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DIAMOND SYNTHESIS ACHIEVED

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

DURING the past sixty years or so, the cry of "wolf! wolf!" has been heard so often that as each new story of " synthetic diamonds " came along it was greeted with little interest and with a shrug of disbelieving shoulders. But, in a quiet and unspectacular manner, scientists have been closing in on the problem. In the place of the patent recipes and hit-or-miss experiments of most of the older workers there have been careful calculations and controlled experiments based on a definite plan, and now at last the synthesis has been achieved. The wolf is not merely at the door but has come right inside, and will probably prove to be a fairly harmless sort of fellow after all.

The news was first published in America on February 14th, and on the following day some fifty journalists and scientific writers assembled in the General Electric Company's research centre at Schenectady, New York, and were shown specimens of the manufactured diamonds under the microscope and on lantern slides, and were given some details of the conditions under which the stones were produced.

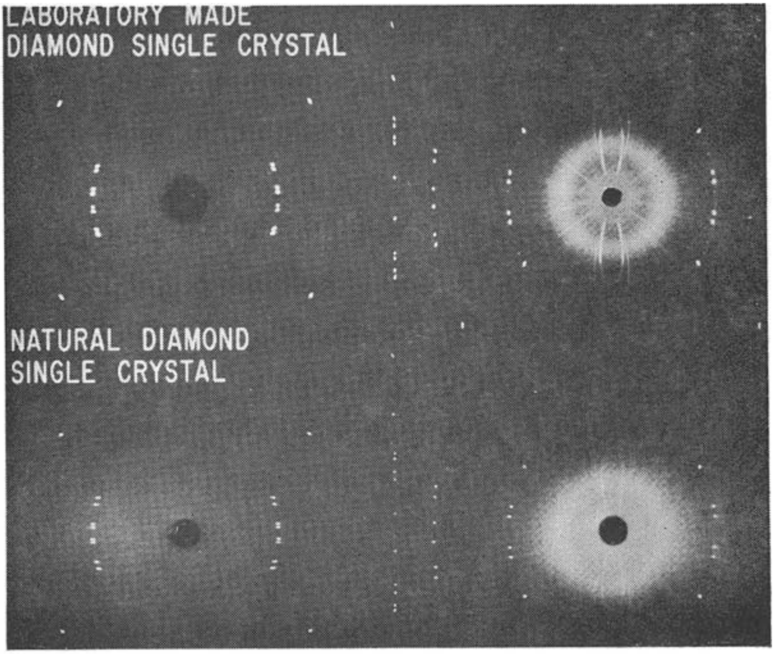
The final success was achieved by two physicists, Dr. Francis Bundy and Dr. Tracy Hall, and a young physical chemist, Dr. Robert Wentfort. But, as in the conquest of Everest, credit belongs not only to those who make the final assault but to the entire team—and, beyond that, to others before them who have planned and shown the way. Indeed, the process used by the General Electric research team may quite properly be called the " Bridgman " process, because it is the logical outcome of ideas promulgated and experiments carried out by Dr. Percy W. Bridgman, professor of physics at Harvard University, who, for more than twenty years has been famous for his work on the physics of high pressures.

In a paper published in 1947 (J. Chem. Phys., 1947, Vol. 15/2) Prof. Bridgman described experiments designed to establish the conditions under which the normal transition of diamond into graphite could be reversed.

The most accurate measurements for the heat of combustion of diamond and of graphite give the figures 94,490 and 94,040 calories respectively—that is, a difference of 450 calories in favour of diamond. This shows graphite to have the lower energy and therefore to be the more stable allotrope under normal conditions, and the figure of 450 calories is also the " heat of transformation " of graphite into diamond. Calculations based on these figures, using an elaborate equation due to Nernst, indicate that at 27° C. and a pressure of 15,000 atmospheres, diamond and graphite should be in equilibrium; while at 1,225° C. the pressure would have to be 40,000 atmospheres for equilibrium to be reached.

In the paper already cited, Bridgman relates how he was able to approach such colossal pressures experimentally, and to apply them at high temperatures to graphite, and to graphite seeded with diamond. He found that at 2,000° C., even under a pressure of 15,000 Kg/cm^2, diamonds were quickly and completely converted into graphite. At increased pressures the transition was less rapid, and at 30,000 Kg/cm^2— the highest pressure he could attain—there seemed to be no tendency for diamond to revert to graphite, so that the equilibrium conditions must have been very nearly satisfied at this point. Unfortunately for Bridgman, he was unable to continue these remarkable experiments further. It is difficult to the layman to appreciate the difficulties involved in attaining such enormous pressures, and in finding materials capable of withstanding them. The cost of researches of this nature is necessarily very great.

