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and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

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OF GREAT BRITAIN
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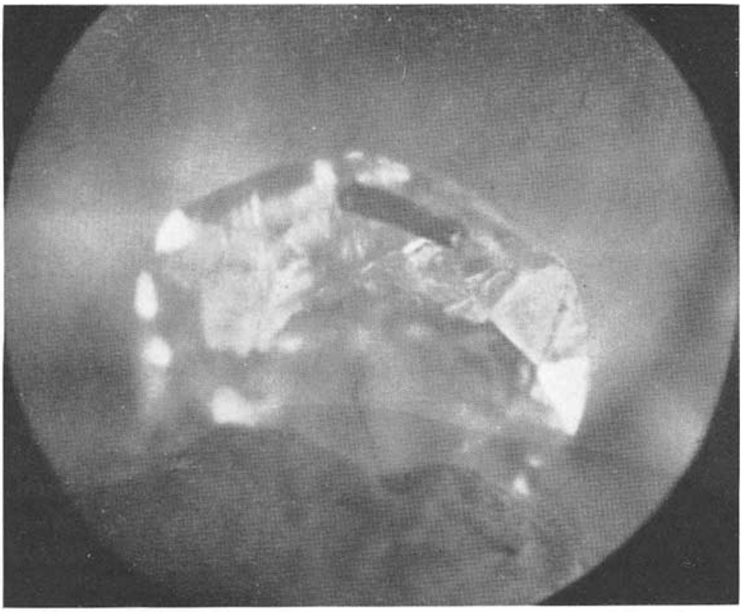
A GARNET PROTRUDES

By A. E. FARN

WORKING in the laboratory has compensations in the fact that one either becomes known or gets to know fellow gemmologists (both in the trade and outside of the trade). Buying and selling is much more interesting and rewarding if one is dealing with goods whose qualities, physical, optical and/or financial are appreciated by both sides.

I am often shown pieces of jewellery for interests' sake, or shall I say, for their gemmological interest. Quite recently a friend, Oscar D. Fahy, sent to me as an item of interest a small diamond which had broken and presumably was a replacement job in jewellery. The stone weighed 0·12 cts and was brilliant-cut with a slice broken away from the girdle as a chord is to a circle. On close inspection a real interest became immediately and vividly apparent. We have known of garnet inclusions in diamond before and seen photographs of them but here was an inclusion with a difference. A garnet certainly was "included" in the broken portion but another, which had caused a plane of weakness and strain, was centred in the rough breakage plane and was still embedded half in and half out of the diamond. The garnet literally protruded from the cleavage face of the break and at first sight it looked as if it had been planted there by artificial means. I know that exhibits of diamond in blue ground are suspect, i.e. they are often put in for show purposes, but this piece really was startling in it's revealing the garnet quite sharply. Yet in so small a stone of only 0·12 ct. it was easily seen with a 10 × lens. My first reaction was to covet the stone from an interest point of view. Here I was very fortunate indeed because on request for a loan of the stone to do more to it, I was generously given it by Mr. Fahy. Having burned my boats by saying I wanted to write it up I was faced with the fact that in an article people like pictures. R. K. Mitchell, to whom I am indebted, took a keen interest in the matter and spent quite a lot of time and patience in obtaining the photographs of the emergent garnet crystal. I understand this is far from an easy job and in fact I was supplied with a small roll of negative of exposures taken of the stone. When one considers that the *stone* is only 3 mm across and the "inclusion" barely 1 mm in length and about 0·1 mm in thickness, it was quite a feat to photograph it with any real sharpness. Had colour photography been possible it would have been a very impressive sight indeed since the garnet was such a vivid red. At first, although garnet seemed to be the obvious solution, I wasn't happy with it's colour since other garnets used as indicators did not seem to have the fine red colour, even in smaller pieces.



My first rather quick check on the garnet by spectroscope showed no absorption spectrum, neither proving or disproving it to be garnet. As I had a lurking suspicion that it could be spinel I placed it very carefully between crossed filters and had absolutely no reaction for chromium—here I felt sure that such a critical test would have given a reaction (since "colourless" synthetic sapphires have glowed faintly between crossed filters due to the finest trace of chromium in their manufacture. Had the inclusion been a spinel—with such colour—it would have glowed a fierce red between crossed filters. This spurred me to further efforts with the spectroscope. By sitting the diamond on a thin wafer of lead and piercing a hole just large enough for the inclusion to fit, I was able to force light through the stone and obviate glare from my eyes. I must confess to little success in this transmitted light method and did not see any spectra.

Later I tried using a two-thirds objective and an eyepiece to focus the stone in the manner described for the spectroscope set up as described in the Journ. Gemmology, April 1962, and, leaving the frosted glass screen on the microscope eyepiece (usually one removes it), I was able to place the spectroscope slit practically on the image of the garnet and, to my relief, I was able to see something like a pyrope spectrum, which since the stone in all probability came from Kimberley was not surprising. The provenance of a stone can be useful in clinching a determination when all other factors add up to 99% and although one "knows" the stone to be whatever it is by sight and rule of thumb, it is very satisfying to know your tests stand firm against all doubts and aspersions now and tomorrow.

Sometimes a stone is presented for checking and one is told it has doubts cast upon it and that one has tested it years before and stated it to be genuine. It is always comforting to find that one's determination of weight, size, shape, spectra, etc., all add up to 100% positive and literally "no stone was left unturned".

NOTES ON THE GEM VARIETY OF THE OUTOKUMPU CHROME-DIOPSIDE

By Y. VUORELAINEN

THE Outokumpu copper ore is situated in Northern Carelia. It is closely connected with quartzite in the Kalevian mica schist formation. The zone is characterized by a number of Ni- and Cr-bearing ophiolites, which have intruded into the rupture zones of the schist formation. In addition to these, there are also skarn rocks, which have been formed by the reaction between the dolomitic varieties of the ophiolites and quartzites. Their most common minerals are Cr-bearing silicates, such as chrome-diopside, chrome-tremolite and chrome-garnet (uvarovite). Chrome-epidote (tawmawite), chrome-tourmaline and kaemmererite are also met with, as rarities. In addition to the silicates and carbonates, oxides also occur, the most common of which are picotite, chromite and eskolaite, Cr_2O_3. A considerable amount of chrome-mica fuchsite is encountered in quartzites. A common feature characterizing the chrome-silicates of most of the occurences is their beautiful, deep emerald-green colour. Due to this colour, attempts have been made to use many of them as gemstones, but only the chrome-diopside has turned out to have any value in this respect.

An almost monomineralic chrome-diopside rock with a width varying from a few centimetres to a few metres is often encountered at the contacts of quartzites. In these rocks the lengths of the biggest, board-like crystals can attain as much as two metres. Usually the mineral has a greyish, emerald-green colour, showing a distinct cleavage, and consequently it is unsuitable for cutting. In limestones and pure quartzites some very beautifully shaped, deep-coloured crystals are encountered, often suitable for cabochon-cutting. In the cabochons, cut along the *c*-axis, a beautiful cat's-eye phenomenon can sometimes be observed.

Extremely rare is zoned chrome-diopside occurring in dolomitic skarns, where the bright emerald-green layers alternate with those of the grey or almost white ones. Among the varieties described above a glassy, beautifully coloured, slightly transparent material, suitable for cutting is only seldom encountered. The first crystals of gem quality were discovered by the author in 1948 among the waste material. The crystals—the biggest of them being 2 by 0·5 cm—were completely embedded in sulphidic material, which in this case was pyrrhotite. Their colour was bottle-green, only the tops having a deeper colour.

Due to this first discovery I began to study the sulphide apophyses which penetrated from the ore body into the skarn rocks. In some pyrrhotite dikes gem quality crystals were found, but their colour was not very good. In 1954 I finally encountered perfectly clear, beautifully coloured chrome-diopside crystals on the walls of apophyses, rich in chalcopyrite, which had been caused by local tectonic movements. Later observations showed that this is the only mode of occurrence of fine chrome-diopside in Outokumpu. The crystals are almost invariably twins, the twinning plane being 100. The biggest, gem quality crystals attain 20 carats. Some of the crystals, which were quite faultless at the moment of discovery, broke a few days after they had been taken to the surface. Unfortunately the number of the good crystals found is rather small; perhaps only a few hundreds have been found. The Smithsonian Institute is probably the only public collection where some of these stones are displayed. Three of them are beautiful, cut specimens, and one is a crystal of about 10 carats, embedded in the matrix.

The mineral is distinctly pleochroic, the colour changing from yellowish emerald-green to deep, pure emerald-green.

Data

R.I. determination with Rayner refractometer

$\alpha = 1{\cdot}668$
$\beta = 1{\cdot}678$
$\gamma = 1{\cdot}700$

Hence opt. +, 2V = ca. 60^0 corresponding ordinary diopside with 6–9% hedenbergite.

X-ray powder diffraction diagram was typically that of diopside.

