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THREE STONES FOR THE RECORD

By B. W. ANDERSON, B.Sc., F.G.A.

BEYOND the beauty which delights the connoisseur, the rarity which intrigues the collector, or the potential profit which is the main concern of the dealer, there are, for the gemmologist, aspects of a stone's behaviour which should add a further dimension to his pleasure in an unusual specimen. In the past few months three stones have been encountered in the course of routine testing which serve to illustrate this fact. Each has shown properties to make it seem worthy of record for the benefit of fellow-gemmologists, but two of them, at least, were commercially too unimportant to interest a dealer and had not enough beauty to attract a connoisseur, while the third, though rare and lovely enough to be prized in all its aspects by any lover of gems, will almost certainly go through all its life as a jewel without its owners suspecting one of its most exciting properties.

One has to admit that, even to the gemmologist, a mere recital of the properties of these three stones might not make them seem very remarkable, but by filling in the background a little the writer hopes at least to justify his own interest in the three speciments.

(1) *A "high" gahnospinel*

The first of the three stones was a small blue spinel weighing 0·87 carat—ostensibly quite insignificant. Fortunately this was submitted as a loose stone, which made it possible to obtain both density and refractive index measurements: it was mainly the outstandingly high figures for these two simple properties which made the stone for us so supremely interesting.

The story of the zinc-rich blue spinels (for which our name "gahnospinel" has been accepted) began in 1935, when T. W. Oliver, then a student in the gemmology classes at Chelsea Polytechnic, drew attention to a blue spinel in his possession which puzzled him because of its reading of over 1·74 on the refractometer. There seemed to be no easy explanation for this, since the spinel was normal or even rather pale in colour and thus obviously not excessively iron-rich. Moreover the density, which proved to be 3·947, was even higher than could be found in the series which leads, via "ceylonite" or "pleonaste", to the pure ferrous-iron spinel, hercynite.

C. J. Payne and the writer then began a diligent search in parcels of blue spinels, and amongst rough pebbles of blue spinel which are, next to zircons, the commonest constituent of the Ceylon gem gravels. This led to the discovery of a whole series of these "high" spinels, which had previously escaped notice. Such stones are admittedly rather rare: for example, out of over 300 specimens of cut blue spinels examined in one test only four were found with densities greater than 3·85.

The colour of these high-reading stones gave no clue to their properties: some were rather dark, others were pale steely-blue. To find the cause for these anomalies, we obviously had to search for some divalent element of relatively high atomic weight compared with that of the magnesium it was replacing, and one which was *not* one of the transition elements with their tendency to affect colour. Our guess was zinc, since the pure zinc spinel, gahnite, was an established mineral, and the densities and refractive indices of our specimens, when plotted graphically, lay convincingly close to the straight line leading from pure magnesium spinel to pure gahnite (see diagram). Qualitatively, this was easily proved by employing a small grating spectrograph, which showed the degree of prominence of the zinc lines in the visible spectrum to increase step by step with the density and refractive index of the specimens tested. Incidentally, the surprising fact emerged that in no case are blue spinels from Ceylon entirely free from zinc.

To clinch the investigation, Dr. M. H. Hey of the Mineral Department of the Natural History Museum carried out a quantitative analysis of one of our "top" specimens—a pale blue stone having

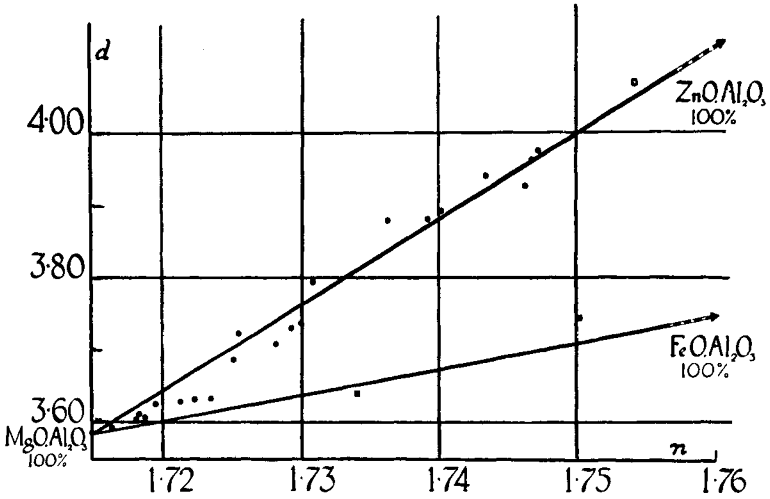

Diagram showing relation of density and refractive index in blue spinels of the zinc-rich (garnespinel) series and iron-rich (cylonite) series.

density 3·967 and refractive index 1·7465—and found it to contain as much as 18·21% zinc oxide. The MgO content of the same specimen was 16·78, while 1·93 FeO accounted for the colour. Our "prize" specimen at the end of this investigation was a stone with density 3·981 and R.I. 1·7469.

In the natural course of events we have frequently encountered gahnospinels since that time, and always give them a friendly nod of recognition in passing, but we have had to wait more than 25 years before finding one to beat our previous best, and in particular to exceed the figures 1·750 for refractive index and 4·00 for density, which for us had formed a "target" analogous to the athlete's four-minute mile. The present small specimen did this handsomely: the refractive index was found to be 1·7542 on the Abbe-Pulfrich refractometer, and the density, also carefully measured, was 4·060. At less than a carat, the stone was not large enough to give a very reliable reading for density by hydrostatic weighing, even when using ethylene dibromide and an aperiodic balance reading to a tenth of a milligram, as is our practice. We therefore chose several low zircons in the target area which were large enough for their density to be well established, and compared these with our spinel specimen when suspended in a specially mixed Clerici solution. Having done this, we feel satisfied that the density quoted is accurate to within ± ·002.

Here, then, is an excellent example illustrating the truth of the opening sentence of this article. In general appearance this small blue spinel had nothing particular to commend it, and the fifty shillings for which it was purchased was probably more than its strictly commercial value. But to us, as gemmologists to whom gahnospinel meant something "special", it was a profound pleasure to meet this stone and to add it to our collection of gemmological rarities.

(2) *A chrome-rich red spinel*

The second stone to be recorded was also a spinel, but in this case a deep red example and, unfortunately, mounted in a 3-stone ring. As with the gahnospinel described above, the stone had no great beauty or commercial value to commend it. Its interest to us lay chiefly in its refractive index, which at 1·7439 was typical, not of red spinel but of pyrope garnet. This reading was at least 0·020 higher than for the normal run of red spinels, and 0·010 above the previous high record.

There is a practical issue here: it constitutes a challenge to the gemmologist to distinguish with certainty between the two red gem minerals pyrope and spinel. The minerals are close to one another in appearance and properties, and the distinction is made more difficult from the fact that both are optically isotropic and that each belongs to a group of isomorphous minerals in which variations in chemical composition and physical properties are to be expected and no exact margins can be established. Even the mineralogist, to whom "no holds are barred" in the matter of destructive tests (such as a rough analysis to determine the presence or absence of silica) has sometimes gone astray in distinguishing these two rather common minerals.

During the war years it happened that the writer investigated this problem in some detail, and even ventured to read a short paper on the subject before the Mineralogical Society. The conclusions then were:—

(1) That though the "highest" spinel might overlap the "lowest" pyrope slightly in refractive index, in all specimens encountered till then a small density gap remained between the highest spinel at 3·611 and the lowest pyrope at 3·643. This is not much to go on, but

in the vast majority of examples the gap between the R.I. and S.G. of the two minerals is far larger and more conclusive.

(2) Fluorescence under ultra-violet light (or as since determined by the more powerful "crossed filter" technique) provided the quickest means of distinction and could be applied equally well with mounted or unmounted gems and with uncut specimens. Pyrope, with its inevitable heavy content of some 6 to 15% of ferrous iron, *can under no circumstances show any trace of fluorescence*, whereas red spinel in general can be relied upon to give a red fluorescent glow which, as analysed by a hand spectroscope, is seen to consist of a highly characteristic "organ pipe" group of lines.

(3) The absorption spectra of the two minerals are also normally distinctive. The broad central absorption region, due to chromium in each case, in spinel is centred in the green near 5400Å, while in pyrope the corresponding band is centred in the yellow near 5750Å, and this can be seen even without measurement to be much nearer the red end of the spectrum. As a further sign, the pyrope spectrum commonly reveals to the practised eye the strongest absorption peak of the almandine spectrum as a rather narrow band at 5060Å. Lastly, in chrome-rich spinels a number of fine absorption lines can be seen in the red end of the spectrum. In pyrope, though the doublet in the deep red may be visible, any further lines in the red are seldom seen.

(4) Inclusions are also revealing. In spinel these are generally octahedral in shape and grouped in serried ranks in one plane as extensive "feathers". In pyrope, inclusions vary according to locality, but either intersecting needles of amphibole or small rounded zircon crystals are the most common features.

(5) If the minerals are in the rough state and to some extent expendable, the behaviour of a small piece when placed in a carbon arc can be distinctive. In the high temperature of the arc-flame pyrope fuses readily to a black bleb of glass. Spinel, on the other hand, fuses reluctantly, and then (as behoves a mineral that can be synthesized under the drastic conditions of the Verneuil furnace) it recrystallizes immediately as a white reticulated mass of linked octahedra.

(6) A further test which has been found effective is to observe the response of the specimen to a powerful pocket magnet. When the stone to be tested is placed on a suitable "insulating" block (such as a large cork) on the pan of a sensitive balance, and exactly poised with weights, etc., on the other pan, the close approach of a small powerful magnet (such as the "Eclipse") to the specimen will be found to upset the poise quite clearly in the case of any pyrope garnet on account of its iron content, while with spinel no appreciable effect can be noted.

