various localities	green	0.08	*	0.04
	green	0.05	0.04	0.17
	bluish-green	0.14	0.06	0.07
	blue	0.11	0.10	0.02
	blue	0.18	0.39	0.53

* = not detected

kornerupines and samples with little chromium and much vanadium showed green colour shades in varying intensity. Chromium will possibly be present as Cr^{3+} in the Mg-Al-silicate kornerupine whereas the valency states of iron (Fe^{2+} and/or Fe^{3+}) and vanadium (V^{3+} and/or V^{4+}) could not yet be determined. The lattice positions of these ions, which theoretically may occupy five different lattice points in the crystal structure of kornerupine, could not yet be determined.

The refractive indices of the optically biaxial negative kornerupine crystals vary for the various determined samples within narrow limits.

Due to the small optical angles, n_y and n_z do not show a big difference.

n_x	1.662 - 1.663
n_y	1.673 - 1.674
n_z	1.674 - 1.675
$2V_z$	6 - 11°
$n_z - n_x$	0.012 - 0.013

Until now, we have only been able to recognize that the kornerupine crystals come from occurrences in Kenya (District of Namanga) and Tanzania (Southern part of the Usambara Mountains or Daluni in the Umba Region). Most probably, there will be discovered more localities of blue kornerupines in Eastern Africa.

We thank Professor Dr. E. Gübelin, Lucerne, Switzerland, and Mr. H.W. Lorenz, Idar-Oberstein, West Germany, for giving research material from Ceylon, Madagascar and Burma from their collections.

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Bluish-Green Zoisite From Merelani, Tanzania

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Since the first publication on the blue variety of zoisite, called tanzanite, from Merelani, Tanzania (Bank et al. 1967), this mineral has become an important gemstone. The colour is caused by traces of vanadium, replacing Al^{3+} in the crystal structure of zoisite (Hurlbut 1969). The absorption spectra of this blue zoisite has led various working teams to different interpretations of the absorption bands (Faye & Nickel 1971; Tsang & Ghose 1971). Most probably, the Al^{3+}-positions are occupied by tri- and tetra-valent vanadium ions (Schmetzer 1978). The colour change of the zoisite crystals from Merelani through heat treatment to approximately 500°C is caused by the disappearance of an absorption band in the blue part of the visible spectrum (at 22,000 cm^{-1}). The following scheme of pleochroism before and after heat treatment is given:

crystals before heating

X	a	reddish-purple
Y	b	blue
Z	c	yellowish-brown

crystals after heating

X	a	reddish-purple
Y	b	blue
Z	c	blue

Green zoisite from Longido in Tanzania, which is coloured by Cr^{3+}, was first reported by Game (1954). The absorption bands in its spectrum are attributed to Cr^{3+} -ions, which have been already described for vanadium, and are located on Al^{3+} -positions in the zoisite lattice (Schmetzer & Berdesinski 1978).

Some time ago, one of the authors discovered in rough zoisite crystals from Merelani numerous bluish-green stones, showing a pleochroism differing from that of pure blue zoisite. When heated up to 500°C, these stones also changed their colour. The pleochroism of heat treated and non-heat treated stones of this bluish-green type is mentioned in the following scheme:

crystals before heating

X	a	reddish-purple
Y	b	bluish-green
Z	c	greenish-yellow

crystals after heating

X	a	reddish-purple
Y	b	blue
Z	c	bluish-green

The optical and crystallographic values of the bluish-green zoisites do not differ from the respective parameters of the blue zoisites. The absorption spectra of the bluish-green varieties show all bands of the vanadium-bearing blue crystals from Merelani and those of the chromium-bearing zoisites from Longido. Microprobe analysis confirms the spectroscopic investigation: the bluish-green crystals contain nearly equal contents of vanadium and chromium (0.06% V, 0.07% Cr), whereas, the iron contents of bluish-green and blue zoisite from Merelani remain very low (0.001% Fe).

The bluish-green zoisite from Merelani must be regarded as coloured by both vanadium and chromium. We regret that we could not find out in which part of Merelani deposit these bluish-green crystals occur. Therefore, there is no possibility to discuss the genesis.

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GEMOLOGICAL NOTES

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Blue Gem Haüyne

Haüyne has been found in absolutely clear blue, rather large pieces in the Eifel mountains in Germany, in lava flows of basalts. About 20 years ago, the author collected one translucent piece in the Trachy-Basalt quarry of F.X. Michels in Niedermendig near Koblenz.