With a spectroscope three lines in the red were observed, the first one the broadest; there was general absorption from blue onward.

An average density figure of 3·286 was obtained by Dr. P. Zwaan, of Leiden, from very small specimens of less than one carat. In view of the smallness of the specimens other values are possible.

THE CLASSIFICATION OF DIAMONDS ON THE BASIS OF THEIR ABSORPTION AND EMISSION OF LIGHT

By B. W. ANDERSON

MOST of the gem minerals have peculiarities of physical behaviour which have made them profoundly interesting to scientists who care nothing for their ornamental or monetary value. Diamond, incomparably the most important gemstone in commerce, is an excellent example of this. Despite the apparently simple composition and structure of the mineral, each individual diamond is less predictable in its reaction to electrical or electro-magnetic energy than a stone of any other species. In particular, in the absorption of infra-red, visible, and ultra-violet rays and in the emission of light in the form of fluorescence and phosphorescence, diamonds are notoriously variable

This paper consists of a brief review of the discoveries in this field over the past 100 years or so, and a more detailed account of recent attempts to bring some sort of order and pattern into these aspects of diamond behaviour by classifying diamonds into various recognizable " types ".

In the last two decades physicists have entered the lists and have accurately measured and codified the phenomena in an attempt to explain matters on their own fundamental level. The gemmologist can gain in understanding by a careful study of their work, but on his own account, with his more limited apparatus and skills, has developed methods of observation which enable him to cope with some success with such urgent practical matters as the discrimination between natural coloured diamonds and those which owe their colour to irradiation.

LUMINESCENCE

The scientific study of luminescence in diamond can be said to have started a little more than a century ago when E. Becquerel,[1] in one of the really " great " papers in the history of science, described the reactions of diamond and other minerals in his newly-developed phosphoroscope. In this ingenious apparatus he was able to study the spectrum of phosphorescent light from diamonds a fraction of a second after they had been illuminated by light from the sun. He found that the phosphorescent light was usually blue when the observations were made only some 1/1000th of a second or less after irradiation, but changed to yellow when the interval was longer. Thus early he discovered one of the interesting facts of diamond luminescence which in our experience is invariable—that a bright blue-fluorescing diamond displays a persistent yellowish phosphorescence. This forms an important practical test for diamonds in jewellery. Becquerel also depicted, in the drawing accompanying his paper, the range of the luminous glow from diamond, showing it to extend from the orange to the blue with a break between the E and F lines of the Fraunhofer spectrum—i.e. between 5270 and 4861Å.

Among other early observers on diamond fluorescence and phosphorescence was Sir William Crookes[2] who obtained spectacular results under cathode rays, including the rarer green, yellow, and even red fluorescence which some diamonds display. Crookes recorded the wavelengths of several bright lines seen in the strong greenish-white fluorescence of a green diamond as 5370, 5130 and 5030Å, which accord closely with more modern measurements. He further mentions seeing " the yellow sodium line " and the " citron line of yttrium " in light from diamond. These are almost certainly lines at 5895 and 5750Å, since established in luminescent diamonds.

Up till about 20 years ago the fluorescence of diamond and its variation were plausibly ascribed to the presence of impurities—the almost invariable cause in other minerals and in chemicals. Spectroscopic analysis does indeed reveal the presence of many trace elements in the mineral, of which Al, Si, Ca, Mg, Cu, are the most commonly present; but even the most careful and thorough experiments, such as those of Chesley[3], failed to provide any consistent connexion between colour, fluorescence, and any specific impurities. Nor did there seem any definite connexion between fluorescence and the locality where the diamonds were found.

In the early 'forties, Sir C. V. Raman and his co-workers in Bangalore investigated with great thoroughness the absorption and emission spectra of diamond and showed the intimate connexion existing between these phenomena. Though they did not interest themselves in the question of colour in diamond, it is largely due to their work that the " impurity " school of thought has been abandoned, except perhaps in certain special cases, and the lattice of diamond itself and defects in the structure of the lattice have been held accountable for variations in fluorescence, absorption, and hence colour of the mineral. In recent years the extensive changes in colour, absorption and fluorescence of diamonds which can be brought about by bombardment with sub-atomic particles have provided further powerful evidence to the same effect.

RELATION BETWEEN ABSORPTION AND FLUORESCENCE

In 1941 P. G. Nayar [4] (of the Raman school) published three papers on the luminescence, absorption, and scattering of light in diamonds, in which he showed that a mirror-image symmetry existed between emission lines or bands in the visible spectrum of a blue-fluorescing diamond and absorption bands found in the near ultra-violet. The " hinge " on which both these systems turned was an important band in the violet at 4155Å, which could appear either as an absorption or as an emission line. This absorption band had been first observed in many diamonds by B. Walter in 1891[5], as described later. Nayar was convinced that there existed a direct relationship between the strength of fluorescence and the strength of the 4155 and associated absorption bands. Our own experiments did not bear this out: many diamonds with a powerful 4155 band are virtually inert under ultra-violet rays. On the other hand, we found that the strength of the 4155 band went step by step with that of another series of bands in the blue and violet, of which one at 4780Å is the most important, and that all these bands increased in strength as the depth of tint in diamonds of the " Cape " series became more and more pronounced.

Another important absorption and fluorescent system in diamond based on a line at 5040Å was found by the writer and C. J. Payne to be characteristic of green-fluorescing diamonds, and a suggestion was eventually made (1943)[6] that diamonds could be classified on the basis of their three main fluorescence colours into 3 groups, as follows:—

Blue-fluorescing diamonds, belonging to the " Cape " series, with absorption bands at 4155 and in the near ultra-violet, accompanied by bands at 4780, 4650, 4520, 4350 and 4230Å and fluorescence maxima at 4285, 4390, 4520, 4650Å;

Green-fluorescing diamonds, belonging to the " Brown " series, with absorption bands at 5040, 4980, 5370, 5120Å, of which all save 4980 can appear also as fluorescence lines;

Yellow-fluorescing diamonds, including true " canary " yellow diamonds, showing no visible absorption or fluorescence lines at normal temperatures.

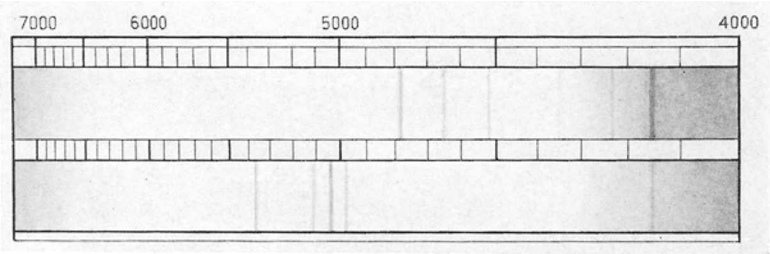
Anna Mani[7] (another of the Raman school) published an important paper in the following year (1944) in which she was able to give full details of the 5040 system, and show that here too there was mirror-image symmetry of absorption bands on the shorter wave-length side and fluorescence bands on the longer wave-length side of the " key " 5040 position.

The absorption bands or lines listed above, and delineated in the illustration can be seen quite sharply through a hand spectroscope at room temperatures, but the fluorescence lines are normally not clearly resolved against the background of a broad emission band unless the stone is at low temperatures such as that of liquid air.

ABSORPTION IN DIAMOND

Having now reached a point in this brief survey where the interdependence of absorption and emission bands in diamond had been recognized, it will be convenient to trace the discovery of the absorptive properties of diamond. Discrete absorption bands were first reported by Walter in 1891, as mentioned above. Using sunlight he found that all the 50-odd diamonds over 1 carat that he examined showed a narrow absorption band which he called " alpha", in the violet near 4155Å, and in yellowish stones other bands, of which the strongest was at 4780Å.

In 1934 came the classic and often cited paper by Robertson, Fox and Martin[8] on " Two Types of Diamond ", in which the now



Absorption bands as seen in diamond through a prism spectroscope
(*top*) *Yellowish diamond of the "Cape" series, blue-fluorescent;*
(*bottom*) *Brown diamond, green-fluorescent.*
(*from a drawing by T. H. Smith*).

familiar division into Type I and Type II diamonds was first made. Type I diamonds have an absorption band in the infra-red at 7.8μ and are opaque, or nearly so, to ultra violet light beyond 3000Å, while the rarer Type II diamonds have no band at 7.8μ and are transparent to about 2250Å. There are other differences, e.g. in photo-conductivity, fluorescence, and X-ray diffraction patterns, but the most conveniently assessed is the ultra-violet transmission.

Many years earlier (1862), Professor Miller[9] of King's College, London, had noticed that two out of three diamonds he tested transmitted much further into the ultra-violet than the others, and Peters[10] made a similar observation in 1893 without following it up. Robertson, Fox, and Martin's paper provides a good example of how much the facts determined depend upon the apparatus and experimental conditions, for, though they studied a large number of diamonds and were well aware of Walter's work, they were able to detect the 4155 absorption band in only one of their specimens and thus dismissed it as not an essential or important feature in diamond. They would have been astonished to know how readily this line can be seen in almost any sizeable diamond with a simple hand spectroscope.