So chrome-rich was the spinel described above that it showed no trace of fluorescence even under crossed filters, and this fact, combined with its very high refractive index, could easily have led to its wrong identification as pyrope. The absorption of light was so intense that with transmitted light only the red end of the spectrum was visible. In this red "window", however, were numerous clear-cut lines, and we were able to measure these as having wavelengths *7073*, 6940, *6820*, 6730, 6620, *6550*, 6480, 6410Å, which agreed with those we had recorded in the past for chrome-rich spinels. These observations made the identification as spinel quite certain. Further evidence was provided by the inclusions, which showed a distinctive ghost-like "feather" of octahedra; while lastly there was no sign of any magnetic pull on the balance.

As already noted, the stone was unfortunately mounted (with diamonds) as a three stone ring, with the result that the density of this exceptional stone remains unknown. Probably it would have proved to be in the region of 3·63.

(3) *A remarkable blue diamond*

The third stone to be described, a blue diamond mounted as a ring, was of very different calibre, being at least as notable for the beauty and rarity of its colour and presumably for its value as for its great interest for the student of unusual diamond behaviour. The specimen was deeper in its blue colour than any we had previously seen, though having rather the hue of a fine indicolite than that usually associated with sapphire. It had a spread of about 3½ carats, step-cut, and was handsomely mounted in a single-stone ring.

Dr. J. H. F. Custers' claim that all natural blue diamonds belong to a special type which he called "type IIb" has so far proved true without exception and this makes it possible to check in the laboratory the authenticity of the colour in any blue diamond without much trouble. This peculiar type of diamond shows no fluorescence under long-wave ultra-violet rays, but after exposure to short-wave rays shows a persistent phosphorescence—this at least is its usual behaviour. A more definite distinction from other types of diamond lies in its electrical conductivity. Normally diamond is an insulator, as are other transparent crystals, but type IIb diamonds can conduct more or less freely when a potential difference of 100 to 240 volts is applied to two sides of the stone. While the stone is conducting a current, blue flashes of "electro luminescence" may be seen, and in some cases the stone may become very hot if the current is allowed to flow for some time.

In the present case, when the mains voltage of 240 volts was applied on the special "hook up" constructed for this purpose by Mr. Robert Webster, the stone caused a voltage drop only to 200 volts, while a brilliant sparkle of blue electroluminescence could be seen around the probe. So far the diamond, though rare in colour, was behaving "according to plan". It was in its luminescent behaviour that it showed its exceptional character. It did indeed show phosphorescence after exposure to 2537Å mercury light: but phosphorescence could be similarly noted after exposure to long-wave ultra-violet or even to visible blue light, and moreover in all cases the glow was distinctly *red* in place of the more usual green or yellowish hue.

Under X-rays a particularly striking effect was noted. There was here visible a dullish mauve fluorescence which, on switching off the rays, did not at first change perceptibly in colour or intensity, but then gradually faded and changed into the red hue seen in the case of the other radiations mentioned above.

Only one diamond had previously been encountered which showed comparable effects. This was a steely blue stone, also mounted as a ring, which was reported upon in a previous article. Though this stone also showed a red glow after stimulation by all types of radiation including visible light, the electrical conductivity was markedly lower than in the dark blue diamond here recorded.

SIMPLE PHOTOGRAPHIC EQUIPMENT

By B. ERICHSEN, F.G.A.

AFTER studying the literature I felt that it would be somewhat expensive to purchase the equipment necessary for photomicrography and I decided to make my own equipment. I took a thin plate of copper and made a funnel with a cylindrical holder to fit the ocular of the Rayner microscope. At the other end of the funnel I made a holder for a cut flat film casket, 6 × 9 cm. (Fig. 1). I made the whole non-reflecting with matt black camera finish. I focused the camera by means of a screen used in place of the film casket and for fine focusing used a pocket magnifier. The advantage of using cut flat films instead of roll films enables one immediately to rectify a wrongly exposed photograph. The accompanying illustration (Fig. 2) shows what can be achieved with this simple apparatus.

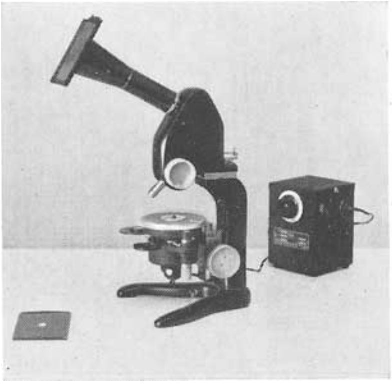

FIG. 1. *Rayner microscope with home-made photographic equipment.*

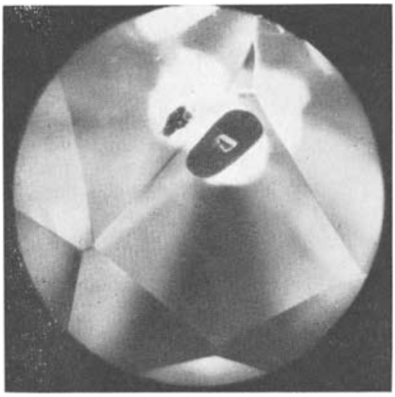

FIG. 2. *Ilmenite inclusions in diamond.*

PLEASE TEST EMERALD

By A. E. FARN, F.G.A.

NOT too long ago many jewellers were happy men who looked at green stones through a filter and said, "It's red, it's emerald". That constituted emerald testing. True, they had to have worrying things like ruby and sapphire tested (albeit reluctantly) and gave grudging admission that there was something in this gemmology business.

However, with the pre-war manufacture of the "Igmerald" in Germany and the Chatham synthetic emerald from America just after the war, it became apparent that the reign of the Chelsea colour-filter devised by B. W. Anderson and C. J. Payne (one of the many very very useful adjuncts to gem testing from these eminent gemmologists) was ending—that is, as a straightforward first-class spot-on test for emerald—but it still has very many uses in the hands of the competent gemmologist. Most people I have seen in the trade seem to hold the stone up to the light (lamp bulb) and look at it through the filter. Actually, best results will be obtained if the stone is held under a light or behind it and then examined, when a much better colour-result will be seen. If the stone is but faintly coloured by chromium and held *against* the light the effect will be weakly seen or not seen at all.

However, circumlocutious as that may be, facts are facts and one is that emeralds in jewellery present a problem to the jeweller, mounter, auctioneer, and dealer. The more recent advent of the synthetic spinel soudé and "emerita" has now practically forced the hand of all jewellers in having their stones tested. Whilst it is not assumed that many present-day gemmologists cannot expertly test emeralds, neither is it assumed that many well established jewellers of much experience do not know their emeralds when they see them. It is still very much a fact that "emeralds" in settings can spring from a variety of sources.

Earlier I wrote an article[1] discussing the relative merits of Standard versus Spinel refractometers (the latter used to be termed the Anderson-Payne Spinel refractometer since again it was a product of their gemmological ingenuity). The spinel refractometer comes very much into its own when testing emeralds and emerald-like stones.

To begin with, then, it is necessary to list the green stones, including emeralds, which could be emerald.

Suppose (as is usual) an emerald in a cluster ring is received for testing. Usually a note briefly states: "Please test green stone in cluster ring". I like to look at a stone with a lens first of all and make up my mind right away before I do a proper test. I like to put into practice all I have been taught in the use of the lens, i.e. double refraction, inclusions, surface structure, etc. Obviously on first seeing a stone the general appearance or "look" of the stone gives a strong indication. Most jewellers or stone dealers have such a fund of "rule of thumb" knowledge that mostly on sight they are able to distinguish a stone. Since emeralds command such fantastically high prices in world markets it is essential to be right every time when dealing in thousands or merely hundreds of pounds. Therefore, having had a look at a stone, then an examination by lens to gain a quick intimation, a proper test takes place. Here, then, the Spinel refractometer takes pride of place, since it is just the right instrument for the job and range of indices to be measured.

A first reading on the refractometer will usually settle the problem or point the line to be followed. If the reading should be 1·571–1·577 and the stone has a chromium absorption spectrum, three-phase inclusions with perhaps pyrite included, then it is certain the stone is a Chivor stone from Colombia, S.A. This is perhaps a rather straightforward nice and easy stone to test. There can be others. For instance, the stone could be backed and foiled as was the last steep cabochon I tested. Superficially it looked all right and pinky red under the filter. The foiled cabochon had two-phase inclusions more typical of green or colourless beryl than the three-phase inclusions of Muso, Chivor, etc. The distant-vision reading by the Lester Benson method (sometimes termed the spot method) gave a mean reading approximate to 1·57 and of course no double refraction. The lens also showed that the foiling was partial, i.e. there were small patches at the back of the stone which were or appeared to be colourless. This rather indicated painting. Although the stone appeared pink under the filter it gave no absorption spectrum or fluorescence bright line due to chromium. A stone must be coloured by chromium to be an emerald. Viewed sideways against a bench lamp, without benefit or bias of the backing, the whole of the side-view of the stone appeared colourless, thus proving it to be a beryl and not true emerald. It would have been possible to immerse the stone and view it sideways in a liquid such as beryl-benzoate, which is a very good match for beryl, but some might have crept under the setting and spoiled the appearance of the stone. Merely to mention three-phase inclusions as being typical of genuine emerald barely touches the edge of the possibilities of the characteristics of emeralds. Recently, at a third year post-diploma course lecture on emeralds, a list of provenance, specific gravities, refractive indices and type inclusions was given by Mr. B. W. Anderson, who lectures regularly at Northern Polytechnic. This list I am reproducing as given to the lecture class. It affords a very condensed but practical list of stones from the lowest refractive indices of Chatham synthetics to the highest of Pakistan emeralds.