High temperatures are needed as well as high pressures because of the time factor involved. Diamond, although it is the

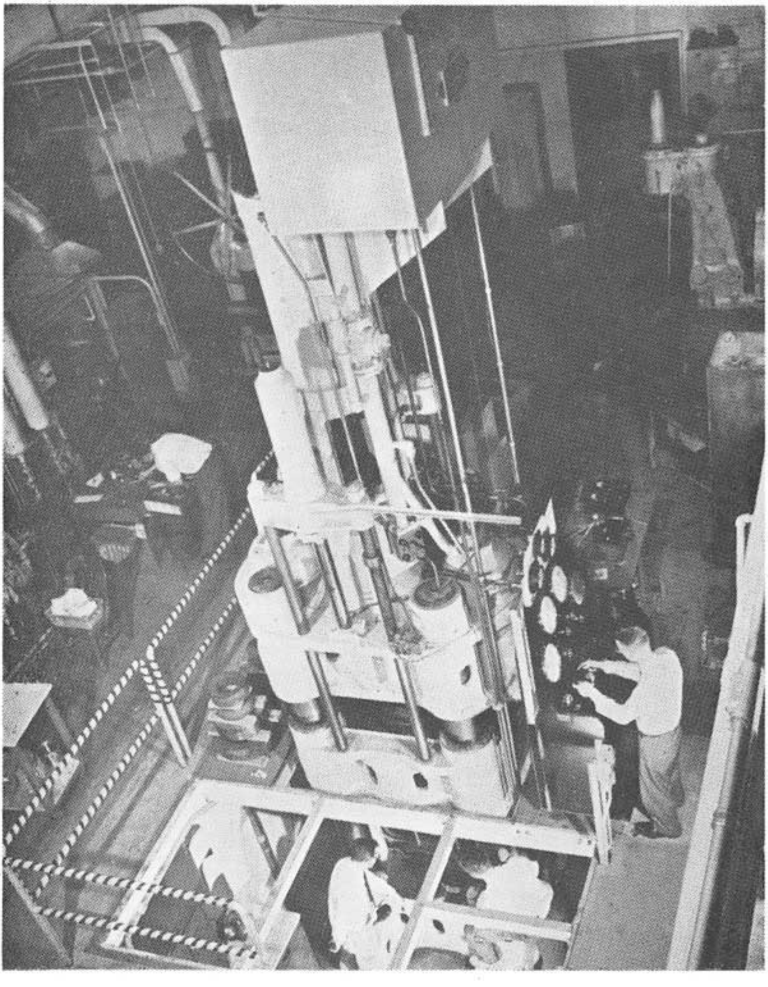


X-ray diffraction patterns of natural and man-made diamonds

(Photo by courtesy of General Electric Research Laboratory)

less stable allotrope of carbon under normal terrestrial conditions, is, as we know, stable enough to endure for millions of years without any trace of graphitization. Only at high temperatures is the change sufficiently rapid to be observed. Similar conditions apply to the conversion of graphite into diamond under high pressures. If sufficient pressure be applied to graphite, the conditions will, in theory, favour the formation of diamond; but unless the temperature is also high the transition will be almost infinitely slow.

The conditions under which an unspecified " carbonaceous compound " was converted into tiny crystals of diamond in the Schenectady laboratories are given as 1,500,000 pounds per square inch and over 5,000° Fahrenheit. Translated, this means rather more than 100,000 atmospheres at 2,775° C.—a far higher pressure and temperature than anything hitherto achieved in attempts to synthesize diamond (except perhaps instantaneously in explosions) but according well with those which one would expect to lead to



General Electric Research Laboratory's 1000-ton press for achieving high pressures. This is the apparatus in which man-made diamonds were first produced.

success from a consideration of the calculations and experiments mentioned above. As the basic pressure-producing apparatus a thousand-ton hydraulic press was used. The pressure chamber in which the diamonds were formed is reported to be very small—"about half the size of a rubber on a lead pencil." The first diamonds were produced last year, and the process has been repeated many times with similar results—showing a "reproducibility" which was utterly lacking in all previous methods, which invariably gave null results when repeated by other investigators.