The distinction between Type I and Type II diamonds and (in Type I stones) between the blue-fluorescing "Cape" series based on the 4155Å band and stones of the green-fluorescing "Brown" series based on the 5040 band continues to form a useful broad basis for classification, though many diamonds are found which are intermediate in behaviour and in most fluorescent diamonds both emission systems are functioning, though in very variable absolute and relative strengths. The fact that all strongly blue-fluorescent diamonds show a yellow-green phosphorescent afterglow, as already noted, demonstrates that the green component is also present though masked in this case by the stronger blue glow. The blue component remains frozen in the stone and can be seen as a blue thermophosphorescence when a stone which has been exposed to 3650Å mercury light is later heated. Another way of demonstrating this is to heat a blue-fluorescing diamond to about 200°C. and then expose it while still hot to ultra-violet light. When the hot stone is withdrawn from the rays it then continues to show a blue glow in place of the usual yellowish green. The strength of fluorescence varies enormously: many stones, as is well-known, remain virtually inert under ultra-violet light. Under X-rays there is far greater uniformity of behaviour, almost all Type I stones showing a sky-blue to whitish-blue glow of fair strength, though usually with little or no phosphorescence. Outside these categories are stones showing pure yellow fluorescence under all exciting radiations, including X-rays, and those showing orange or red fluorescence and phosphorescence[11]—though these, by virtue of their ultra-violet transparency, should perhaps be classed as Type II diamonds.

TYPE II DIAMONDS

To distinguish rigidly between Type I and Type II diamonds has in fact not been found possible in many cases. While in general Type II diamonds are less fluorescent than those of Type I, Raman's workers found that strongly blue-fluorescent stones transmitted further into the ultra-violet than the usual limit at 3000Å: moreover, very thin pieces of normal Type I diamonds have been proved to pass light down to 2250Å.

Dr. J. H. F. Custers[12] discovered in 1952 that all natural blue diamonds available for test belonged to a separate category which he designated Type IIb. These are characterized by showing phosphorescence after exposure to short ultra-violet rays, and by pronounced electrical conductivity. Sutherland, Blackwell, and Simeral[13], in an article in " Nature " on " The Problem of Two Types of Diamond " (1954) referred to results by Dr. J. Grenville Wells (now Dr. Milledge) on anomalous X-ray streaks which are normal to Type I being found in some stones which transmit light beyond 2400Å, and exhibit further anomalies in the infra-red absorption region. Since the absolute absorption edge in diamond should (by analogy with high-branched hydrocarbons such as adamantane) be in the 2200Å region, these workers suggested that the anomalous absorptive properties of Type I diamonds may be due to impurity centres consisting of foreign atoms, or carbon atoms which are not in the same electronic state as the majority of atoms in the diamond lattice. More recently the astonishing discovery was made that such impurity centres do exist, and consist of nitrogen atoms, which can be present to the extent of 0.2% in Type I diamonds.[14]

Type II diamonds are far less rare than they were originally thought to be: especially perhaps in stones from certain localities, and in industrial diamonds. Custers[15] has stated that the four largest diamonds examined in his laboratory since 1951 were all of Type II. These were pure white stones weighing respectively 34½, 66, 160, and 426½ carats. He also expressed the opinion that nearly all the larger gem diamonds belong to this category. In this connexion it may be remembered that two of the three stones tested by Miller were marked transparent to short ultra-violet. Of the four " portrait " diamonds randomly collected by the writer, three were transparent well beyond the 3000Å limit, and a large pink diamond tested also showed a Type II transmission. The few yellow-fluorescing diamonds so far tested in our laboratory have all passed the 2537 mercury line quite freely, while Prof. Kathleen Lonsdale has stated that all the synthetic diamonds she has so far examined have shown Type II X-ray patterns.

IRRADIATED DIAMONDS

It is by now well known that the irradiation of diamonds by alpha-particles, neutrons, deuterons, electrons, and even gamma rays, has a pronounced effect upon the colour of the stone; also, that the resultant colours can be further altered by subsequent heat-treatment or " annealing ". The earliest treatment of this kind was carried out by Crookes at the beginning of the century by placing diamonds in close contact with radium salts for several months. The effect was to turn the stones green—from light to dark tourmaline green, depending on the time of exposure to the alpha particles from the radium. The colour at one time was thought to be due to a thin layer of graphite which might well have formed at the surface: very thin scales of graphite were found to show a grey-green tint by transmitted light, and in heavily-treated stones little dark discs were seen under the microscope to have formed at the surface. Radium-treated stones were easy to test, as they had acquired a pronounced degree of radioactivity which could not be removed even by drastic chemical cleansing. This radioactivity has been shown to persist at least forty or fifty years, and can only be removed by repolishing the stone or heating it for several hours at 450°C, when the colour also will have disappeared. It is now realized that the induced colour was due to damage caused to the lattice by the violent atomic bombardment, and the appearance of the 5040 line in so many of these stones was highly significant, as will be seen in what follows.

The absorption and fluorescence of diamond are markedly affected by all forms of bombardment, and it is of great practical concern to gemmologists that they should be able to recognize from the evidence afforded by these phenomena whether or not a given " fancy diamond " owes its unusual colour to nature or to artificial treatment. Since it is probably true to say that none of the absorption or fluorescence bands in irradiated stones are entirely foreign to natural diamonds, it will be realised that the investigator is faced with no easy task. In the absence of a detailed absorption curve, obtainable only with a spectrophotometer and preferably at liquid air temperatures, there is, in fact, no easy cut-and-dried solution for every case; but as the result of long experience and patient experiment certain features have emerged which are of very real assistance in making such distinctions, using only simple apparatus.

R. A. Dugdale, who had at his disposal the resources of the A.E.R.E. (Harwell), carried out a series of controlled experiments on the colour changes induced in diamond by different forms of bombardment, and the further changes brought about by heat-treatment of the bombarded stones. These were described in admirable detail in a paper published in 1953[16]. Fortunately for the gemmologist he also recorded changes in the absorption spectra and fluorescence of his specimens at each stage.

Neutron bombardment in the atomic pile produced the most consistent results, shades of green deepening to black being induced in all cases, depending on the size of the stone and the dosage given. The green colour was very similar to that produced by the alpha particles from radium described above, and unlike the more apple-green tints seen in the rare natural green diamonds. Unlike radium-treated stones, these displayed only a short-lived radioactivity. Any luminescence in the original stone was almost completely quenched by the bombardment. Apart from general absorption in the red and violet no notable changes were seen in the absorption spectra of the treated stones. Subsequent heat-treatment of the deeply " greened " stones produced a change of colour to brown, then to brownish yellow and yellows of attractive shades as the radiation damage was more or less completely annealed away—though it should be noted that a bombarded diamond never quite returns to its original colour.

When the bombarded stones were heated for some hours at

350°—400°C., Dugdale found that the absorption line at 5040Å appeared in considerable strength, sometimes accompanied by a band at 4920Å. After heating to 425° these bands vanished completely. The writer has recently repeated this experiment on a rose-cut diamond " greened " in the pile with the same remarkable result. Heating in the range 600°—1000°C. resulted in the appearance of a line at 5920Å., though this was not seen in all cases. After heating at 700°—1000°C. in an inert atmosphere the 5040 line again made its appearance, with sometimes a companion line at 4970Å. After heating in the 650°—700°C. range many stones showed a greenish fluorescence, and, when heated to a higher temperature, the original fluorescence of the stone tended to reappear, though this often seemed to be only a surface effect.

Dugdale also observed bands in the deep red: a line at 7350 and diffused bands at 7230, 7000, and 6700Å after heating near 600°C. Occasionally we have seen bands in this region, but never clearly enough for measurements to be made.

During all these changes in absorption due to bombardment and heat treatment the line at 4155 and the band system at 4780, 4650, etc., if originally present seem relatively stable: it is the 5040 line with its nearby associates and the mysterious 5920 line which are definitely induced by treatment. In natural diamonds the 5040 line is found typically in brown or greenish diamonds having a green fluorescence. It is *never* seen in yellow or yellowish stones having a strong Cape spectrum. Since the latter are frequently chosen for treatment owing to their low commercial value, these are important aids to discrimination. A clear 5040 line (usually accompanied by a line at 4980Å), if seen in addition to a Cape spectrum is a strong indication that the diamond has been treated.

Evidence that the 5040 line is induced by bombardment was already forthcoming in our earlier observations on radium-treated stones. It was, indeed, first seen (1933) in a green stone of 0·30 carat which had been radium-treated some years earlier. The majority of radium-treated stones tested since then have shown this line, usually accompanied by the 4155 band, indicating that the stone chosen for treatment belonged to the " Cape " series. It has been suggested that natural brown or greenish diamonds owe their colour to bombardment by radiations emanating from radioactive minerals with which they have been in contact. This certainly seems plausible in the light of modern knowledge.