Provenance	*Specific Gravity*	*Refractive Indices*	*Birefringence*	*Inclusions*
Chatham synthetic	2·65	1·560–1·563	·003	Curling feathers and phenakite crystals.
Zerfass synthetic	2·66	1·555–1·561	·006	Similar to above
Gilson synthetic	2·65	1·560–1·563	·003	Possibly a yellower green in colour.
Lechleitner "Emerita"	2·69–2·81	1·566–1·571	·005	Crazing on surface structure.
Brazilian	2·68–2·69	1·568–1·573	·005	Usually very clean and pale.
Chivor	2·69	1·571–1·577	·006	Pyrite crystals and three-phase inclusions.
Muso	2·70–2·71	1·574–1·580	·006	Calcite and three-phase inclusions.
Siberian	2·72–2·74	1·581–1·558	·007	Actinolite blades and flaky structure parallel to basal plane.
Habachtal	2·74	1·584–1·591	·007	
Indian	2·73–2·74	1·585–1·592	·007	Hockey stick patterns. Stumpy comma.
Sandawana	2·74 2·76	1·586–1·593 1·588–1·595	·007	Curved fibres of tremolite.
Transvaal	2·74–2·76	1·586–1·593	·007	Fuchsite micaceous inclusions.
Pakistan	2·74 2·77	1·588–1·595 1·590–1·598	·007 ·008	Insufficient data.

In the list some sources such as Muso and Chivor overlap somewhat, which is not surprising since they are both Colombian stones. Not a lot can yet be written about typical inclusions in Pakistan emerald. By and large the finest stones come from Colombia. "Possibly" the finest colours (but small stones) come from Sandawana. I purposefully put "possibly", since as in all cases it is a matter of opinion on colour. Basically, the straightforward test for an emerald that is mounted is the refractometer, and preferably the spinel refractometer. The refractive indices and amount of birefringence are the proving factors and, if unmounted, of course the specific gravity. Fortunately the Chatham synthetic and its European counterparts, the Gilson and Zerfass synthetics, have very low refractive indices of 1·560 to 1·563 and double refraction of only ·003. These factors keep synthetic emeralds well away from the next on the list, the Brazilian stones—coupled with the added factors that, stone for stone, synthetic emeralds, both Chatham and Gilson, are relatively a fiercer red under the filter and have typical curled liquid-drop feather inclusions (they are so typical of synthetic emerald and are one of the safest possible signs to be seen in testing). These feathers are, of course, more plentiful in the cheaper grades of synthetic emerald (not that recent synthetics seem cheap); the feathers which are included have a tendency to curl and interlock with each other and are easy to recognize. The Gilson synthetic emerald has a yellower green look than the Chatham and possibly a higher proportion of feathers as against feathers and phenakite crystals of the Chatham synthetic. The higher grades of synthetic emeralds are comparatively clean, but their refractive indices and specific gravity remain constantly low. Because a stone is clean and looks good it will command a high price (high means astronomical in the emerald market). If a stone commands or purports to command a high price—serious thinking and testing must result. It cannot be over-emphasized that it pays to have emeralds tested.

Synthetic emeralds when loose are even more obliging and literally give themselves up. A density liquid with a colourless quartz suspended in it will be sufficient to check any synthetic emerald. Better still, a density liquid with a known laboratory-tested sample of synthetic emerald suspended in it will serve as a ready means of identification. The synthetic emeralds have a density of 2·650, lower than any other genuine emerald, and very close to the 2·6508 of quartz. Whilst most synthetic emeralds will turn red under the excitation of long and short wave ultra-violet lamps, this colour-change is not by itself a reliable diagnostic feature, since some natural emeralds have this tendency.

Lechleitner "emeralds", known as "Emerita" stones, are preformed cut stones of beryl of colours from colourless, pale green to pale pink beryl, which are used as a seed. They are then given a coating of synthetic emerald, presumably hydrothermally. Thus the stones have natural inclusions, appear red under the Chelsea filter, have refractive indices probably in ranges from 1·566 to 1·571 but which may be higher according to the seed used. The density can be from 2·69 upwards. Fortunately since the coating of synthetic emerald does not "take" readily on the beryl surface (it is not in an acceptable growth orientation) a crazing appearance is seen when the surface is examined by lens. The appearance of emerita under the filter gives an indication of red only around the perimeter of the stone. Similarly under ultra-violet light a red outer rim is seen on Emeritas. Of course, good trade practice and knowledge will tell a stone dealer that the stone looks wrong.

Next in line come the Brazilian emeralds. These can be a bright, pleasing, somewhat pale green and often almost clean. I would consider them to be the most taxing of all stones, especially when in a closed-in or awkward setting. The refractive indices of Brazilian emeralds are 1·568 to 1·573, giving a birefringence of ·005. The specific gravity is given as 2·68 to 2·69, and if there are any distinctive features in Brazilian stones they are usually two-phase and more indicative of beryl than emerald. However, in this case, provided chromium fluorescence can be seen as a bright line in the red end of the spectrum and the refractive indices are close to 1·568/1·573, then it is safe to term it emerald, and not synthetic.

Chivor and Muso mine stones come from Colombia, South America, and are the world's finest stones. Their refractive indices, birefringence and specific gravities are very close indeed to each other, but the Chivor stones are distinguished (although I think it straining one's gemmological faith a little) by the pyrite inclusions and three-phase inclusions which are common to them from the Muso stones, which have calcite rhomb inclusions and occasionally pink rare earth inclusions (parisite). This latter fact I can remember seeing demonstrated by the late Sir James Walton, who was terribly excited by the queer absorption spectrum seen in a portion of an emerald he possessed. One end of the stone (or crystal) had a band of parisite as an inclusion and it gave a distinctive strong rare earth spectrum, bearing out exactly what the better written text books depicted or told. The fact that parisite is an inclusion in emerald is interesting and a reminder of how enjoyable was the enthusiasm of Sir James, whom it was a privilege to have known. Chivor stones' refractive indices are 1·571 to 1·577 with birefringence of ·006 and specific gravity 2·69, three-phase inclusions of jagged outline and frequently pyrite as an inclusion. Muso stones range from 1·574 to 1·580, have a density of 2·70 to 2·71 and double refraction of ·006, and have calcite as an inclusion but three-phase inclusions as well.

Siberian emeralds from the Ural Mountains are red under the filter, slightly heavier with S.G. 2·72/2·74, have refractive indices 1·581 to 1·588 and double refraction of ·007, and are much more interesting under a microscope since they contain actinolite fibres, which have lines or cracks crossing them giving them the appearance of the growth structure seen in some woody shrubs akin to a bamboo shoot. This latter description comes from B. W. Anderson and I cannot alter it, better it—or omit it.

Closely related in characteristics are the slightly mysterious emeralds of Habachtal. The emeralds (seldom seen) are mined in Austria, in the district of Salzburg, in mountainous regions 7000 feet above sea level. Since they and the Russian emeralds come from similar rock formations they have similar structures inside. Their refractive indices are 1·584–1·591 (a birefringence of ·007) and their specific gravity is 2·74. The Habachtal mines have been worked intermittently and possibly are uneconomic, but in London to-day there are a few thousand carats of genuine Habachtal emerald crystals waiting to be purchased by some keen, wealthy or commercially minded gemmologist.

Indian emeralds are heavier, deeper and a somewhat more saturated green and do not go red under or through the Chelsea filter. Fortunately Indian emerald inclusions are strongly characteristic, resembling a short stumpy hockey stick. They have slightly higher refractive indices again, at 1·585 to 1·592, a density of 2·73 to 2·74 with birefringence of ·007. The important factor to note is that, although when these characteristics are listed in an ascending order of R.I. and S.G. they do not seem to be much removed one from another and the variations are small, the birefringence coupled with the refractive indices and specific gravity of synthetics are lower in all cases than those of the lowest of genuine emerald. This is quite a clear-cut division and is seen to best advantage on the Anderson-Payne spinel refractometer.

Sandawana, one of the more recent finds of emerald from the continent of Africa, apart from being beautiful, are very interesting indeed in their inclusions, these being a series of criss-crossing curved tremolite needles—an instance (and there are many) where nature does not adhere to rigid straight line formation seen in the usual silk and colour zoning of stones. The curved nature of the included tremolite needles in Sandawana is quite delightful. It is not usual to find large sizes in Sandawana emeralds; they usually run small and very good or large and coarse. Sandawana emeralds have a specific gravity of 2·74 to 2·76 and refractive indices of 1·586 to 1·593, giving a birefringence of ·007.

Higher on the scale are the emeralds from South Africa (Gravelotte). These emeralds are a sad colour, usually almost a touch of yellow/brown to them owing to the predominance of mica plates as inclusions. Usually these Transvaal emeralds do not show red through the filter, but are coloured by chromium, as the spectroscope will prove. Their S.G. ranges from 2·74 to 2·76, a birefringence of ·007 and refractive indices 1·586 to 1·593. Lots ofTransvaal emeralds are of very poor quality and were exported to India until political crises stopped their importation.

Pakistan emeralds at the moment have the highest constants, being 2·74 to 2·77 S.G. and refractometer indices 1·588/1·595 with birefringence ·007. Very few consignments of these emeralds have so far been examined. They are a good deep green, go a darkish red under the filter and their inclusions are quite varied but are each in themselves to be seen in other types of typical emerald. That is to say, they have micaceous inclusions, two-phase inclusions, feathers, etc., in fact they have a whole host of natural inclusions, none of which to me so far seem typical for Pakistan but fit most emeralds.

Broadly speaking, the foregoing are the emeralds and synthetic emeralds at present upon the market, and it is surprising, with so many to write of, one seldom sees any emeralds of superb colour, size and cut.