In the Bridgman process, some stones were formed in a few minutes, but the main batch was allowed to grow for sixteen hours and yielded blue, black, yellow, and colourless specimens of diamond. The largest crystal so far made had a maximum length of about 1·2 millimetres. A polycrystalline mass synthesized under more extreme conditions of temperature than the diamond just mentioned, weighed approximately 0·1 carat. This may seem small, but is quite large when compared with the specimens made by J. B. Hannay in 1880, which represent the only previous authenticated instance of artificial diamond production.

So far, at least, the news has been handled with commendable restraint and there has been no absurd panic to undermine the world confidence in the value of natural diamonds. This is as it should be. Some day, perhaps, the Bridgman process will have appreciable industrial importance. At present it can be hailed as a great technological triumph—the culmination of more than a century of scientific endeavour to achieve this end.

REFERENCES.

This list of references has been reproduced with permission of the General Electric Company's Research Laboratory from their March, 1955, publication "Man-Made Diamonds," published by Research Information Services, Schenectady, New York.

NOTE.—References centring about the claims of Hannay and of Moissan, which are the major ones, are dealt with chronologically. Earlier references extending back to 1828 are considered in J. W. Mellor's "Comprehensive Treatise on Inorganic and Theoretical Chemistry," Volume V, Longmans Green and Co., 1924.

1. J. B. Hannay, *Proc. Roy. Soc.*, **30**, 188 (1880) or *Chem. News*, **41**, 106 (1880). Preliminary announcement of diamond synthesis by heating a mixture of hydrocarbons, bone oil, and lithium at red heat in a sealed wrought iron tube. A product identification including a density of 3.5 and a 97.85 per cent carbon content is given.

2. N. Story-Maskelyne, *The Times*, February 20 (1880), or *Chem. News*, **41**, 97 (1880). The British Museum on the basis of its own analysis labels as genuine diamonds received from Hannay and lauds him for his successful synthesis.

3. J. B. Hannay, *Proc. Roy. Soc.*, **30**, 450 (1880) or *Nature*, **22**, 255 (1880). A detailed account of the work announced in (1).

4. H. Moissan, *Comptes rendus*, **118**, 320 (1894) and **123**, 206, 210 (1896). Work summarized in "Fours Electrique," published in 1904 ; English translation, "The Electric Furnace" (Easton, Pa., 1920). Diamond is made by dissolving carbon in molten iron and quenching the solution to crystallize the carbon. The products have the optical properties of diamond and give some carbon dioxide on combustion.

5. J. B. Hannay, *Chem. News*, **86**, 173 (1902). Takes the Encyclopedia Britannica to task for calling his diamonds carborundum.

6. W. Crooks, *Diamonds* (London, 1909). Confirms Moissan's work.

7. O. Ruff, *Z. anorg. allgem. Chem.*, **99**, 73 (1917). Confirms Moissan's work.

8. C. A. Parsons, *Proc. Roy. Soc.*, **79**, 532 (1907) ; *J. Inst. Metals*, **20**, 5 (1918) ; *Phil. Trans.*, *A*, **220**, 67 (1920). Confirms and extends Moissan's work, differing only on details and underlying causes. Reports failure with Hannay's method.

9. H. LeChatelier, *Leçons sur le carbone* (Paris, 1926), page 24. Expresses scepticism of the way in which the identification of supposed synthetic diamonds has been made.

10. C. H. Desch, *Nature*, **121**, 799 (1928). Summarizes new evidence submitted by Parsons to the Editor of *Nature*. Parsons' new work clearly and unequivocally demonstrates how he has been misled into regarding as diamond various transparent, singly refracting minerals (spinels) which are very resistant to chemical reagents and will not burn. Parsons repeats Moissan's work many times and obtains many particles which resemble diamond but will not burn. Unfortunately, none of Moissan's own products can be found for re-examination. Parsons also repeats the work of other investigators who have claimed to have made diamonds, but with negative results. It is Parsons' final conviction that neither he nor anyone else has ever succeeded in making diamond in the laboratory.

11. J. W. Hershey, *Trans. Kansas Acad. Sci.*, **31**, 52 (1929) and **40**, 109 (1937) ; *The Book of Diamonds*, Hearthside Press, 1940. Duplicates Moissan's work with production of even bigger diamonds. (No more has been heard from anyone concerning this claim.)