The line at 5920Å is not often so easily detected, being very narrow, weak, and with a faculty for disappearing altogether when the stone is warmed, which is most disconcerting. But, when seen, it acts as a very valuable indicator that the diamond concerned is a treated stone. Though the appearance of the line in treated stones was first observed by Dugdale (as noted above) it was G. R. Crowningshield of the Gem Trade Laboratory in New York who was able to check its almost universal appearance in yellow and brown diamonds which had been pile-treated and later annealed. With characteristic thoroughness he examined some thousands of such stones, and was also privileged to examine stones before and after treatment. Crowningshield's article in Gems and Gemology[17] is the most helpful to the gemmologist that has yet appeared on the subject. Our more limited experience agrees with his. The 5920 line is exceedingly rare in natural diamonds: we have, in fact, only seen it in some six specimens. In the writer's absorption notebook an entry dated Feb. 1943 reads as follows: " When examining brown diamond crystals from Obanghi (French N.W. Africa) to check the constancy of the 5040 line, I observed in two or three specimens a faint unresolved line or band in the " rare earth " (Dy) region. Measured with some difficulty owing to its elusive nature... as 5950Å approx." It is worth noting that the " elusive " nature of this line was evident on its first appearance. A later note (1950) records the line as 5920Å when it was measured in a yellowish Sierra Leone crystal.

In addition to dark green, brown, and yellow stones, dealt with above, diamonds of aquamarine or zircon blue tint may be produced by electron bombardment, perhaps with subsequent annealing treatment. In such stones the colour is only skin-deep, and may be removed by a thorough re-polishing. Custers who, as stated earlier, discovered the rare Type IIb category of diamond, maintains that all natural blue diamonds belong to this category and are thus readily recognised by their pronounced conductivity. A simple arrangement for making a conductivity test has been issued from the Diamond Research Laboratory in Johannesburg, and alternative circuits have been independently assembled by Lester Benson in Los Angeles, Edward Gübelin in Lucerne and Robert Webster in London, and have proved effective for making this test. It is interesting to note that the famous " Hope Blue " was tested with the G.I.A. conductivity apparatus and was duly proved a Type IIb diamond. The amount of current passed by these stones is very variable, but so far no exceptions to the rule have been reported. Thus, any blue diamond which passes no current may be assumed to have been electron-treated.

The main distinguishing features of natural green, brown, yellow and blue diamonds and of those owing their colour to irradiation techniques have now been dealt with. Observations on certain unusual types of diamond, though interesting in themselves, have not been included here as they would tend to confuse further an already complicated picture. Some of these are dealt with in a recent paper by the present writer on " Lines and Line systems in the fluorescence spectra of diamond ".[18]

Some indication will have been gathered from the foregoing of the ways in which physicists in many centres are devoting their energies to research in diamond. The Diamond Corporation and its subsidiary organizations have been most active in fostering pure research in this field. There can be no doubt that many of the idiosyncrasies of diamond will eventually receive a rational explanation. But sometimes, in the mood of Ralph Hodgson's lines—

" *Reason has moons, but moons not hers*
Lie mirror'd in her sea,
Confounding her astronomers,
But O! delighting me ".—

one may be forgiven for hoping that some mysteries will remain, and that in some aspects of its behaviour this incomparable mineral will remain for ever unpredictable.

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Gemmological Abstracts

CROWNINGSHIELD (G. R.). *Developments and Highlights at the Gem Trade Lab. in New York.* Gems and Gemology, Vol. X, No. 11, pp. 336-341, Fall 1962.

Mention is made of a number of imitation and " compressed " turquoises. A report is given on black treated opals in which the opal has a granulated mosaic structure. The results of tests made on such pieces are given. Other specimens referred to are a glass cat's-eye sold as synthetic cat's-eye, a cut willemite, two faceted zincites and a colourless brazilianite. A brilliant-cut yellow tourmaline, a boracite dodecahedron, a pyrope garnet of 16 carats, and some odd colours in sapphires and diamonds are also mentioned. Emeralds coated with green plastic are noted.

10 illus. R.W.

DUYK (F.). *Ein Erkennungsmal von Brillianten.* Identification marks on diamonds. Zeitschr.d.deutch.f.Gesell.Edelsteinkunde, 1962 no. 39, pp. 22-24.

Photographic methods of identifying individual stones, not only diamonds. The table facets of each stone are photographed with a micrometer, so that on the photographs one can read off the size of each separate table facet. These facets are bound to vary slighty and the same set of figures will not be found on any other stone.

W.S.

JOHNSON (P. W.). *Cerro de Mercado Mine.* Mineralogist, 1963, 31, 1, pp. 4-6.

Cerro de Mercado hill is Mexico's chief source of iron ore. Yellow apatite crystals (locally called *amarillos*) are found in the locality. Much of the apatite is fractured during the blasting for the iron ore but high grade material is obtainable from miners in the nearby town of Durango.

S.P.

Liddicoat (R. T.). *Developments and Highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. X, No. 11, pp. 342-346, Fall 1962.

More serpentine than ever has been seen in the lab, and a number of pieces of plastic imitations of amber, which are sometimes sold as " Chinese amber ", have been examined. More treated turquoise is referred to. Unusual stones examined were pollucite, cassiterite, datolite, diopside, sinhalite, beryllonite and feldspar cat's-eye. An interesting item consisting of a diamond and platinum brooch contained many different colours of diamonds. It is remarked that it is not yet possible to make definite statements about the colour of green diamonds. A report is given on a red spinel and a black star-sapphire, which had been damaged. The scaling of some pearls was found to be due to the peeling off of a coating of hair setting lotion which had got on to the surface of the pearls.

2 illus. R.W.

Webster (R.). *Howlite—natural and stained.* Australian Gemmologist, No. 17, pp. 10-11, November 1962.

A general article on the mineral howlite which has been used in an unstained condition for ornamental objects. The mineral is tumbled and stained blue, when it represents turquoise.

P.B.

Ostwald (J.). *An introduction to the optics of gemstones.* The Australian Gemmologist, (Part 4) No. 13, pp. 5-10, July 1962. (Part 5), No. 17, pp. 5-9, November 1962. (Part 6), No. 18, pp. 5-10, December 1962.

Part 4 of this series deals extremely fully with the behaviour of light in anisotropic crystals. Conical refraction is discussed as well as specific rotation. Amethyst is referred to in respect of optical activity in crystals. In part 5 the writer deals with the reflection of monochromatic light. The final part (part 6) treats of dispersion, diffraction, interference and selective absorption. The F and V centres are discussed and also luminescence and fluorescence. Pleochroism is gone into very fully. The text is somewhat mathematical.

17 illus. R.W.

GÜBELIN (E.). *Ekanit, ein neuer metamikter Edelstein aus Ceylon.* Ekanite, a new metamict gem material from Ceylon. Zeitschr. d. deutsch. Gesell. f. Edelsteinforschung, 1962, 40, 14–34.

A detailed account of the new gem material found in Ceylon, similar to those which have appeared in other gemmological journals (Journ. Gemmology Abs. 1962, VIII, 7, 228).

S.P.

MEEN (V. B.). *Gem hunting in Burma.* Lapidary Journal, 1962, 16, 7, 636–653; 16, 8, 720–741; 16, 8, 816–835.

A fascinating three-part article describing a visit to the Burmese gem areas. Occurrence and methods of mining, cutting and marketing are discussed in detail.

S.P.

POUGH (F. H.). *Hong Kong is a lapidary center too!* Lapidary Journal, 1962, 16, 8, 838–845.

An interesting account of the lapidary work carried out in Hong Kong and details of the many carved gem materials available.

S.P.

CURTIS (G. E.). *Diamond hunting in British Guiana.* Lapidary Journal, 1962, 16, 8, 846–854.

British Guiana is rich in mineral resources and diamonds are recovered from the gravels of the Mazaruni area. Mining statistics for 1900–1961 are given; in the latter year 112,679 carats were recorded.

S.P.

LEIPER (H.). *How did British Guiana diamonds get there?* Lapidary Journal, 1962, 16, 8, 855.

The conjecture that Africa and South America were once a single land mass is briefly discussed but the question about the alluvial occurrence of diamonds in the colony remains.

S.P.

HARDY (E.). *Pearl-producing molluscs.* Gemmologist, Vol. XXXI, No. 375, pp. 194-196, October 1962.

Biologically it is possible for " pearls " to be formed by any mollusc lining its shell with nacre. Pearls are said to be occasionally found in the common mussel, oyster, scallop, cockle, periwinkle and pinna. There is an old reference which tells of pearls being found under the shield of the sea slug. In Scotland locations mentioned are Loch Ern, Tay Rannoch and Lubuaig and the rivers Don and Leith. The Irish fisheries and those of France are also mentioned. The cultured pearl industry of Australia is said to have grown up owing to the bad times the Australian pearl shell industry experienced, this being to a great extent due to the advance of the plastics industry and their button production.