Stones which surprisingly enough are sent for testing and which one presumes to be imitating emerald, are glass, paste soudé, garnet-topped doublets, fluor, aventurine, microcline, backed, foiled and/or painted beryl, heat-treated tourmaline, peridot, demantoid, zircon, stained chalcedony, chrysoprase, jadeite. These are quoted for the simple reason that at some time or other they have been presented for testing. Straightforward glass which is faceted, is easy on the refractometer—particularly the spinel refractometer—or is given away by bubbles and/or swirl striae and/or the heavy cross seen between crossed polaroids, which is due to strain. Paste is a little higher up the scale in refractive index and usually is revealed by the colour fringe due to its high dispersion, seen on the scale of the spinel refractometer when a reading is taken. Swirl striae and bubbles are often apparent—sometimes (as a word of warning) it is possible to have a cluster of small gas bubbles, closely knit and linked together, forming a kind of feather-pattern which, viewed quickly, can be most deceptive. Soudé emerald is readily detected by the reliable spinel refractometer; some soudés go red under the filter but not many.

Garnet-topped doublets seem to puzzle many people and I have known one well known "expert" buy a garnet-topped doublet graduated bracelet as the finest range of demantoids he had ever seen. However, the red glints or reflections seen from the garnet top and the flattened bubbles (of trapped air) all in one plane should in themselves be sufficient indication. Sometimes the garnet top has natural inclusions, but these are different from what is expected in an emerald (rutile needles and diopside crystals as opposed to three-phase inclusions, etc.).

In a green stone which is a garnet-topped doublet it is very often possible to see the junction if the garnet, top edge with the glass base. Sometimes the garnet top is very thin indeed, almost a flashing of garnet. It is seldom symmetrical, but if it is not closed in by the setting careful scrutiny with a 10 × lens will reveal the junction, since the garnet has a higher refractive index and takes a better polish than the glass base and it is impossible to obviate the difference showing where these two meet. It is quite rewarding to spot the doublet. In point of fact the garnet-top doublet doesn't offer any serious problem to a jeweller who applies even one test to the stone—he may not detect it, but he knows it isn't emerald.

Green fluorspar, especially if it is carved, can be a teaser. Fluor turns red under the filter but fortunately is much heavier than emerald, S.G. 3·18; and its refractive index is single at 1·434. It is soft—very soft—and usually exhibits marked signs of cleavage, which is its weakness. Because of its low refractive index fluorspar when cut has a very empty lack-lustre look which gives it a very poor glass-like appearance. No confusion could possibly occur if the spinel refractometer were used; even the Lester Benson method would give a sufficient indication to identify a cabochon or carved piece. One of the strengths of the distant vision method is that whilst no very sharp reading can be taken, say, of 1·434 or 1·575, it is capable of giving an indication of the area of mean refractive index sufficiently to distinguish between emerald and fluor.

Green aventurine quartz, which appears red under the filter, is coloured by flakes of fuchsite mica which give it a spangled effect, and when examined internally by lens or microscope an apparently regular wealth of somewhat irregular inclusions, all of similar outline, defy comparison or mistake for any sort of emerald inclusion. Admittedly the specific gravity of aventurine is 2·65 and its refractive index 1·55, but its external and internal structure divorce it even from synthetic emerald.

Microcline feldspar, or amazonstone, is a bright hard blue-green stone which does occasionally look something like coarse green beryl but should not be considered as emerald. The name microcline indicates that in its crystal structure one of its axes is slightly inclined (orthoclase feldspar is monoclinic, amazonite is triclinic). Amazonite cleaves very readily and easily and has two directions in which this occurs. It is because of this so called incipient or easy cleavage occurring during polishing that a series of minute flats reflect light back from the polished surface and give a twinkling or shimmering effect, especially if the article is rotated. Having a density of approximately 2·57 and refractive index between 1·52 and 1·53, it would be difficult indeed to consider microcline as a serious possibility as emerald.

Heat-treated tourmaline can be a very attractive bright green stone, since the heating tends to lessen the dichroic effect. Attractive as it is, green tourmaline is quite easily separated from emerald, since it has distinct double refraction of 1·620 to 1·640, a wide birefringence of ·020. It does not go red under the filter and, all told, is merely a green stone easily separated from emerald. Peridot is in the same easy group as tourmaline, because it has wide birefringence of ·038, refractive indices 1·650–1·688, a specific gravity of approximately 3·35 and a distinctive absorption spectrum. Demantoid garnet, possibly the world's loveliest stone, has the deep true green of emerald but a much superior fire. Demantoid turns red under the filter but usually has some trace of asbestos fibres included, usually of a horse-tail plume in aspect. The high refractive index of 1·88 or higher separates it from emerald. Green zircon is a most attractive stone, which by heft alone should warn the jeweller—however, as it never truly resembles emerald it should give no worry. No reading is possible under normal conditions, either with the standard or spinel refractometer, and a quite distinctive absorption spectrum totally unlike any other green stone helps to distinguish it from emerald. Green zircon remains one of our least appreciated colourful gems. Light grey chalcedony, stained rather bright green by chromium solutions or lesser apple-green by nickel solution, when seen in a closed setting could be imagined as emerald. The former will appear red under a Chelsea filter.

Fortunately the spinel refractometer serves admirably to show form birefringence typical of the cryptocrystalline varieties of quartz. The fixed reading of about ·004 between refractive indices of 1·530 to 1·540 steer this material away from even the lowest possible emerald reading. This "form birefringence" seen in chalcedonies is not solely typical for quartz familes but can be observed in other materials of mixed varieties. True chrysoprase does not turn red under the filter, because it is not coloured by chromium but by nickel. Chrysoprase is a scarce material, but its indices of refraction and specific gravity are those of stained chalcedony.

Jadeite, cut "en cabochon", when particularly fine could look like an emerald cabochon. When jadeite is so fine it is termed emerald jade or imperial jade. Like emeralds, jadeite owes its wonderful green to chromium.

Fortunately a Lester Benson distant vision refractive index reading will easily differentiate between the mean refractive index of emerald 1·57 (approx.) and jadeite 1·66 (approx.). Jadeite, because of its variable hardness, shows a dimpled surface structure which seems to be a characteristic (when seen) not shared by any other material of similar quality of colour. Jadeite, of course, is much heavier than emerald, its S.G. being approximately 3·33. The absorption spectrum of emerald-green jadeite and fine quality emerald are not easily sorted out by average gemmologists, but the refractometer once again serves as the reliable testing instrument.

Having now thought of most green stones which could, with a little licence, look like emerald (and I don't doubt there are others which do not spring readily to my mind), it behoves us to consider those stones which literally do look like emerald, have the refractive indices of emerald, turn red under the filter and are often found in an antique setting, foiled or painted. Usually the article is not suitable for immersion and here one has to use skill in determining emerald or not.

At first sight, because of the quality of the mount and intrinsic value of the item, one assumes emerald (mentally noting foiled but possibly even a better colour than immediately apparent). It has been found that some emeralds foiled by the Victorians or having a black matt-finish background as a backing actually prove to be better emeralds when removed from settings. It is usual, though, to find that foiling, backing, etc., are used as a means to accentuate or "improve" that which nature was lax in doing. Since human artifice can seldom vie with nature at her best, it is palpably evident when an attempt has been made to "gild the lily".

Very often when a stone purporting to be an emerald is in a closed setting in an antique piece of jewellery it will often turn red or paler shades of red, red pink, or brown-red, through the filter. This can be misleading, especially if the stone has natural-looking inclusions related to beryl. Then, unless the stone is taken out, it is only possible to deduce emerald by the absorption spectrum by reflected light. Here one finds the Beck intensity-lamp with its focusing device extremely useful for pin-pointing a strong beam of white light on to the stone in question. The spectroscope, held in the white light on to the stone in question. The spectroscope is held in the hand close down to within a half inch of the stone and the slit of the spectroscope slowly carried across, and up and down over the stone in order to pick up the corresponding angle of reflection at its optimum point of light quality. Here, then, when one gets the absorption bright line fluorescence indication of chromium one can say the green stone is emerald, no matter how pale the stone may be. If no chromium spectrum is seen, even though red under the filter and full of natural inclusions typical of beryl, the stone is not an emerald.

The method of using an intensity-lamp to pin-point light specifically on to a backed stone need not be thoroughly followed in detail, since any sort of improvisation will bring results. The set-up used in "Testing a sapphire"[2] with a microscope and flask of water will work quite well if a smaller lens is used to focus the condensed light from the flask onto the stone. Emphasis has been laid in these instances of backed or foiled stones on obtaining an absorption spectrum by scattered light—obviously stones which are not backed can be treated as with transmitted light through the microscope in the accepted manner. I am fond of coining phrases, but some phrases already coined seem so apt as to defy improvement. Such a phrase, well known to readers of gemmological journals, is "If there's a doubt, have it tested". Never were so few words succinctly coined to describe the many reasons for having all emeralds tested.

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2. ————. *Testing a sapphire.* Journ. Gemmology. (1962) 8, 6, p. 215

Gemmological Abstracts

NEWNHAM (Robert E.) and co-workers. *Crystal structure, synthesis, and magnetic properties of chrysoberyl.* Laboratory for Insulation Research, Massachusetts Institute of Technology Technical Report 183 (Nov. 1963).

"The study of gems has proven fruitful, not only to the jewelry trade, but to the scientist and engineer as well. Numerous publications describe the properties and applications of synthetic diamonds, rubies, emeralds, spinels and garnets. By comparison, relatively little interest has been shown in chrysoberyl".