12. F. A. Bannister and K. Lonsdale, *Nature*, **151**, 334 (1943) ; *Mineral Mag.*, **26**, 309 (1943). The diamonds Hannay sent to the British Museum are shown by X-ray analysis to be true diamonds of a rare type. There is a great improbability that natural diamonds of such a rare type unrecognized at the time should be selected for fraudulent introduction either by dispirited workmen or by Hannay himself. These workers feel that Hannay has in fact succeeded in making diamonds.

13. C. H. Desch, *Nature*, **152**, 148 (1943). Reviews his previous article (10) and then summarizes Hannay's experiments. In view of the findings in reference (12) he feels that the whole question of man-made diamonds is re-opened and that perhaps diamond can be made under the conditions used by Hannay, Moissan, and Parsons.

14. Rayleigh, *Nature*, **152**, 597 (1943). Reports that his father has told him that a later paper submitted by Hannay to the Royal Society in about 1894 was rejected by a publication committee because there was distrust of his good faith. An offer of a demonstration was refused on the ground that no demonstration by Hannay himself would satisfy the sceptics. Rayleigh also points out two instances in which Hannay's work in other fields was branded by his contemporaries as being in bad faith. Rayleigh himself feels that one of these instances clearly shows that Hannay's critics had something more than prejudice to go on.

15. M. W. Travers, *Nature*, **152**, 726 (1943). Dismisses the foregoing incidents as an honest youthful mistake and repeats the praise and trust he accorded Hannay in an earlier memoir—*Chemisty and Industry*, **17**, 507 (1939).

16. J. W. French, *Nature*, **153**, 112 (1944). Reports that Hannay was not the type to fake a result but that he had indeed become concerned lest some practical joker had interfered with his experiments. French's father had been Hannay's partner.

17. K. Lonsdale, *Nature*, **153**, 669 (1944). Her work proves that the crystals in the British Museum were diamonds but not that Hannay made them. She feels that Hannay has a strong case and that his claim should be given the benefit of the doubt.

18. D. P. Mellor, *J. Chem. Phys.*, **15**, 525 (1947) ; *Research*, **2**, 314 (1949). Feels that Hannay has a very strong case but that its validity can finally be established only by a successful repetition of the work.

19. P. W. Bridgman, *J. Chem. Phys.*, **15**, 92 (1947). Contributes data valuable in thermodynamic consideration of the equilibrium between graphite and diamond.

20. F. D. Rossini, *Chemical Thermodynamics*, page 453, Wiley, 1950. Discusses the thermodynamics of the transition of graphite to diamond.

21. N. V. Sidgwick, *Chemical Elements and Their Compounds*, Volume I, pages 491-3, Oxford, Clarendon Press, 1950. Feels that the artificial production of diamonds has never yet been shown to be a success.

22. T. Moeller, *Inorganic Chemistry*, page 669, Wiley, 1952. Says the synthetic production of diamond has been singularly unsuccessful.

23. H. Eyring and F. W. Cagle, Jr., *Z. Elektrochem.*, **56**, 480 (1952). State that the literature contains no certain example of the artificial production of diamond. Also conclude on thermodynamic grounds that it is exceedingly unlikely that synthetic diamonds have been produced.

24. A. Neuhaus, *Angew. Chem.*, **66**, 525 (1954). Reviews scientific literature on diamond making.

ASTERISM in CORUNDUM

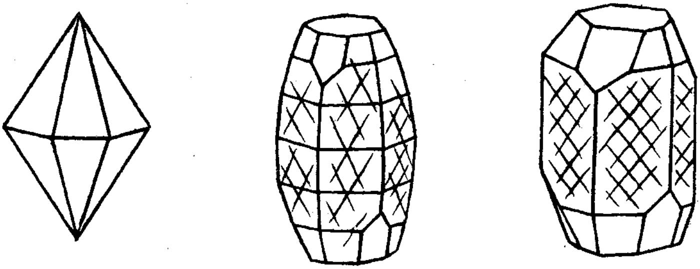
by ALICE SUMNER TAIT, M.Sc., F.G.A., C.G.