R.W.

ANON. *Growing of artificial emeralds.* International Electronics, Vol. 5, No. 2, p. 21, 1963.

A new method of growing artificial emeralds for microwave masers includes a variety that is piezo-electric and fluorescent. The technique uses dehydrated beryl, berylium-oxide, ammonium-chromium-sulphate and vanadium-pentoxide heated in a platinum crucible. By varying the amounts of chromium impurities, Bell Labs scientists can grow beryl single crystals of emerald green or lighter colours.

T.B-S.

The Rangoon newspaper *The Nation*, February 6th, 1963, has reported that:

Foreign nationals have been ousted from the jade mining industry in the Kachin State following an order of the Kachin State Affairs Council last month decreeing that only Burmese citizens should work the mines.

Chinese nationals are specially hard hit by this order, because they formed the majority of foreigners operating the mines. In the past, only a few foreign nationals were in this industry, but subsequent to the Government's take-over of the pawnshop and the liquor-distribution business, which for years had been monopolised by the Chinese, Chinese nationals turned to other fields of enterprise. For various reasons, they were attracted to the jade mining industry, and many of them rushed to the Kachin State to sink their idle capital in the industry.

Most of the jade mines are situated in the Kamaing Subdivision of the Kachin State. They are clustered around a string of villages such as Phakan, Tamakhan, Maimaung, Hwekha and Tawmaw. Places along the Uruchaung creek are also noted for their deposits of jade.

The mines are of two kinds—those worked by mechanical pumps and those worked by manual labour. The former are situated on low, level land, especially in the valley of the Uruchaung creek, and need varying amounts of capital investment for purchase of pumps. The latter are dotted along the mountain sides and need no more capital than payment of wages for labour. Each small mine has to employ four workmen.

At present, there are about 1,000 jade mines in the area, and more than half these are owned by Chinese nationals.

Operations in all the Chinese-owned mines have since been suspended, resulting in some 2,000 workmen being thrown out of employment. The state Affairs Council has reportedly assured them that foreigner-owned mines will be transferred to them if they want to work them on a collective or co-operative basis.

HANDEL (S.). *Natural and synthetic crystals in electronics.* Electronic Equipment News, Vol. 4, No. 9, pp. 60-61, December 1962.

Less than ten years ago the accepted definition of an electron device was one in which conduction of electricity takes place principally in a vacuum or a gas. The addition of the phrase " or in a semiconductor " in recent years is a belated recognition of the growing importance of certain crystalline solids in which electrons are transported in unusual ways compared with true metals, electrolytes or gases. Progress in these semiconductors is so rapid that information on them can barely be kept up to date. The use of crystal rectifiers antidates the thermionic valve of Fleming in 1904, fifty years before which the rectifying properties of copper oxide were known. Some comparison of the thermionic valve with crystal rectifiers is made, and mention is made of the point contact transistor and of the theory of electrons and holes in semiconductors. The ideal crystal contains no foreign atoms nor any irregularity in the crystal lattice. It is the slighty imperfect crystal which is, however, the basis of crystal devices. Semiconductors are insulators in the pure state, and they conduct at normal temperature only when they contain impurities. Natural blue diamonds, which are said to be true p-type conductors are used for certain apparatus. The article provides a brief survey of the nature and use of crystalline materials and indicates possible future developments. There is a table of the electronic applications of crystalline materials.

R.W.

TISDALL (F. S. H.). *More about garnets.* Gemmologist, Vol. XXXI, No. 376, pp. 199-200, November 1962.

The author compares the properties of rhodolite garnet from North Carolina with similar material from Madagascar which he had earlier reported upon. (Abstract. Journ. Gemmology. Vol. VIII, No. 8, p. 296, October 1962). Higher density and refractive index were found in the case of the N. Carolina stones examined than are usually ascribed to this garnet. The absorption spectrum and magnetic attraction are described. Both the Madagascan and N. Carolina stones showed anomalous double refraction with four times darkness through a complete rotation. The article also refers to a repaired diamond.

R.W.

HOPKINS (I.). *Diamond mining in Sierra Leone.* Gemmologist, Vol. XXXI, No. 374, pp. 159-163, September 1962.

Diamonds are mined from the alluvial deposits of the Sewa and Bafi rivers for the mines of the Sierra Leone Selection Trust in Kono District. The methods of mining the gem gravel are explained as well as the methods used in the recovery of the diamonds. The diamond crystals are found as octahedra, dodecahedra, cubes and combinations of these forms.

7 illus. R.W.

TISDALL (F. H. S.). *Some notes on iolite.* Gemmologist, Vol. XXXI, No. 373, pp. 139-140, August 1962.

A general survey of the mineral iolite. Some constants are given and discussion is made on the absorption spectrum and on the inclusions seen in the stones.

R.W.

THURM (R.). *Ungelöstes Geheimnis Amethyst.* Unsolved mystery of the amethyst. Deutsche Goldschmiedezeitung, 61, 1, pp. 29-31, 1963.

Amethyst was known 3000 years ago. In all its properties it is a quartz. Seen between crossed nicols, a slice of the amethyst cut at right angles to the optic axis shows a very lively colour play. The cause of the colour is not known. It has been attributed to colloidal distributed manganese, but no trace of this element can be found with the spectroscope. The colour is not heat-resistant. Between 400°C and 500°C amethysts become yellow, and are then saleable as citrines. Over 575°C they lose all colour, resembling moonstones. These quartz "moonstones" when viewed under UV light appear slightly green, while the orthoclase moonstones are definitely pink. The synthetic spinel which imitates moonstone fluoresces green-blue. There are also glass moonstone imitations on the market which fluoresce light blue. There are no synthetic amethysts on the market.

E.S.

(ANON). *Neue Synthesen und Imitationen.* New syntheses and imitations. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, no. 41, pp. 24-27, 1962; no. 42, pp. 27-28, 1962/3.

Some white corals are being imitated by mother-of-pearl. Diamond doublets are on the market with the top of diamond and bottom of synthetic spinel. Turquoise is imitated by the mineral howlite. A short note is added on improvements in the synthesis of diamond. Serpentine is sometimes miscalled "new jade". Diamond has now been synthesized in Japan by the firm of Tokio-Shiwaura-Electric. A fairly poor imitation of black opal is on the German market, as is also a glass imitation of cat's-eye.

E.S.

THURM (R.). *Verschiedene Methoden der spektroskopischen Edelsteinuntersuchung im reflektierten Licht.* Various methods of examining gems by spectroscopy in reflected light. Deutsche Goldschmiedezeitung, May 1962, 5, 60, 345-346. Zur Technik des Spektrokopierens. Technique of spectroscopy. Zeitschr.-d.deutsch. Gesell.f.Edelsteinkunde, 1962, 39, 30-31.

Both these articles deal with an adaptor for the microscope. The stone to be examined rests on the spectroscope stand, but mounted gems can also be tested. Good results are claimed even with such small stones as diamonds of 0·01 cts. The 4155 Å line in a diamond of 0·02 cts. usually cannot be seen under transmitted light with a microscope, while by reflected light it was easily visible. All larger diamonds showed this line also in transmitted light. Good results were obtained with a fixed slit model, which is simpler to handle than the wavelength instrument. The same slit-width is used, only the focussing and lighting being varied.

E.S.

EPPLER (W. F.). *Spectrolite — Labradorite.* Deutsche Goldschmiedezeitung, 61, 3, 161-162, 1963.

For some time a mineral called "spectrolite" has been on the market. It looks like labradorite, has a dark basic colour, and a beautiful colour play of blue and red, also green, yellow and reddish. This material is found in alluvial deposits in the south-eastern part of Finland. The author compares the material with the labradorite mined in Labrador and also with the labradorite mined in Madagascar and in the beginning wrongly classed as moonstone. There are six photomicrographs, two of each occurrence.

E.S.

BOOK REVIEWS

SINKANKAS (J.). *Gem Cutting.* A Lapidary's Manual. 2nd edn. D. Van Nostrand. 1963. 297 pp., 191 illus. $11.75 (84s.).

The second edition of John Sinkankas' standard work on gem cutting has been usefully enlarged and wisely pruned. A chapter on collecting gemstones and references to the origin of gems and unnecessary lists have disappeared as they are covered in other books by the author. More attention has been given to the tumbling of gems and techniques required for carving and mosaic work, while cabochon and faceting work, which remain the most important styles, are still given most consideration.

The author has emphasized the need for keeping up-to-date with the new ideas and techniques which are rapidly taking place in the lapidary world.

The author's style is straightforward and each aspect of lapidary work is broadly described. An interesting feature is the advice given on buying rough gem material with advice for obtaining good results. The crisp sentences make for easy reading and the second edition of Gem Cutting is the most comprehensive work on gem cutting yet published.

S.P.