Robert E. Newnham and co-workers at the Laboratory for Insulation Research at Massachusetts Institute of Technology have synthesized crystals of yellow chrysoberyl and alexandrite up to several carats by a flux-fusion technique. (A satisfactory composition for producing chrysoberyl was found to be Pb0 66·6, Al_2O_3 16·7 and BeO 16·7 mole percentage, for alexandrite $LiMoO_4$ 40·4, MoO_3 50·6, Al_2O_3 : Cr 4·5 and BeO 4·5 mole percentage, the furnace temperature being held at 1375°C for 5 hours in the making of chrysoberyl, and at 1000°C for 2 hours for alexandrite). Chrysoberyl has an orthorombic space group. The authors show that the two crystallographic sites for Al differ appreciably in size and symmetry, and that the trivalent Fe and Cr ions substituted for Al in $(Al,Fe)_2$ BeO_4 and $(Al,Cr)_2$ BeO_4 prefer one of the Al-sites to the other.

Information on colour, pleochroism, inclusions, S.G., R.I. or dispersion is not given. The authors state, though, that further experiments on chrysoberyl, alexandrite, and the isomorphous olivine family are in progress, including optical absorption and fluorescence spectroscopy, besides electron paramagnetic resonance.

U.H.B.

GRANTHAM (D. R.). *The diamond deposits of Panna, Central India.* Industrial Diamond Rev., pp. 30-35, No. 279, Vol. 24. February 1964.

The author of this important article has drawn the facts from official publications and from his own observations made on a recent visit to the area. Panna, in the state of Madhya Pradesh, lies at an altitude of about 1100 feet above sea level, and the diamond fields, which have been known for several centuries, stretch in two belts. The streams of the area drain into the Ganges basin. There are three different types of diamondiferous deposits; pipes, conglomerates and alluvials. The geology of the area is explained and the ancient workings discussed. Full details are given of the Majhgawan pipe and mention is made of a second pipe at Hinota some two miles away from Majhgawan. The second type of deposit, the conglomerates, consists of pebbles of jasper, quartz or quartzite, which are either in fine-grained and loose material or hard-cemented with silica, and some are simply pebbles in shale. The alluvial deposits are extensive and lie along the Baghain river east of Panna. The diamonds found in the Panna region are distinctive for the high degree of curvature of their faces, causing the diamonds to be nearly spherical. Something is told of the colours and qualities of the diamonds found in the area, and of the values obtained. The methods of mining, recovery and the sale of the crystals are given.

5 illus. R.W.

HANNAFORD (G. B.). *Diamond mining and recovery to-day.* Gems and Gemology, pp. 67-79, No. 3, Vol. XI. Fall 1963.

Details of the author's visit to the African diamond mines and fields. The Williamson mine, the pipe mines around Kimberley, the Premier mine and the fields of South-west Africa were those visited. The various mining operations and methods used to recover the crystals are considered in detail.

6 illus. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology, pp. 88-87, No. 3, Vol. XI. Fall 1963.

Records interesting items which have been handled by the New York laboratory. A blue sapphire intaglio, a crystal-like bubble seen in a glass stone, wear on the facet edges of a diamond, growth lines in another diamond and some notes on orange-coloured cyclotroned diamonds are mentioned. A bluish-green treated diamond which transmitted light beyond 7000Å and which showed clearly lines at 7350, 7230 and 6700Å with a moderate line at 4300Å, and also the unusual behaviour of a highly conductive grayish-brown diamond were two other interesting items. Mauve-dyed jadeite, tinted amber, surface-stained limestone beads imitating dark-blue turquoise, dyed lapis-lazuli and an eight-foot long necklet of jet are mentioned. Red-brown quartz crystal groups (ferruginous quartz) which had been mounted on a chain bracelet, treated opal and new types of synthetic emerald are also mentioned.

12 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, pp. 88-92, No. 3, Vol. XI. Fall 1963.

The Gem Trade Laboratory refers to "black pearls" without orient (one in particular being with an almost metallic lustre, having an R.I. of about 1·70 to 1·75 and a density of 1·30), a pearl necklet of Biwa non-nucleated cultured pearls and a large Tridacna pearl. Imitations of "cross twin" crystals of staurolite are referred to and notes are given on the ultra-violet transparency test for natural and synthetic emeralds.

5 illus. R.W.

MALES (P. A.). *An unusual colour pattern in precious opal from Andamooka.*

A type of opal with an unusual play of colour is explained as being due either to unreplaced oolites surrounded by a cement of precious opal or to the replacement or partial replacement of the oolites by precious opal. Two references are given.

R.W.

WALKER (W. H.). *A new type of simulated heat-treated "black opal".* Lapidary Journal, p. 655, No. 6, Vol. 17. September 1963.

Opal matrix from Andamooka is treated in order to produce a "black opal". As far as could be found out by the author during a visit he paid to Australia, the method used to treat the opal is as follows. First the cabochons are cut and polished and then they are heat-treated in an oven under carefully controlled conditions. They are then removed from the oven and placed in a sugar solution for an undetermined time and then into sulphuric acid. This treatment, which is analogous to the production of black onyx, darkens the matrix which brings out the colours of the opal part, which itself is not altered in colour by the treatment. The best stones are those in which the matrix is coloured throughout; when only the surface is coloured black the stones are not so satisfactory.

R.W.

POUGH (F.H.). *The gem collection of the American Museum of Natural History, New York City.* Lapidary Journ., 1964, 18, 1.

A concise account of the gems in the Morgan Hall of the Museum. The collection owes much of its present magnificence to the pioneer work of Dr. G. F. Kunz and to the generosity of J. Pierpont Morgan.

S.P.

JOBBINS (E.A.). *The gemstone collection of the Geological Museum, S. Kensington, London.* Lapidary Journ., 1964, 18, 1.

A description of the gemstones housed in the museum and the methods of displaying them. The coloured illustrations of gems, which are included with the article, are better printed than the museum's own sheet, well known to U.K. gem collectors, and which was issued in 1952.

S.P.

NAUSSAU (K.). *Growing synthetic crystals.* Lapidary Journ., 1964, 18, 1.

The first of a five-part series on the growing of synthetic crystals. The two major methods used are growth from solution and growth from melt. Flux growth and the Czochralski technique (a method for the growth of single crystals) are discussed in the first article.

S.P.

BANK (H.). *Fundortsangaben bei Edelsteinen.* Publication of occurrences of gems. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 44, pp. 15-18.

This article discusses the difficulty of finding out where any particular gems have been found. In Africa and South America the author found that either he was not told at all where the gems came from or in the place given no such gems had ever been found; this may be due to the facts that the miners do not attach much importance to the geological question—this is even more true of the dealers, who are also interested that their customers do not know where the stones come from—and also that the gems change hands many times before they are bought by the interested collector. Various examples are given.

E.S.

GÜBELIN (E. J.). *Two new synthetic emeralds.* Zwei neue synthetische Smaragde. Zeitschr. d. Deutsch. Gesell. f. Edelsteinkunde, 1964, 47, pp. 1-10.

Two new synthetic emeralds have appeared on the market recently. Chemically, physically and in appearance they are emeralds. The quality is quite good and may be compared to second rate genuine stones of several occurrences. However, differentiation from genuine stones is easily effected due to lower physical constants and typical inclusions, i.e. lace-like feathers as seen in all synthetic emeralds. Slight variations in the inclusions and of appearance under UV light allow the gemmologist to identify synthetic emeralds of different manufacture.

The first of the new synthetics was described over a year ago by Prof. K Schlossmacher. The producer is W. Zerfass, of Western Germany. The second made by P. Gilson appeared on the market at the end of 1963. It is produced in Northern France. Table 1 shows some of the properties of the Zerfass and Gilson synthetics together with those of the Chatham and IG Farben synthetic emeralds. Apart from the constants and properties listed in the Table, each synthetic displays characteristics which are described in detail. The Zerfass synthetic emerald, with its low refractive index, allowed Prof. Schlossmacher to observe variations of the Becke line effect. These were described in detail by R. K. Mitchell (*Journal of Gemmology*, 1963, VIII, 2, p.280). Schlossmacher also drew attention to the honey-comb pattern of the lace-like feathers. This pattern can best be seen if the stone is viewed in a direction parallel to the C axis. At right angles to the optic axis the walls of the honey-combs can be seen to be formed by liquid-drop feathers, which consist of parallel channels. The feathers do not penetrate the stone for long distances parallel the C axis but are interrupted and thus form bands and streaks more or less parallel to the basal plane. So far good quality stones up to $\frac{1}{2}$ cts have been produced. Bigger stones have not been satisfactory. The smaller stones described by the author were of a vivid deep blue-green colour similar to genuine Chivor or Gachala Columbian emeralds. They showed distinct dichroism. The author points out that the honey-combs could be observed especially in the centre, creating the impression that a hexagonal cell had existed first and been surrounded afterwards by other prisms. Looked at in this way the crystal growth could be visualised. Parallel to the basal plane the author observed the zonal bands described by Prof. Schlossmacher. Between straight dark lines, bands of different hues of green to colourless could be seen. Most of these parallel layers contained liquid feathers, others were completely clean. This seems to indicate that the synthetic crystals did not grow continually but in stages, depending on the temperature and concentration of the solution. During these periodic intervals germ crystals can be formed which are either emerald (if the composition of the solution remains constant) or phenakite, if the solution lacks aluminium. Most of the layers were under stress, causing cracks into which the solution could penetrate. The cracks could thus partly heal and form the well known feathers. Within the bands the liquid inclusion formed small channels parallel to the C axis, causing a streaky appearance. The arrangement of these parallel feathers is much more regular than in other synthetic emeralds. Tapered tubes were similar to those observed in Nacken and Lechleitner synthetic emeralds. They "stand", probably, on minute phenakite crystals and taper off in a direction parallel to the C axis. These tapered tubes are two-phase inclusions (liquid and gas bubbles) which allow the conclusion that Zerfass made use of a hydrothermal method in contrast to the diffusion-melt method of Chatham.