PRIOR to the last war the cause of asterism in corundum had not been definitely determined. There had been many suppositions and in most text books on minerals and gems asterism in corundum was described. Dana's Textbook of Mineralogy[1] states in the section on asterism that in corundum " it is explained by the presence of thin twinning lamellae symmetrically arranged," and in the section on corundum it says, " the cause is due to the presence of minute cylindrical cavities which lie parallel to the prism planes," while Kraus and Slawson[2] gives the explanation that in many cases this is due to regularly arranged inclusions of minute size. Dr. G. F. Herbert Smith[3] describes asterism in corundum in his latest edition as follows: " Its cause may be traced to a regular arrangement of bundles of lines within the structure which are at right angles to the principal crystallographic axes and are severally inclined to one another at 60°. The lines may be composed of included needles of rutile, tubular cavities, or even colloidal particles. The tendency to conform to the hexagonal arrangement is linked with the lamellar twinning characteristic of corundum."

It was these numerous and varying definitions and statements describing the cause of asterism in corundum that led me to take up the problem with the hope of finding more conclusive data concerning, not only the phenomenon of asterism, but the nature of the inclusions said to be the cause.

As early as 1878 the inclusions of corundum were observed and described. G. von Tschermak[4] found hair-like inclusions in ruby which he claimed were rutile. These lay parallel to the prism faces. In 1892 Prinz described the inclusions of corundum as gaseous, liquid and solid. In recent years Dr. Edward Gübelin[5] has done a great deal of research on inclusions in gemstones and has also described the inclusions of corundum as gaseous, liquid and solid, naming rutile and zircon as solid inclusions. He identifies included zircon in Ceylon sapphire by characteristic halos. In the Laboratory of the London Chamber of Commerce Messrs. B. W. Anderson, C. J. Payne and R. Webster have done much valuable work on inclusions corroborating Gübelin's findings.

Corundum belongs to the rhombohedral class of the hexagonal crystal system. It is commonly found in doubly terminated twelve-faced pyramids and hexagonal prisms with three rhombohedral faces above and three below, terminated in basal faces often triangularly marked due to the rhombohedral parting of polysynthetic twinning. The prisms often have a tendency to be barrel-shaped and are striated also with the rhombohedral twinning planes. The twinning habits of corundum are the repeated or polysynthetic twinning producing a laminated structure with basal parting (perfect 0001) and rhombohedral (1011), and penetration twins. The laminated structure of the polysynthetic twinning has given rise to one of the popular explanations of asterism and it is interesting to note that the authorities making the statement that asterism in corundum is due to the repeated twinning have offered no satisfactory scientific proof.



FIGS. 1, 2 & 3.

Figures 1, 2 and 3 illustrate the common crystal types of corundum with Fig. 2 showing the striations of the rhombohedral parting of the polysynthetic twinning.

The first problem was to get enough material from a variety of known sources. Fortunately a large quantity of material personally collected in Montana from Yogo Gulch in the Judith Basin, and from Sapphire Gulch near Philipsburg, plus a few North Carolina specimens, was available. The rest of the material was supplied by the late Albert Ramsey, an enthusiastic gem collector and dealer. He was most kind in supplying unlimited quantities of corundum from the gem gravels of the Ratnapura district of Ceylon; the Bo Pie district in Batambang, Siam; Mogok mines in Upper Burma; and from gravels near Anakie, Queensland, Australia. Mr. Ramsey not only allowed the study of pounds of