LIDDICOAT (R. T.). *Handbook of Gem Identification*, Gemological Institute of America, Los Angeles, sixth edition, 1962 396 pp. $8.75 (63s.).

Fifteen years have passed since the first edition of this book appeared, and a comparison between the earlier version and this latest issue provides a most interesting picture of the way in which American Gemmology has altered and developed during this short but fruitful period. The author is still quite a young man; and I hope one may be forgiven for saying that in the fifteen years he too has developed considerably. What formerly was written largely by rote, from principle and theory, now springs from the more valuable basis of practical knowledge and experience gained in grappling with the problems of all kinds of gem-testing in a laboratory of world status. This has resulted in a very readable and very useful book on its highly specialized subject.

The " Handbook " is just short of 400 pages in length, printed on good paper, and there are 156 black-and-white illustrations in addition to no fewer than 114 realistic drawings (by G. R. Crowningshield) of absorption spectra. The first nine chapters (112 pages) are devoted to instruments and methods used in gem testing. Then follow chapters on synthetic gemstones, on assembled stones and imitation gems, on pearls, cultured pearls and imitation pearls, before returning to instruments again with a chapter on the spectroscope.

Undoubtedly it is in the recognition of the importance and value of the hand spectroscope in gem-testing that this edition of

Liddicoat's book differs most markedly from his earliest issue, where a reference of only 8 lines was considered a sufficient cover for the subject. Though Crowningshield's drawings (mentioned above) are in black and white, they approach more closely to what is actually seen through a prism spectroscope than any previous attempts have succeeded in doing, and by dint of giving several drawings of the spectra seen in most of the gem varieties, he has been able to delineate many of the differences in the prominence of the bands, etc., seen in stones having a different depth of tint, which the beginner often finds so puzzling when there is only a single rather idealized drawing to help him. The general absorption at each end of the spectrum, which is often disregarded, is particularly well rendered in these drawings. The instrument used as standard by the G.I.A. and recommended to their students is the Beck prism model incorporating a superimposed wavelength scale. For this reason the drawings are unfortunately given with the red end on the right, presenting a strange appearance to the British gemmologist unless the page be turned upside down. The name of the gemstone is printed under each spectrum drawing: if these names were in bolder type it would greatly assist those whose eyesight is no longer good. The " star " system for assessing the diagnostic importance of the various spectra has been adopted here. Some of these assessments are rather surprising—that idocrase (Californite variety), for instance, should have been awarded three stars, while zircon should have been awarded a maximum of two!

Chapter 14 gives a brief résumé of " Instruments essential to gem testing "—presumably as a guide to those forming their own laboratory. Next comes a series of brief but very useful " Descriptions and property variations of gemstones " arranged in alphabetical order. This occupies fifty pages, and brings us to page 247. The remainder of the book is taken up with systematic identification procedures as recommended for stones in a large number of different colour categories. An excellent feature in these is the emphasis laid on the importance of preliminary inspection of the stone under examination, using a 10 × loupe. In a number of cases this may lead to a positive identification without any further tests, while in all cases it will serve to narrow considerably the range of possibilities. To an experienced gemmologist, of course, this preliminary inspection and mental sorting-out process is largely automatic, but for the beginner a systematic approach of the type suggested by Mr. Liddicoat is of great assistance.

The book concludes, as one might expect, with a number of " Property tables ". Of these, the refractive index and specific gravity tables are very full, but the birefringence list contains, for some reason, only 18 entries, and thus is far too brief to be a really useful reference guide for this important diagnostic property. Anyone who has had to compile tables of constants will know how difficult it is to decide on the best typical figure for each stone. In this book Mr. Liddicoat has chosen his values so wisely that even one so fanatically interested as the reviewer in accuracy in these matters can only find a few he would wish to alter. Among these may be mentioned 3·71 as a preferable figure to 3·73 for the density of chrysoberyl, and 2·99 instead of 2·94 for brazilianite: ·036 rather than ·038 for the birefringence of peridot, and ·022 rather than ·028 for the dispersion of pyrope garnet.

The bulk of the text has been so well written that there is far more to admire than to criticize. The chapter on specific gravity, however, could be much improved: it remains too elementary to encourage the keen student of the subject to obtain really accurate measurements of this highly important constant. To avoid the difficulties attendant on the high surface-tension of water in making hydrostatic determinations, the use of either commercial carbon tetrachloride (" Carbona ") or of water to which one twentieth of its volume of powered detergent has been added is recommended by Mr. Liddicoat. In the former case the student is instructed simply to multiply his results by 1·59—the approximate density of the fluid. Where accurate results are sought by using liquids of low surface tension it is worth-while, surely, to take the trouble to obtain an exact correction factor for the particular sample of liquid used, linked always with the temperature at which the experiment is carried out. In our experience, ethylene dibromide is the most suitable liquid, and a sample, once calibrated, can be used for years if kept in a stoppered bottle.

One must take exception also to the derogatory remarks on the X-ray diffraction method for distinguishing between natural and cultured pearls. This, one feels, may be due to the fact that the G.I.A. Laboratories do not employ this technique. In the first place, the diffraction patterns shown, reproduced from a paper by William H. Barnes, are of insufficiently good quality to give a fair idea of the capabilities of the method. Properly used, diffraction photographs can save the gemmologist from possible error in cases where natural pearls show a sharply defined spherical " nucleus " of natural origin, or in cases (admittedly rare) where a cultured pearl has been grown on a drop-shaped or a button-shaped nucleus, giving a misleadingly genuine appearance to radiographs of the specimens. Pearl radiography, as developed in the U.S.A., and used by an experienced operator, is undoubtedly the more generally useful, speedy, and flexible technique; but we in the London Laboratory would feel very unhappy if we were unable to make use of diffraction pictures in certain doubtful cases.

In conclusion, it should be said that the reviewer has derived both profit and pleasure from reading Mr. Liddicoat's book, and can heartily recommend it to anyone undertaking practical gem-testing or interested in the techniques, sometimes very simple, sometimes highly exacting, for identifying gem materials.

B. W. ANDERSON.

HAMMES (J.). *Edelsteinen.* Gemstones, 157 pages, 7 colour plates. Dfl. 3·95. Phoenix pocket No. 77. De Haan, N.V., Zeist, The Netherlands.

In this paper-back the subject of gemstones is looked at from all aspects in a manner intelligible for the lay reader. The book is interspersed with anecdotes, legends and historical stories which make the described subject-matter come alive.

The difficult question of the nomenclature which, as used in trade, often deviates from that used in science, is touched upon at the right moments and misnomers have been left out on purpose, a principle which should be welcomed.

Gemstones and their physical properties are competently described, particularly the optical phenomena. Some mention is made of gemstones and man, then of gemstones and jewels. Another chapter deals with a description of diamonds, together with cutting process, some famous diamonds and the diamond-trade. Next, ruby and sapphire are considered, followed by emerald and a number of common gemstones. Attention is paid to Biblical and zodiacal stones, as well as synthetics.

A table with the properties of the most important gemstones and a list of references conclude the booklet. This is a most useful work which, unfortunately, the author did not live to see published.

P.C.Z.

THE PFUND HIGH INDEX REFRACTOMETER

By J. OSTWALD

IN 1948, in the "Journal of the Optical Society of America", the late Professor A. H. Pfund of Johns Hopkins University proposed in principle a refractometer which could read the R.I. of crystals up to $n = 2{\cdot}6$. An experimental model was constructed in his laboratory and the R.I.s of some half dozen minerals were determined. The main advantage this new type of instrument has over the standard type is that it needs no contact liquid and the upper limit is governed purely by the R.I. of the transparent hemisphere of the instrument. Professor Pfund used a hemisphere of synthetic rutile, with $N_o = 2{\cdot}610$.

Basic theory of the Pfund refractometer

(1) *Fresnel's Equations:* In Fig. 1 a ray of monochromatic light is incident at an angle α to the normal on a block of isotropic crystal. Part is reflected, and part is refracted at an angle of β to the normal. Now let E_p, R_p and D_p be the components of the incident, reflected and refracted rays in the plane of incidence while E_s, R_s and D_s are the components at right angles to the plane of incidence. Then the following relations hold.

Reflected amplitudes:

$$R_s = -E_s \frac{\sin(\alpha - \beta)}{\sin(\alpha + \beta)} \qquad (1)$$

$$R_p = E_p \frac{\tan(\alpha - \beta)}{\tan(\alpha + \beta)} \qquad (2)$$

Refracted amplitudes:

$$D_s = E_s \frac{2 \sin \beta \cos \alpha}{\sin(\alpha + \beta)} \qquad (3)$$

$$D_p = E_p \frac{2 \sin \beta \cos \alpha}{\sin(\alpha + \beta) \cos(\alpha - \beta)} \qquad (4)$$

These equations were originally derived by Fresnel in 1823 from the elastic solid theory of the ether and they can also be derived from electromagnetic theory.