Now there have been about 50 pieces available showing the following properties: (Bank 1977)

R.I. average	1.496
varying from	1.490 - 1.500

Haüyne is chemically

$$(Na, Ca)_{4\text{-}8}(SO_4)_{1\text{-}2}Al_6Si_6O_{24}$$

and crystallizes in the isometric system. It got its name by Brunn & Neergard 1807 after the abbé Haüy.

Troeger et al.

Reported R.I.'s of up to	1.508
S.G. =	2.45
Hardness	5 to 6

Webster (1975) mentions orange-red luminescence under long wave ultra-violet light.

An X-ray powder diagram confirmed the material as Haüyne.

The stones go up to the weight of 3 ct. per piece.

Demantoid Garnet From Korea

Demantoid belongs to the andradite garnets:

$$Ca_3Fe_2(SiO_4)_3$$

(1868 named by Dana/Nordenskjold 1878) and owes its colour to Cr.

The finest demantoids are known from the Ural Mountains in Russia and there have also been found demantoid garnets in Italy in the Fassa Valley.

New stones are now reported from Korea.

(green DIN - card 6164 1 : 5 : 3).

They form idiomorphous crystals with the Deltoid – Icositetrahedron as the common crystallographic form.

The crystal lattice was determined using the Debye-Scherrer X-ray powder diagram method (Camera 114.8mm., Fe Kα

$a_0 = 12.0587 \pm 0.0002$ Å).

The Refractive Index was determined with the minimum deviation method for

n_D (589 nm) = 1.8889.

The Specific Gravity was measured 3.82 ± 0.002.

The chemical analysis:

SiO	36.56%	
Al_2O_3	0.12%	
Cr_2O_3	0.06%	
Fe_2O_3	30.34%	
CaO	33.93%	Microprobe ARL - EMX
MgO	0.05%	
MnO	0.03%	
	101.09%	

Absorption spectra with LEITZ-Unicam SP 800 show maxima at 16200 cm^{-1} and 22800 cm^{-1}, which cause the yellow-green colour. Amthaur et al. have found the same bands in andradites from Val Malenco and think that they belong to Cr^{3+}. This would apply to the analysis by microprobe of the Korean stones with the Cr_2O_3 contents of 0.06%.

According to the nomenclature, such andradites may be called demantoids.

Blue to Red Colour Changing Garnet From East Africa

In the last years, East Africa has become a supplier of rare minerals and unusual colours and varieties of old known and common minerals.

Thus, it was not entirely unexpected when a rare colour change garnet turned up. In 1970, Crowningshield, of the Gemological Institute of America, had already described a "rare alexandrite garnet" from Tanzania, of 1.70 cts. with a refractive index of 1.765 and a specific gravity of 3.88.

The semi-quantitative analysis gave:

SiO_2	38.35%
Al_2O_3	26.25%
MnO	16.73%
Cr_2O_3	0.54%
V_2O_5	0.324%

Further Elements: Ti, Cu and Ni.

Therefore, it was no new variety of garnet, but a mixture of pyrope and spessartite.

Inclusions similar to fingerprints were present, and noted.

In 1975, a similar garnet was described by Jobbins et al. Again, it was a loose stone with a definite colour change, blue to red.

R.I.	1.757
S.G.	3.84

The absorption spectra indicated spessartite, the R.I., pyrope. An X-ray diagram which showed an elementary lattice unit of $a_0 = 11.578$Å proved the result: Garnet, rich in spessartite.

An analysis of the elements resulted in Si, Al, Mn, Mg, Ca and Vanadium. Chromium was not detected.

During the International Gemological Conference in Den Haag (1977) the author studied a 3.10 carat stone which had been offered as a spinel and in which a distinct colour change from blue to red was visible, an R.I. of 1.764, together with the density of

3.88, showed that it could not be a spinel.

A X-ray powder diagram confirmed that it was really a garnet with the $a_0 = 11.568Å$.

Further investigations showed:

Cr_2O_5	0.5%
V_2O_5	0.3%
MnO	22.0%

The occurrence is also East Africa.

At the same time, the author investigated a green-blue to red colour changing stone of 1.87 carats, which had been offered as an alexandrite.

The isotropic material furnished an R.I. of 1.778 and a specific gravity of 3.89.

A Debye-Scherrer powder diagram showed that it was a garnet, close to spessartite:

$$a_0 = 11.654 Å$$

Trace elements are:

Cr_2O_5	1% and an extraordinary contents of
V_2O_5	2% and
MnO	22%

The stone came from Sri Lanka. The mine is said to be 20 km. NE of Ratnapura.

Two Interesting Treated Diamonds

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Recently, through the Gem Identification and Appraisal facilities of the Buenos Aires City Bank were admitted two brilliant-cut colored diamonds for color origin determination.