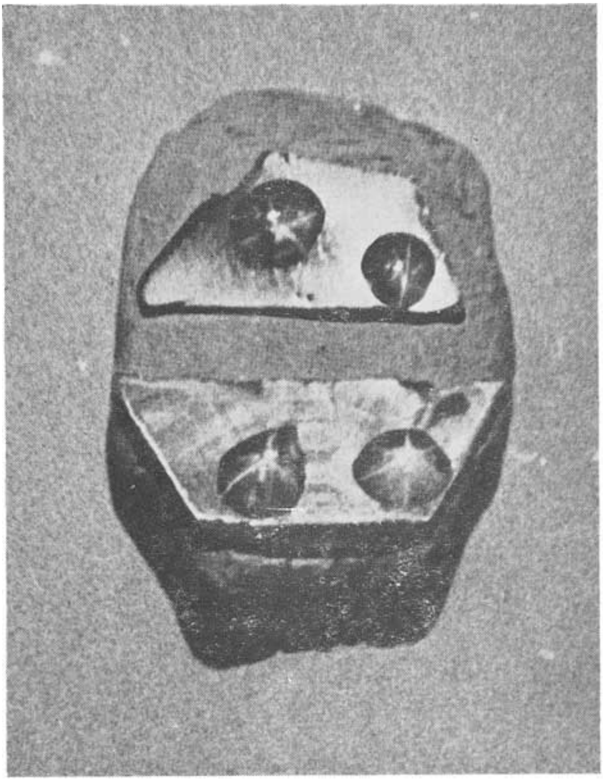


FIG. 4

material, and hundreds of cut stones, but he very kindly made thin sections to facilitate the study of the inclusions. These were cut in the basal plane of prisms enabling the author to examine the inclusions and their arrangement without distortion in both transmitted and reflected light and under high magnification.

As the problem was confined to the description of the phenomenon and the determination of its cause, inclusions other than those directly related to asterism were necessarily incidental, but it was impossible not to note that there were definitely the three types mentioned above.

Microscopic examination of star-stones and thin sections from star-producing corundum showed that the star was produced by the rod-like or needle-like inclusions which lay parallel to the prism faces of the hexagon and in the basal plane thus being severally inclined to one another at 60°, and that when material containing an adequate number of these inclusions evenly distributed was cut cabochon with the principal axis of the stone (the axis at right angles to the base) parallel to the principal axis of the corundum crystal (the optic axis or c axis) a six-rayed star resulted.

Upon examination in transmitted light in thin section the inclusions were the red-brown colour of included rutile in quartz, and appeared to be the same mineral though finer than any the author had encountered in quartz. Under 900 x it was possible to see square cross-sections when viewed laterally. Conclusive proof that the inclusions caused the star of the material examined was the perfect stars seen in drops of water placed upon the thin sections of star bearing material (Mr. B. W. Anderson demonstrated this, and Fig. 4 shows these water-drop stars as seen in a beam of paralle light).

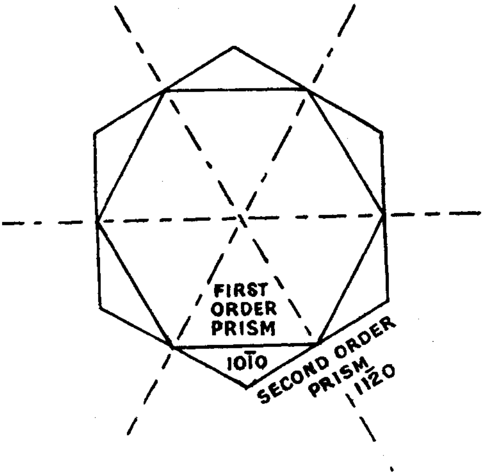


FIG. 5.

During this study a cause for twelve-rayed stars revealed itself, and can be seen by the photograph in Fig. 4 where the drop of water in the upper left-hand corner shows a ray normal to the prism face and not parallel to it. In examining star material on the lookout for a possible cause, it was found that much star material had at least some inclusions lying in the basal plane which were not parallel to the first order prism faces, but normal to them. It apparently is very rare to find material with sufficient concentrations normal to the prism faces to produce stars. Mr. Ramsey had a

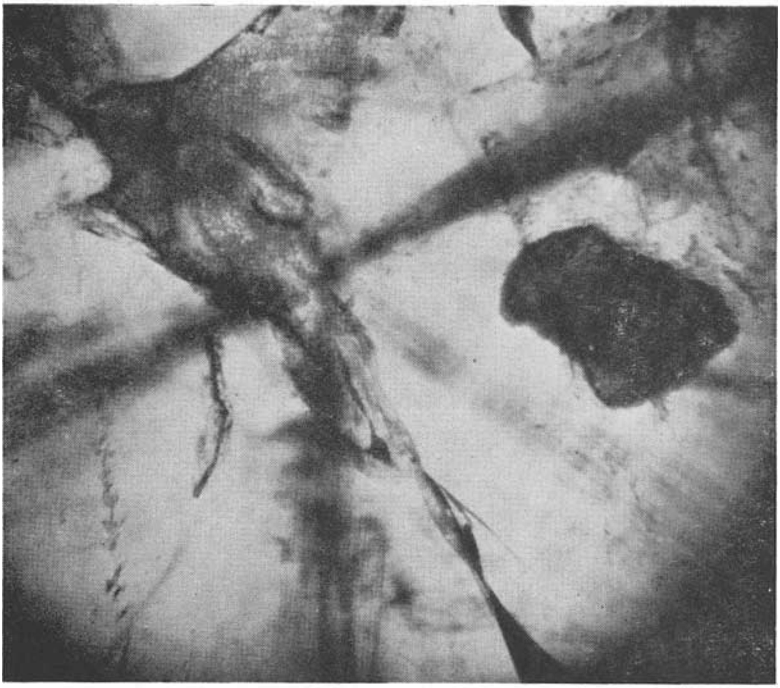


Fig. 6.