The Gilson synthetic emeralds display a warm green colour with a yellowish tint and resemble good quality genuine stones from Muzo and Sandawana. They are comparatively clean but still show the familiar lace-like feathers of all synthetic emeralds. The feathers are similar to those of the Igmeralds or the Chatham synthetic and allow the conclusion that the French product is made by the diffusion-melt method. Accordingly no phenakite inclusion of any size was found.

TABLE 1

COMPARISON OF PHYSICAL PROPERTIES OF SYNTHETIC EMERALDS

Producer	*Refractive index*		*DR*	*SG*	*Fluorescence*		
	ε	ω			*3650Å*	*2537Å*	*crossed filters*
I G Farben (Igmerald)	1·559	1·562	·003	2·65	strong red	strong bright red	glowing red
Chatham	1·560	1·563	·003	2·65	strong red	strong bluish-red	glowing red
Zerfass	1·558	1·562	·003–·004	26·6	strong red	dull bluish-red	glowing red
Gilson	1·558	1·562	·004	2·65	olive green	weak olive-green	glowing red

W.S.

PLEOCHROISM IN CRYSTALS

By J. OSTWALD, B.Sc., F.G.A.A.

INTRODUCTION

The phenomena of pleochroism are perhaps so well known to students of minerals that it may seem out of place to discuss them in a scientific journal. Be this as it may, the author, in his studies of the optics of ore minerals was forced to admit to himself that there was more to the subject that what he had learned as a student from the textbooks, and, what was more important, the statements on the subject in some of the older and more elementary texts were definitely incorrect. This short paper then is an attempt to systematize the author's knowledge on the subject. The complete theory cannot be given here, as it involves the electromagnetic and quantum theories, but rather those parts of the subject which are of fundamental importance or are useful in laboratory investigations are described.

HISTORICAL

Possibly a study of some of the older texts on mineralogy would reveal the first reference to the phenomenon of pleochroism. Perhaps it was discovered in the same way as the author discovered it, by accident, as a first year student of Geology. He was holding to the light a fine crystal of green transparent aegirine and was surprised to note it change from green to yellow as he rotated it through a right angle. Actually of course, the light reflected from the window glass must have been partially plane-polarized and this explained the colour change. Epidote will give the same effect.

In 1819 Sir David Brewster first noted the "houppes" on the surfaces of a cleavage fragment of phlogopite mica in ordinary light. These dark brushes or idiocyclophonous figures are actually the result of pleochroic absorption.

By 1838 the phenomenon was well known among mineralogists and physicists, for in that year Babinet published the result of his studies of absorption in crystals. He found that most negative crystals—calcite, corundum, tourmaline, emerald, etc.—absorbed to a greater extent the ordinary ray, while most positive ones—zircon, smoky quartz, etc.—absorbed more the extraordinary ray. He thus claimed that the greatest absorption in a crystal coincided with the direction of greatest refractive index. He also found that certain minerals, mainly red tourmaline and ruby, transmitted rays of their own colour without any polarization.

The invention, in 1845, of the dichroscope by Haidinger is a point of importance in the history of the study of pleochroism. Wilhelm von Haidinger, born in Vienna in 1795, was the son of a famous Austrian mineralogist. After studies at the University of Vienna and the famous School of Mines at Freiberg in Saxony, he travelled widely in England and Europe and in 1840 became director of the Cabinet of Minerals in Vienna. It was while he held this position that he developed the familiar tube with low power eyepiece and iceland spar rhomb for the study of the twin absorption colours of crystals.

In 1880 H. Laspeyres published in the "Zeitschrift fur Krystallographie und Mineralogie" a description of the absorption axes of pleochroic minerals. Just as in the case of refractive indices, he found that certain biaxial crystals had direction of least, intermediate and greatest absorption and, more fundamental, the axes of absorption did not always coincide with the Fletcher indicatrix axes. At this time absorption of monochromatic light was expressed in terms of the coefficient of absorption α where α is defined by the following equation:

$$I = I_0 \cdot e^{-ad}$$

where I_0 is the intensity of incident light.

I is the intensity of the light after passing through a distance d.

e is the base of Naperian logarithms.

About the same period Mallard proposed his "ellipsoide inverse d'absorption". It we imagine rays of monochromatic light moving radially outwards from a point in a coloured crystal, then if it is anisotropic each ray has its α. If we lay off on each ray a distance proportional to $\frac{1}{\sqrt{a}}$, using the α for that direction then the surface obtained gives us a mental picture of the brightness of rays vibrating in all possible directions in the crystal.

Mallard further recognized three cases:

(*a*) *Singly refracting crystals* — The surface for every colour is a sphere. There is thus no pleochroism.

(*b*) *Uniaxial crystals* — The surfaces are rotation ellipsoid, the rotation axis being the optic axis direction. By the symmetry of these figures only two values of α are possible for each colour, namely α_1 for rays whose vibration directions are normal to the optic axis and α_2 for rays with vibration directions parallel to the optic axis. But every wavelength has its α_1 and α_2 and thus for different colours the absorption surface has not only a different size but also a different shape.

(*c*) *Biaxial crystals* — For each colour the surface is a triaxial ellipsoid, with axes equivalent to the absorption axes of Laspeyres. In white light the colours arising from the absorption of rays vibrating parallel to these axes are termed axial colours, and at least two observations with the dichroscope for directions at right angles must be made to determine the colours.

In the hand specimen, without the instrument, we can see none of these colours separately. The colour we see is a mixed colour, the facial colour (the Flächenfarbe of Haidinger).

About 1885 Professor P. Groth, of the University of Munich, proposed a modification of Radde's International Colour Scale for the designation of pleochroic colour. This was to consist of wedges of glass of different colours so that the intensity of the colour (measured by the thickness of the wedge) could be stated as well as the colour itself.

Between 1880 and 1900 Voigt and Drude, with the aid of Maxwell's electromagnetic theory, produced the elements of the modern theory of pleochroism and differential absorption in crystals. It is largely on the work of these two authors that the following elementary notes on theory are based.

THEORY OF PLEOCHROISM

When a ray of monochromatic light of intensity I_o passes into a coloured isotropic crystal its intensity is decreased by (1) scattering, (2) reflection at the crystal surfaces, and (3) atomic absorption. We must neglect (1) owing to the difficulty of its measurement—usually it is small in a clear crystal but must take into account (2). If n is the R.I. of the medium and I_t the true intensity and I_m the measured final intensity then

$$I_t = I_m\left[\frac{(n+1)^2}{4n}\right]^2 \qquad (1)$$

We may measure the atomic absorption by the following equation

$$I = I_o \cdot e^{-(4\pi kd/\lambda)} \tag{2}$$

where k is the absorption coefficient.

According to Drude the R.I. of a coloured isotropic crystal is $n - ik$ where i is the square root of minus one.

In the case of a thin parallel-sided piece of coloured isotropic crystal k may be measured by the formula:

$$k = \frac{2 \log_{10} (1 - R) - \log_{10} D}{4\pi d \log_{10} e} . \lambda \tag{3}$$

where R is the reflecting power of the surface. This may be calculated from Fresnel's equation $R = \frac{(n-1)^2}{(n+1)^2}$ (4)

if k is small, or actually measured with a photocell if k is appreciable. D is the observed transmission ratio, λ is the wavelength, and d is the thickness.

Now on entering a low symmetry crystal (i.e. orthorhombic, monoclinic or triclinic) in general a ray of normal light is split into two elliptically polarized waves. The two ellipses have the same ellipticity but have their axes at right angles. In certain directions (the plane polarization cones of J. Woodrow, 1950) the ellipses degenerate into lines and the crystal transmits two plane-polarized waves. These crystals have also four rotation axes in place of the normal two optic axes. For a fuller description of the transmission of light by coloured crystals the reader is referred to the paper by the author in this journal July, 1962.

Pleochroism is generally stated in a qualitative way by stating the colour for vibrations along the principal axes of the indicatrix and also by noting any difference in intensity, e.g. tourmaline: *e* yellow, *o* brown, *o* > *e*.

For measurements of a quantitative nature the pleochroism is stated as $k_1 - k_2$ where 1 and 2 may be any of the symbols ε, ω, α, β, γ, the use of which in relation to refractive indices of crystals, is well known. For example in the case of a red ruby measured by J. A. Mandarino, at 5000Å, $k_\omega = 104 \times 10^{-6}$, $k_\varepsilon = 75 \times 10^{-6}$ and thus, at this wavelength $k_\varepsilon - k_\omega = 29 \times 10^{-6}$. This is the biabsorption. To be of any practical value curves should be plotted showing the variation in k_ε and k_ω across the spectrum and thus the range of biabsorption.

It might be well here to digress a little and distinguish between dichroism (the simple case of pleochroism now under discussion) and dichromatism. In the first case the transmitted colour depends on the appropriate value of k, which depends strictly on Beer's exponential law. Thus the greater the thickness the greater the saturation of the particular colour. In the case of some crystals, such as alexandrite, and some organic solutions, such as cyanine and nitroso-dimethyl aniline in alcohol, the above law does not appear to hold true. In these the colour depends on thickness. For thicknesses greater than the critical thickness the substance is red, for lesser thicknesses it is green. Not only these two colours are possible—cyanine layers and cobalt glass sheets can show either red or blue. In alexandrite the intensity of the green is greater than that of the red. If we use the old-fashioned term co-efficient of transmission "a" where $I = I_o \, . \, a^x$ (5)
with the usual notation with x as a thickness then we may assume that a_g (coefficient of transmission for green light) is less than a_r (coefficient of transmission for red light).