One of the diamonds weighed 1.16 cts. and the other one 3.02 cts. No internal imperfections were observed under 10X magnification. Their color was a dark tourmaline-like yellowish green and the smallest stone was lighter in color than the larger one.

Neither diamond was fluorescent to long or short-wave ultraviolet light but they showed a bluish white X-Ray fluorescence without any visible phosphorescence.

As they were suspected to be artificially colored diamonds, a detailed examination was performed with the Gemolite searching for the "umbrella" effect commonly observed as a consequence of the modern cyclotron color treatments. The results were negative.

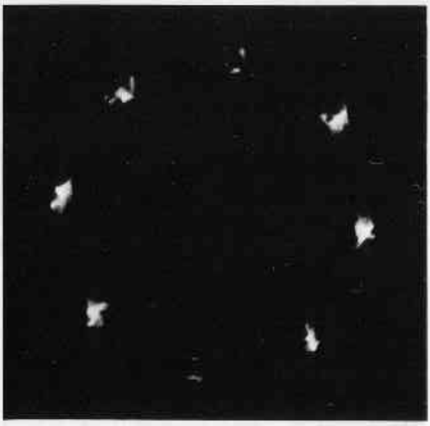

Fig. 1: Autoradiograph of the 1.16 carat radium treated diamond after 72 hours film exposure.

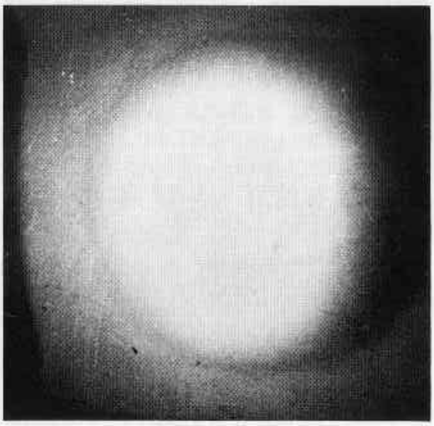

Fig. 2: Autoradiograph of the 3.02 carat radium treated diamond after 94 hours film exposure.

Next, the absorption spectrum was studied and this showed no lines characteristic of treated diamonds.

A zinc bisulfide screen test was also carried out and did not show any sparkling effect.

Next, a radiographic-plate test was carried out by placing each diamond in contact with an unexposed film in a light-tight paper holder. After a seventy-two hour exposure, the smallest brilliant left a spotted octagonal-shaped photographic impression (see photograph #1) delineating the table outline. The largest diamond left a less defined but strong impression after ninety-four hours exposure, showing a stronger residual radioactivity (see photograph #2).

Under magnification, the diamonds did not show the flat, disclike, brown spots characteristic of the Radium-diamonds.

Finally, a qualitative verification of the water contact angle *(Gems & Gemology,* Winter 1977/78) was carried out. This led to quite lower values than the contact angles for non-treated diamonds. However, the test is not conclusive because no way was available to accurately measure the contact angle and then compare it to an untreated diamond as a standard.

The tests performed certified they both were artificially colored Radium-treated diamonds. Radium treated diamonds are now quite rare on the diamond market and these made an interesting study.

The authors wish to thank the Buenos Aires City Bank for the facilities given to make this work possible and the permission to publish the results.

BOOK REVIEWS

BEANS ABOUT CARATS, "A Guide for the Serious Salesperson" by Rick Thomas.
Published by GEM PUBLICATIONS, Logan, Utah.
Illustrations by the author in black and white. 165 pages. Paper bound.

At age 23 the author has condensed some inspirational sales techniques set forth by well known authorities and sales courses into this easy-to-read book. He has added interesting personal experiences and oriented the entire text toward jewelry sales people as he exhorts them to "work smarter."

He is very open with his readers and shares with them his successes, large and small, and with humility, his failures and shortcomings as well. His insight as to the thinking process of prospective customers in their last stand before the persuasion of the salesperson reflects much original thought and practice in the technique of closing a sale.

For one who entered the jewelry business with some misgivings after completing high school, it reveals fresh, stimulating thoughts of a very young man who has already come a long, hard way.

The work should not be considered a text book. The reader must overlook numerous errors in grammar and spelling, considering only the thoughts of the author. The famous industrialist of Carnegie, United States Steel Corporation, and Bethlehem Steel, for example, was Charles Schwab, not Charles Schaub.

Rick has taken the liberty of inserting frequent mention of other publications and services that he has or expects to provide which might have been more tactfully promoted elsewhere.

The book is easy to read with large type printed on quality paper. One extra sale derived from an idea presented in the book would be worth much more than its cost.

J. Burton Streeter

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