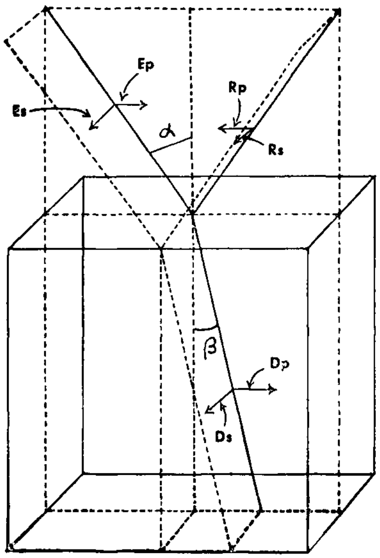

FIG 1

Now if we apply the basic law of refraction

$$\frac{\sin \alpha}{\sin \beta} = \frac{V_1}{V_2} = \frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}} = n \tag{5}$$

we can obtain the following equations:

$$2E_s = D_s\left[1 + \frac{\sqrt{\varepsilon_2} \,.\, \cos \beta}{\sqrt{\varepsilon_1} \,.\, \cos \alpha}\right] \tag{6}$$

$$E_s\left[\frac{\sqrt{\varepsilon_1} \,.\, \cos \alpha}{\sqrt{\varepsilon_2} \,.\, \cos \beta} - 1\right] = R_s\left[\frac{\sqrt{\varepsilon_1} \,.\, \cos \alpha}{\sqrt{\varepsilon_2} \,.\, \cos \beta} + 1\right] \tag{7}$$

$$2E_p = D_p\left[\frac{\cos \beta}{\cos \alpha} + \frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}}\right] \tag{8}$$

$$E_p\left[\frac{\cos \alpha}{\cos \beta} - \frac{\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2}}\right] = R_p\left[\frac{\cos \alpha}{\cos \beta} + \frac{\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2}}\right] \tag{9}$$

(2) *Total Reflection:* When a ray of light is incident at the boundary separating an optically dense from a less dense medium, the refracted ray vanishes for angles of incidence greater than a certain critical value, the energy being totally reflected. We will

analyse this case. Here β is not real. Let us substitute $\frac{\sin\alpha}{n}$ for $\sin\beta$ in the above equations. Thus

$$\cos\beta = \sqrt{\left(1-\frac{\sin^2\alpha}{n^2}\right)} \tag{10}$$

which is imaginary if

$$\sin\alpha > n$$

We can write this in the form

$$\cos\beta = -i\sqrt{\left(\frac{\sin^2\alpha}{n^2}-1\right)} \tag{11}$$

where $(i)^2 = -1$.

Now if we consider the effect of these equations on equations (6) and (8) above it will be seen that the refracted amplitude is not zero so some of the energy penetrates a small distance into the second rarer medium. It can be shown by analysis of Maxwell's equations that the electric and magnetic forces in the rarer medium are proportional to the real parts of the following expression.

$$e^{\frac{i\,2\pi}{T}\left(t-\frac{x\sin\beta+z\cos\beta}{V_2}\right)} \tag{12}$$

Now if we eliminate β with the use of equation (11), we obtain (12) in the following form.

$$e^{-\frac{2\pi}{T V_2}\sqrt{\left(\frac{\sin^2\alpha}{n^2}-1.z\right)}}\cdot e^{\frac{i\,2\pi}{T}\left(t-\frac{x\sin\alpha}{n V_2}\right)} \tag{13}$$

This formula represents a wave moving along the boundary of the two media in the plane of incidence. The amplitude is seen to decrease rapidly with the depth of penetration and it is zero within the order of one wavelength. Another (apparently) strange fact is that these boundary waves are no longer transverse. However, according to Quincke, if the second rare medium is quite thin, of the order of one wavelength then this wave of variable amplitude is converted into one of constant amplitude.

The existence of these waves can be demonstrated experimentally if a convex lens of large radius of curvature is placed in contact with the surface under study. At the point of contact there is a circular patch over which total reflection fails.

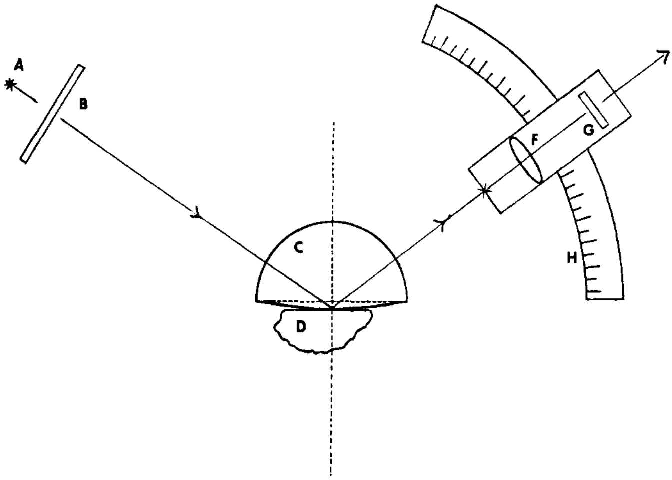

FIG 2

Apparatus and use

The apparatus used by Professor Pfund is shown in a schematic fashion in Fig. 2. A is a sodium light source, B a frosted glass diffusing plate, C the hemisphere of high index material with slightly convex lower surface, D the material under test, F a converging lens, G a polaroid disc and H a graduated scale.

The essential feature of the apparatus is C. This was made from clear synthetic rutile, with $N_o = 2{\cdot}61$ and $N_e = 2{\cdot}897$, of 11 mm radius, the radius of curvature of the lower face being 15 cm. The polaroid in the eyepiece is necessary to eliminate the effects of the extraordinary ray.

The phenomena observed in the eyepiece are as follows:
Case 1—Angle of incidence less than critical angle of air and rutile. A central black spot surrounded by Newton's Rings will be seen. This should be centered in the eyepiece.
Case 2—Angle of incidence exceeds this critical angle. The Newton's Rings disappear, leaving the black spot.
Case 3—If the telescope is moved slowly, a point will be reached when the black spot will disappear. Here the angle of incidence has just exceeded the critical angle of rutile and the test material.

Using this apparatus Professor Pfund studied the R.I.s of the following five minerals. The figure in each case depends for its accuracy on the N_o of synthetic rutile, assumed = 2·61. These values may be compared with figures taken from Winchell, probably measured by the spectrometer method.

	A. H. PFUND	A. N. WINCHELL
Zircon N_e	1·991	1·968 – 2·015
Zircon N_o	1·936	1·923 – 1·96
Diamond	2·419	2·419
Calcite N_o	1·658	1·658
Corundum N_e	1·760	1·7599 – 1·7613
Corundum N_o	1·768	1·7681 – 1·7695
Fluorite	1·434	1·434

Fig. 3 shows in a graphical manner the relationship between the refractive index and the critical angle for a material under test, for the Pfund rutile refractometer.

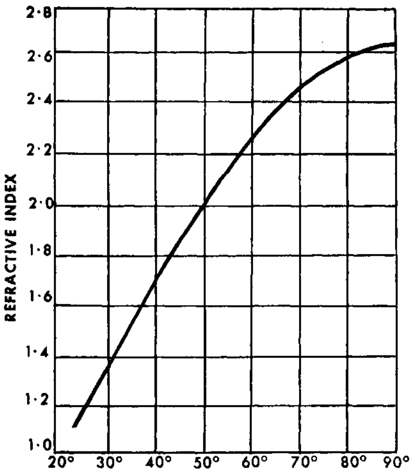

FIG 3 (AFTER PFUND)

Conclusions

With the use of a refined optical system and compact arrangement of parts the apparatus should be of great use in the determination of the refractive indices of crystals, polished mineral surfaces and gemstones up to about $n = 2·6$. No immersion liquid is necessary, though a drop of oil on the hemisphere would perhaps prevent scratching. On the other hand a sodium light must be used, on account of the high dispersion of the rutile hemisphere.

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1. Born, M., and Wolf, E. *Principles of Optics.* Pergamon Press, 1959.
2. Drude, P. *The Theory of Optics.* Dover Books, 1959.
3. Pfund, A. H. *A High Index Refractometer.* Journ. Opt. Soc. Amer., Vol. 39, No. 11, pp. 966-969.
4. Winchell, A. N. *Elements of Optical Mineralogy,* Part III. John Wiley and Sons, 1939.
5. Wood, R. W. *Physical Optics.* MacMillan, 1919.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 30th January, 1963. Mr. N. A. Harper, Vice-Chairman, presided.