Thus for small thicknesses $I_g \, . \, a_g^x$ will be greater than $I_r \, . \, a_r^x$ and the reverse for thick layers. At a thickness equal to x, the Critical Thickness defined by $x = \dfrac{\log I_g - \log I_r}{\log a_r - \log a_g}$ (6)
the intensities of the red and green will be equal. More important in our case is the fact that, for any thickness, the transmitted colour will depend on the incident light. This is the cause of the change in colour of alexandrite.

Biabsorption may be calculated from the intensities of transmission by the use of the following formula (given for uniaxials).

$$k_\varepsilon - k_\omega = \lambda . \frac{ln \; (I_\omega / I_\varepsilon)}{4 \; \pi \; d} \qquad (7)$$

Another (unrelated) phenomenon is mentioned by Weinschenk. This is pseudodichroism, which occurs in colourless crystals and is probably a diffraction effect. If the crystal contains a large number of oriented inclusions with R.I. markedly different from that of the crystal, then rays vibrating parallel to the direction of the inclusions are dispersed, while rays vibrating at right angles are not effected. Weinschenk lists brown and grey as possible colours, and this is perhaps independent of mineral or R.I. difference between inclusions and mineral.

LABORATORY MEASUREMENT

In this Journal for July, 1961, p. 86-87, E. J. Burbage and T. G. Jones advocated the use of a cadmium sulphide photocell for the quantitative measurement of pleochroism. This idea is not new, for as far back as 1934 Vogel investigated absorption in ruby and emerald with a photocell. In both cases absorption is indicated only by galvanometer reading.

One of the greatest difficulties in the measurement of pleochroism is the fact that a parallel sided sheet of the material of known thickness must be studied. This is not an impossibility in the case of uncut natural crystals as sets of parallel facets may be cut at critical positions on the crystals, or actual slices cut from them in these directions. But in the case of specimen crystals and cut gemstones (except perhaps some emerald—or trap—cut stones) parallel surfaces are not usually present, and, if by accident they are, they are not usually in critical positions.

Of the laboratory methods the Mandarino or double image method is the simplest. Here the pleochroic sheet is arranged between a monochromatic light source and a Wollaston prism. When the vibration directions of the prism and sheet are parallel two images are seen in the eyepiece. One image represents the intensity of light transmitted by the ordinary ray of the sheet, the other by the extraordinary. A nicol (between eyepiece and Wollaston prism) is now rotated from zero until the two images are equal in intensity. Now

$$\frac{I_\omega}{I_\varepsilon} = \tan^2 \alpha \qquad (8)$$

where α is the angle of rotation of the polar for equal brightness.

If the two images are of unequal brightness before the pleochroic plate is introduced then the nicol may have to be rotated from zero by a small angle β.

If so,

$$\frac{I_\omega}{I_\varepsilon} = \tan^2 \alpha \cdot \cot^2 \beta \qquad (9)$$

from this we obtain

$$\frac{I_\omega}{I_\varepsilon} = e^{-(4d\pi/\lambda)\,(k\omega - k_\varepsilon)} \qquad (10)$$

from which the biabsorption may be found. This gives the value for one wavelength. To be of value the variation across the whole visible spectrum should be measured and plotted graphically.

CONCLUSIONS

It is not the object of this paper to go more deeply into such interesting aspects of the subject as the interference figures of pleochroic crystals, the possibilities of katoptric measurements or Drude's classification of absorbing crystals. Rather its purpose is to demonstrate the complexity of what is often passed over as a simple property of some coloured minerals.

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ASSOCIATION NOTICES

TENTH ANNIVERSARY OF THE DANISH GEMMOLOGICAL ASSOCIATION

To celebrate the tenth anniversary of the Danish Gemmological Association, an invitation was extended to B. W. Anderson to give a talk to assembled members in Copenhagen on 7th March.

After an excellent dinner, for which the menu began with " Soup Aventurine " and continued with " Roast Pork Ribbon Agate ", etc., Mr. Anderson was invited to talk for as long as he pleased around the general title " Some stories from London's Precious stone Laboratory ". Under the influence of an interested and friendly audience, and with no sense of the pressure of time, the talk extended to three hours. The great debt that the Danish Association owes to the enthusiasm and guiding influence of Mr. Ove Dragsted was mentioned by Mr. Jorgen Möller in a short after-dinner speech.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. S. Barczinski, F.G.A., Rio de Janeiro, for a gift of a Brazilian blue apatite crystal and a green beryl crystal.

OBITUARY

John P. Turton, F.G.A. (Diploma 1962), March 1964.

REQUIRED BY THE ASSOCIATION

Back numbers of the *Journal of Gemmology* from 1947 up to and including Vol. IX, No. 1 (January, 1963) are required. Please send details to the Secretary of the Association.

LETTERS TO THE EDITOR

DEAR SIR,

Mr. R. Webster's article on "Composite Stones" in the January 1964 issue brought back memories of my apprenticeship days in the Jura mountains, after the First World War.

After the day's work and our evening meal, a small pile of doublet moulds were put on the kitchen table, together with a packet or two of thin slices of garnet and also a mound of glass squares. Everyone sat down to their respective job, even neighbours who called in to pass the evening with us. Some put in the garnet, others would place a piece of glass on top.

The moulds were made of baked clay, measured about 16″ × 10″, and the number of indentations to take the doublet depended on the size required. I recall making doublets size SS4. One had to be young and have good eyesight to undertake such trying work. Actually, it was a very pleasant way of passing an evening, refreshments were ad-lib and the conversation always interesting and amusing.

Friday was an important day, the kiln was stacked with the prepared moulds, the fire lit and heated to the correct temperature. Best of all, the fire heated the water system and we were able to have our weekly bath, this, in the heart of the mountainous countryside was certainly a luxury in those days.

Next morning the moulds having cooled, were removed, the results put into their different colours and sizes ready to be given to the local craftsmen who cut them in their homes. Cutting was then a homecraft.

Perhaps the following will help Mr. Webster with his dates. Firstly, in my opinion the sales of doublets began to slacken about 1923, synthetic stones having then become so cheap that doublets were not worth making.

Again, I have been in communication with an elderly relative who is now 84 and she remembers working on the moulds as a child, shall we say, 10 years of age? This takes us back to 1890.

For further proof I quote from a little known book, "L'Industrie Lapidaire" by G. Burdet, who in chapter 6 attributes the invention of the doublet, as we know it, to Cartier, lapidaire de la Combe de Mijoux, in 1845.

Yours faithfully,

April, 1964. FRANK E. GOLDIE.

Mr. Axon and the Scientific Gemmologist

DEAR SIR,

On reading Mr. G. V. Axon's interesting article in the April *Journal*, many gemmologists will be inclined to echo the sentiments incorrectly attributed to Voltaire in disagreeing whole-heartedly with his opinions, whilst stoutly upholding his right to express them. Many worthy gemmologists are no doubt lamentably shaky on the subject of petrogenesis, and it is arguable that, given infinite time, a sound knowledge of geology, physics, and chemistry would provide a useful basis for one's gemmological studies. However, like the Lesser Sacraments in Anglican theology, these studies, although valuable, are not essential to salvation, and, having regard to the complexity of modern science, Mr. Axon's programme for extended education into the basic drills is Utopian rather than practical. After all, one may legitimately use a table of logarithms when remaining blissfully unacquainted with the exponential function, and a total ignorance of colloid chemistry does not inhibit one from becoming a competent photographer.

It is to be hoped that Mr. Axon's thesis that a divergence exists, and will develop, between "trade" and "scientific" gemmology is without foundation, as such a development would not be in the interests of the trade, or of science. Moreover, it will be an unhappy day when the gemmologist has to rely on complex and expensive gear of the type described. Such apparatus could be owned only by a very few lavishly-endowed institutions, where, one suspects, the average gemmologist would be *persona non grata.* Much worthwhile research has been carried out by pioneers using means of the crudest and most makeshift character, and one instinctively feels that advances in gemmology may more hopefully be expected from workers who look to Woolworth's for experimental material, rather than in the direction indicated by Mr. Axon.

Yours sincerely,
E. S. BURBAGE
THOROLD JONES.

May, 1964.

HERBERT SMITH MEMORIAL LECTURE 1964

The 1964 Herbert Smith Memorial Lecture was given by the President of the Association, Sir Lawrence Bragg, F.R.S., on Thursday, 9th April, at the Royal Institution, Albemarle Street, London, W.1.

Sir Lawrence spoke about "Early problems with minerals and how ideas about their structures came into being", and explained how his school in Manchester 30 years ago had played a big part in establishing the structure of minerals. The lecturer pointed out that the earth's crust was very thin in relation to the whole mass of the earth and that in this crust were some 92 elements; were they all to combine with each other there would be an infinite number of compounds. There was no such infinite number. The truth was that the minerals were limited in number and indeed only half-dozen or so minerals composed most of the earth's crust.

Minerals are typical inorganic bodies. From the ph6sicist's point of view this implies that they are composed of charged atoms or "ions". A redistribution of the electrons between the atoms takes place in such a way that each atom, by gaining or losing electrons, attains a number appropriate to a structure in a symmetrical state; symmetry leads to a structure of low energy and hence stability. In an organic compound electrons are shared between atoms, and this implies bonds as if the atoms were riveted together at definite points. In the inorganic structure, on the other hand, there are no such bonds. The ions are held together by the attraction of positive and negative charges. They are quite free to move relatively to each other, as if they were slippery spheres. The condition for stability is that the electric field between them should have as low an energy as possible.