twenty carat star-stone that had two stars slightly off centre from each other which formed a twelve-rayed star. Examination of a cut stone precludes any accurate data resulting from optical examination due to distortion. But the fact remains that there are sections in which the inclusions lie normal to the prism faces and parallel to the second order prism $(11\bar{2}0)$, which are shown in Fig. 5 below and in the photograph (Fig. 6) where the concentrations of inclusions bisect the colour zones at right angles. The edge of the prism face can be seen dimly.

The next step was to determine the mineral species of the inclusions. Optical examination under the microscope up to 900 x added little as the inclusions were so fine. The Becke method to determine the refractive index of the included material was also impossible for the same reason. From the relative brightness of the light reflected from them it seemed very possible that they were considerably higher in refractive index than the material in

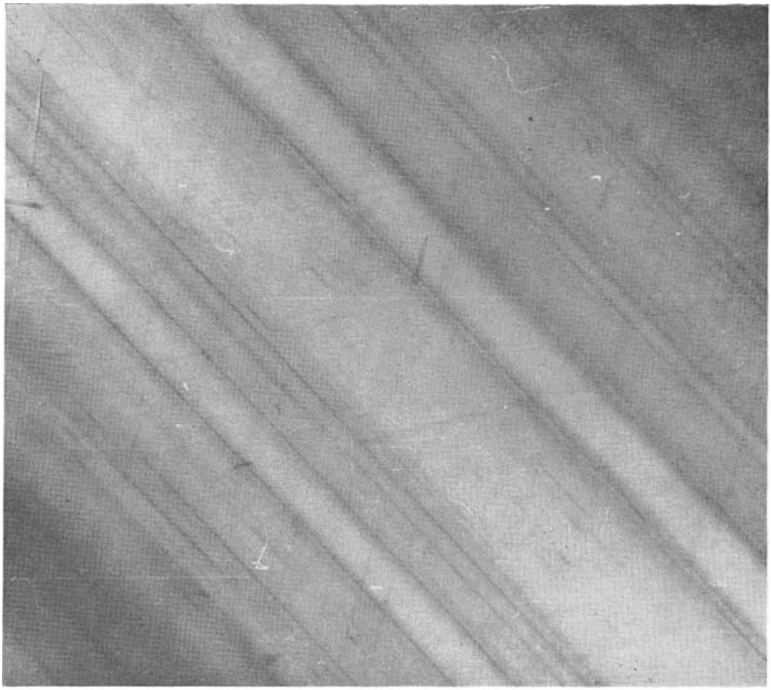


Fig. 7.

which they were included. Microscopic examination up to this point had given the following information: that the needle-like bundles or concentrations were the cause of the star, that they were in transmitted light red-brown in colour, and appeared to have square cross-sections. There was now one thing to do—find the chemical composition.

Micro-chemical analysis failed because the concentration of included material was too small. X-ray powder method also failed for the same reason. There was one course left, that of spectrographic analysis.

Insufficient experience with such a delicate test caused much time to be lost. Ultimately it was found that no mortar could be used to prepare the samples and that the apparatus used must be absolutely clean. (Not as easy to find as one would think.) A diamond point was used to scrape material from colourless corundum, inclusion - free under 20 x (solid inclusions), moderately