The following were elected:—

FELLOWSHIP

Jokinen, Pertti, Helsinki, Finland
Rybom, Lene, Fredrikstad, Norway

ORDINARY MEMBERSHIP

Axon, Gordon V., New York, U.S.A.
Hunt, E. M., London
Johnson, Arthur William, London
Johnson, Charles R., Houston, Texas, U.S.A.
Lecolle-Brown, Ian H., Johannesburg, S. Africa
McCann, James C., Dublin, Ireland
Sirett, Benjamin, London
Stäedelin, Alwin, Lucerne, Switzerland
Weatherill, Katherine, Long Beach, U.S.A.
Wood, Mary B. H., Sidmouth

PROBATIONARY MEMBERSHIP

Collard, Edwin, Bridgwater
Smith, Lance C., Bognor Regis
Duncan Taylor, Lynne, London
Weare, Roy, Harrow
Wilkinson, Ben R., Croydon

The Council approved the arrangements made by the Midlands Branch for the Herbert Smith Memorial Lecture to be held at the Auctioneers' and Surveyors' Institute, Birmingham, on 26th April. Mr. E. D. Lacey, B.Sc., A.R.C.Sc., F.G.S., of the department of geology, Birmingham University, had kindly consented to give the lecture, which would be entitled "Perfect and imperfect crystals".

A draft syllabus for the diamond course examination was approved.

MIDLANDS BRANCH

A meeting of the Midlands Branch was held at the Imperial Hotel, Birmingham, on 24th January, 1963. Mr. M. Bowen, the Branch Chairman presided, and introduced the guest speaker, Mr. Hans Caesar, Chairman of the Deutschen Edelsteingesellschaft, who spoke about the gem-cutting industry of Idar-Oberstein. In Idar local cutting dates back to the 11th century and the first official documents to 1454. During 1618-1648, in the 30 years war, practically all cutting mills were destroyed, which brought stonecutting to a standstill. When in 1700 the first goldsmiths began their work, the demand for gemstones became greater and stonecutting revived. From Novgorod, the Russian commercial city, came unpolished lapis-lazuli, malachite, and Persian turquoise. Towards the end of the 19th century, with the arrival from India of the first garnets, rubies and sapphires, new cutting methods had to be developed because of the extra hardness of these gems; thus lapidary cutting came into existence. By 1914 Idar Oberstein had become the world's greatest stone cutting centre. Now some 2,000 men are employed on diamond cutting and polishing, about 900 on lapidary work and 600 approximately on polishing agate; this gives some idea on the vast extent of the industry there.

Mr. Caesar concluded his talk by showing a special film on Idar Oberstein including a 14th century water mill with all its old world charm, to its present day modern factories, with their exquisite examples of polished agate bowls, carved chrysoprase leaves and flowers, amethyst and other gem ornaments, and lapidary work with fine examples of aquamarine, citrine and many other gems.

Many questions were put to the speaker

Mr. Norman Harper proposed the vote of thanks to Mr. Caesar which was heartily endorsed by all present.

The Midlands Branch of the Association held a Dinner and Dance at Quinton, Birmingham, on Wednesday 27th February, 1963. Mr. W. W. Bowen, Chairman of the Branch, welcomed guests who included Mr. E. D. Lacy, of Birmingham University, Mr. N. A. Harper, Chairman of the National Association of Goldsmiths and Mr G. F. Andrews and Mr. H. Wheeler from Head Office. It was a very successful evening. Mr. Bowen expressed the Branch's indebtedness to the Secretary, Mrs. S. Hiscox, for the arrangements.

MEMBERS' MEETING

A meeting of members was held on Friday, 15th February, 1963, at the Medical Society of London's Hall, when several members showed and described various coloured slides they had taken. The slides were varied and included modern and antique jewellery, photography of fluorescence, inclusions and objets d'art. Contributors included Messrs. W. Stern, E. Bruton, R. K. Mitchell, R. Webster, M. Webb, E. R. Levett, and J. E. Edwards.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mrs. Gladys E. Cox, of Chilliwack, B. Columbia, for a specimen of nephrite from British Columbia.

OBITUARY

Leechman, George Francis (Frank), 9th February, 1963. Mr. Leechman, a former Master Mariner, gained his diploma, with distinction, in 1938, and later was awarded the Association's Research diploma for his work on the cause of colour in opal. When he left the Merchant Navy Mr. Leechman took up lapidary work and had a business in Cornwall. Subsequently he went to Australia and became greatly interested in opal. At one time he was Secretary of the Gemmological Association of Australia. His admirable book *The story of Opal,* published in 1961, is a standard work appreciated by all who regard opal as one of the most fascinating of gems.

TALKS BY MEMBERS

Raven, R. H.: " Gems ", Chelmsford Ladies' Circle, 17th January, 1963.

Blythe, G. A.: " Gemstones ", Southend E. Conservative Assoc. (Women's Section), 26th November, 1963; Young Conservatives, Southend, 31st January, 1963; West Leigh Townswomen's Guild, 20th February, 1963.

Baglee, G.: " Gemstones ", Stockton-on-Tees, Y.W.C.A., 10th January, 1963.

Bayliss Brown, A. J.: "Gemstones", Geological Society, King's College, London University, 8th March, 1963.

Sampson, Mrs. E.: "Pearls", Gerrards Cross Club for Women, 6th February, 1963.

Caffell, E. W.: "Gems", Racal Works Canteen, Bracknell, 4th February, 1963.

Havem Björlykke, U.: "Natural and man-made gemstones", Geological Museum, Oslo, 10th February 1963.

Kennedy, N. W.: "Gemstones of the British Isles", I.C.I. Ltd., (General Chemicals Division), Widnes, 29th November, 1962. "Gemstones and gem materials in the field of the chemist", London University Convocation (Manchester University), 8th February, 1963.

JEWELLERY TRADE CENTRE IN EXETER

A technical centre was formally opened in Exeter on 11th March for the benefit of trainees in the retail jewellery trade. The centre has been made possible by the trustees of the R. W. Yeo Trust and although juniors from the R. W. Yeo group of companies will be the first to receive assistance in their careers it is intended that as the scheme progresses to make training facilities available to trainees from other firms.

The centre, which contains sections on gems, watches, clocks, modern and antique silver and jewellery making and repairing (and a jewellery repairing workshop), is extremely well-equipped and many firms, apart from the trustees, have contributed many items of outstanding educational interest. The gemmological section is strong, with an adequate number of instruments and an excellent display of gem minerals in rough and cut form.

The originator of the scheme, Mr. R. W. Yeo, obtained his diploma with distinction in 1929 and has cherished the idea of an educational centre for young persons in the jewellery trade for many years.

WEST OF SCOTLAND BRANCH

An extremely interesting evening was held by the West of Scotland Branch on 21st February, 1963, in Glasgow, when Mr. W. C. F. Butler spoke to members about "The manufacture of synthetic gems". Mr. Butler illustrated his talk with many examples of synthetic stones, including an early specimen of synthetic ruby made by Fremy down to the latest synthetic emerald-coated beryls.


Rayner
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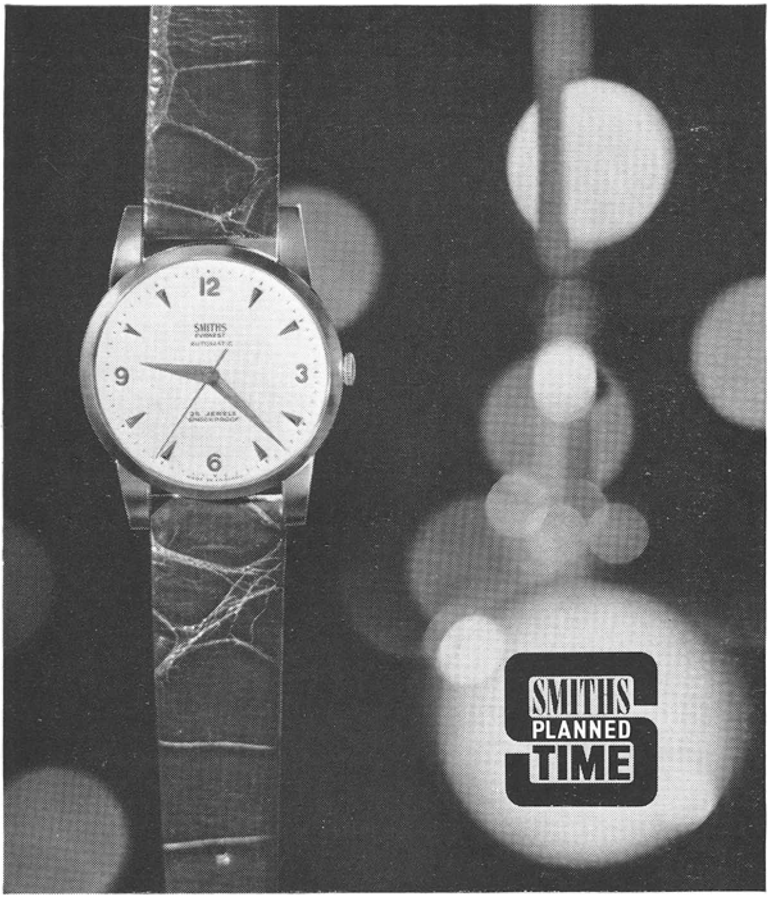
LONDON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