This basic physical character of inorganic bodies is the prime reason for the existence of a limited number of minerals. Only certain patterns of ions fulfil the condition of lowest energy, which must hold for bodies of the lasting nature of minerals. It is just these patterns which one finds in nature.

The greater part of the earth's crust is composed of silicates, and the silicon-oxygen pattern is the backbone of the mineral. The ratio of silicon to oxygen varies from one type of silicate to another, but it is found that invariably every silicon atom is surrounded by four oxygen atoms at the corners of a tetrahedron. In some minerals such as olivine this corresponds in a simple way to the formula (e.g. Mg_2SiO_4) and analysis shows in fact that there are independent SiO_4 groups. In others the proportion of oxygen to silicon is less than 4 to 1, but the tetrahedral groups are still there. The lower ratio is realized by a sharing of oxygen atoms between neighbouring groups, and it is the extent of this sharing which determines the characters of the main groups of silicates. This was illustrated by means of tetrahedral groups attached magnetically to a board. There are separate tetrahedra (olivines), tetrahedra linked in strings (pyroxenes and amphiboles, asbestos), tetrahedra in sheets (mica, talc, clay) and tetrahedra attached by all corners in a three-dimensional framework (feldspars and zeolites).

The feldspars were very common minerals and very light, which accounted for their being found on the surface of the earth's crust, as distinct from the denser minerals which only appeared when thrust to the surface by volcanic eruption or similar phenomena.

It had been a long standing puzzle that in the feldspars one had crystals of identical chemical constitution and very similar form, but widely different optical properties. An X-ray study has showed that this was due to what is generally known as the "order-disorder" phenomenon. The nature of this phenomenon is spectacularly shown by iron. Below the "Curie Point" iron is highly magnetic because the atomic magnets are aligned parallel to each other in "domains". Above the "Curie Point" the heat motion destroys the order, and iron ceases to be ferromagnetic. To demonstrate this a powerful magnet was suspended above a sheet of asbestos. A lump of red hot iron was placed on the asbestos and while the red heat remained the iron was not attracted to the magnet. As soon as it had cooled sufficiently for its structure to return to the normal state, it was attracted to the magnet with a loud "clunk".

The order in the case of the feldspars is one of arrangement of the iron and aluminium atoms in its framework. At high temperatures these atoms replace each other in a random way. At low temperatures they are in ordered arrangement. It requires the vast times of geological ages to attain this order. A study of the feldspar gives an indication of the conditions under which it was formed.

The lecturer also referred to the curious character of some of the platy structures, the clays, which had a different character on one face from that on the other. This led them to curl up like drying sheets of bread and butter, and hence to crystallize very imperfectly. Clay hence consists of minute spangles, a most fortunate circumstance for life because the finely divided clay sheets held the elements on which plants depend for their food.

In summary, minerals are characteristically structures in which the atoms have been so arranged as to be in a state of the lowest possible energy. Since any rearrangement of the atom would lead to a state of greater energy, they are extremely stable structures which indeed they must be to have lasted in the earth unchanged for so long a time.

Minerals stand at the opposite extreme to the organic structures of living bodies, where the directed bonds between atoms make structures possible which are very far from being ones of the lowest energy and are of the greatest complexity In contrast with these living structures, a mineral, just because it is so perfect, obeys such rigorous laws, and is so incapable of change for the better, is the most dead thing we can imagine.

Mr. B. W. Anderson proposed a vote of thanks to Sir Lawrence and said the audience were greatly indebted to the President for providing them with such an interesting and entertaining evening and in explaining in a manner which enabled everyone to understand something about the structure of minerals.

ANNUAL GENERAL MEETING

The Thirty-Fourth Annual Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 15th May, 1964. Mr. F. H. Knowles-Brown presided and in commenting upon the work of the year suggested that demand for services might outweigh the strength and resources of the Association in the future. He recalled that 1963 marked the 50th anniversary of the first gemmological examination. It was well, he said, to consider the progress that had been made during those 50 years and the problems which expansion would bring in the future.

The audited accounts and annual report were adopted. The following Officers were re-elected:—

President:	Sir Lawrence Bragg, F.R.S.
Chairman:	Mr. F.H. Knowles-Brown
Vice-Chairman:	Mr. N. A. Harper
Treasurer:	Mr. F. E. Lawson Clarke.

The Chairman said they were very grateful that Sir Lawrence, who had so kindly given the Herbert Smith Memorial Lecture this year, was continuing as President.

The following Fellows were re-elected to the Council:—

Miss I. Hopkins, Dr. E. H. Rutland and Mr. W. C. Buckingham.

Messrs. Watson Collin & Co., chartered accountants, signified their willingness to continue as auditors to the Association.

TALKS BY MEMBERS

CAIRNCROSS, A., " Gemstones ", St. John's Episcopal Mothers' Union, 8th January; Pitlochry Rotary Club (Pearls), 14th January; St. Andrew's Church W.G., Blairgowrie, 20th January; North Kirk Mothers' Union, Perth, 5th February; Wilson Church W.G., Perth, 18th February; St. Leonards Youth Fellowship, Perth, 23rd February; Balbeggie W.R.I., 12th March; St. John's Episcopal Young Wives, 18th March; Brighter Moments, Wilson Church, Perth, 25th March; Glencarse W.R.I., 6th April; Meikleour W.R.I., 8th April; Balmerino W.R.I. (Scottish stones), 13th May; Handicapped Children, Blairgowrie, 21st May, 1964.

CAFFELL, E.W., "Gemstones and the story of diamonds", '61 Fellowship and Senior Anglican Young People's Association, Cobham, Surrey, 19th April, 1964.

MIDLANDS BRANCH

Mr. Robert Webster was the speaker at a meeting of the Branch held in Birmingham on the 12th March, 1964. His subject was "Some Highlights in Gemmology; old and new". Mr. Webster referred to the 18th Egyptian dynasty, a time when the colour of stones was more important than their genuineness. He surveyed the introduction of reconstructed rubies towards the end of the 19th century, which were superseded by synthetic corundum produced by the Verneuil method. Reference was also made to the discovery of new gemstones, such as Brazilianite (1944), Taafeite (1945), Painite (1957), Ekanite (1953).

Mr. W. A. Perry proposed a vote of thanks to Mr. Webster.

Branch members then inspected a fine collection of both rare and beautiful gems which Mr. Webster had brought along.

The evening concluded with a stone quiz, arranged by the Secretary, in which Mr. C. Drapkin received 1st prize.

* * *

Mr. J. R. Shaw presided at the annual meeting of the Midlands Branch of the Association held at the Imperial Hotel, Birmingham on 17th April, 1964. The Chairman reported on the past year's activities, which included the Herbert Smith Memorial Lecture, held for the first time in Birmingham. The speaker on this important occasion had been Mr. E. D. Lacy, of Birmingham University. At the Autumn Meeting, Mr. N. A. Harper gave a very instructive lecture on " The classification and grading of diamond crystals ", and in November a dinner and cabaret at " La Reserve " had been enjoyed by members and their friends. The new year commenced with a most lively Branch Meeting in the form of an open forum. In March, Mr. Robert Webster addressed the Branch with interesting highlights in gemmology.

During the past year, the British Association for the Advancement of Science had given approval for the Branch to become affiliated to its own West Midlands Branch.

The following officers were elected: Chairman, J. R. Shaw; Deputy Chairman, W. W. Bowen; Vice-Chairman, N. A. Harper; Committee: Messrs. G. W. Davis, K. Hoskyns, D. E. Price, P. W. Spacey. Ex officio: Messrs. W. W. Bowen, A. E. Shipton, T. P. Solomon; Secretary, Mrs. S. E. Hiscox.

The evening then concluded with two films: " Brilliant Fire "—the formation of diamond and its mining through to cutting; and " A hundred Million to One " —mining and recovery of diamonds from desert coast of South West Africa.

Mr. P. Spacey on behalf of members present thanked Mr. Solomon for bringing along his projector and equipment and for making this film show possible.

PRESENTATION OF AWARDS

A reunion of members and the presentation of the 1964 awards will be held at Goldsmiths' Hall, by kind permission of the Wardens, on Monday, 26th October, 1964.


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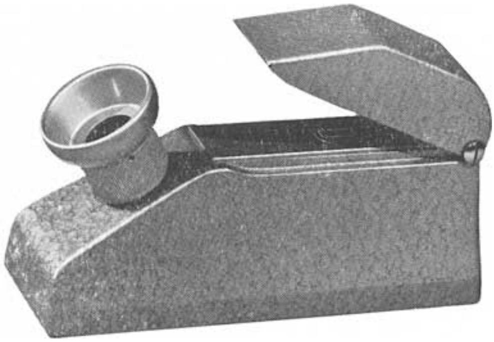

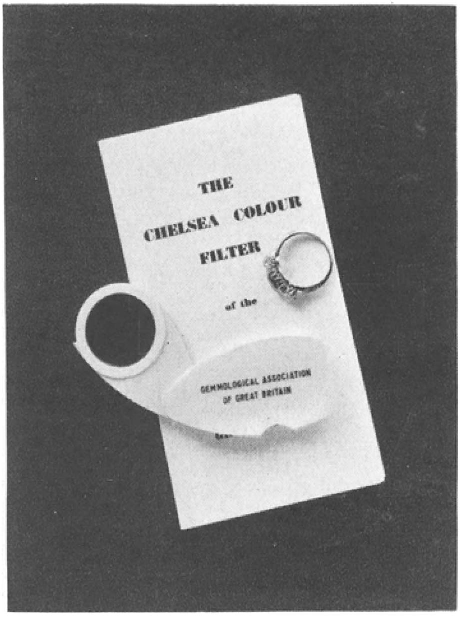
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