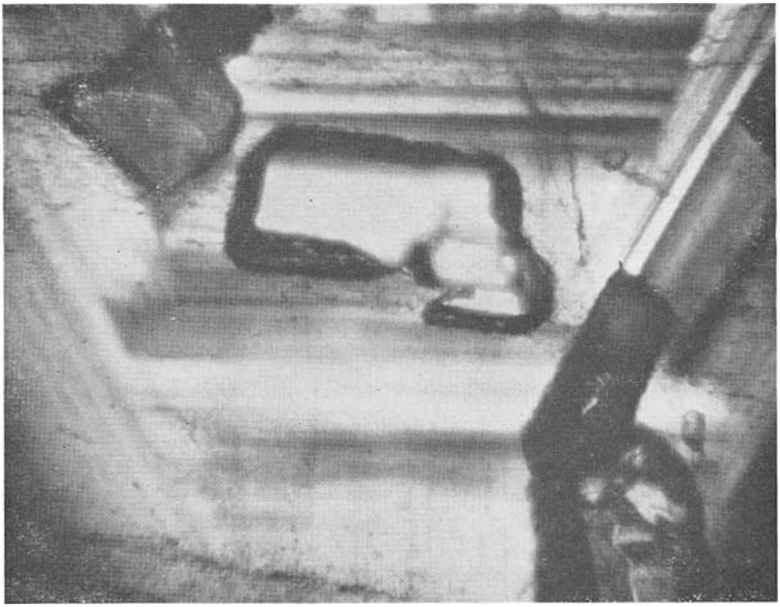


FIG. 8.

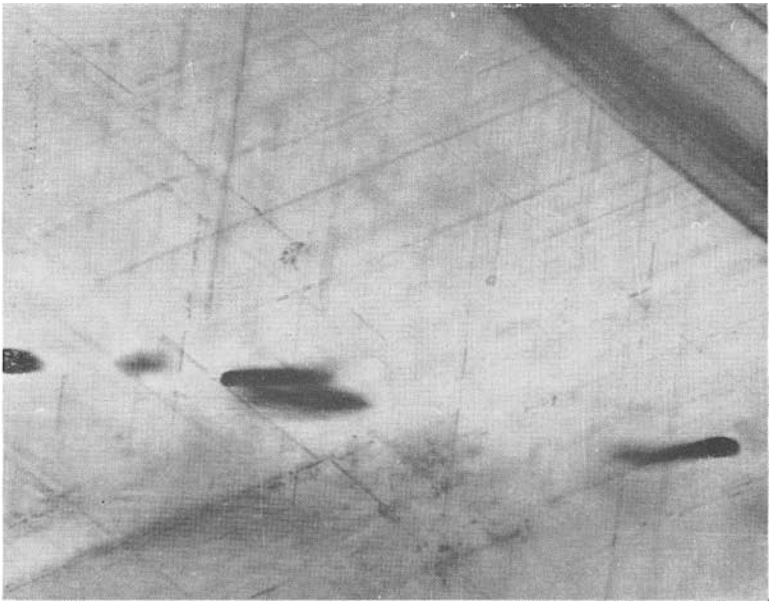


FIG. 9.

included material, and heavily included samples which had produced stars.

The following results were attained:—

Inclusion-free samples:

Al with a trace of Cr and Fe

Heavily included samples:

Al	
Ti	.001%
Fe	.009%
Cr.	trace

The results pointed to the possibility of the mineral being rutile, octahedrite or brookite. Octahedrite could be eliminated because of its crystal habit (octahedral or tabular) and brookite on the same grounds.

In summing up it was concluded that the cause of asterism in corundum is due to the symmetrical arrangement of included rutile needles which lie in the basal plane parallel to the prism faces of the hexagon.

Fig. 7 shows a micro-photo (300 x) of material which produced a cat's-eye effect rather than a star because the concentration of inclusions is one-directional. Fig. 8 shows material which would only produce one star because of the concentric arrangement of inclusions. This photograph also shows the inclusions lying normal to the prism faces too sparsely distributed to be seen in reflected light when the stone is cut. Fig. 9 is a perfect example of material which would produce a star cut anywhere providing the axis of the stone is parallel to that of the optic axis of the crystal. The dark bands are not inclusions, but colour zones.

REFERENCES.

1. Dana's *A Textbook of Mineralogy*, revised W. E. Ford, 1932.
2. Kraus and Slawson, *Gems and gem materials*, 1941.
3. G. F. Herbert Smith, *Gemstones* (12th edition), 1952.
4. G. von Tschermak, *Min. Mittp.*, **1**, 362, 1878.
5. E. Gübelin, *Inclusions as a means of gemstone identification*, G.I.A., Los Angeles. *Journ. Gemmology*, Vol. 1 (7), 1948 ; Vol. 2 (7), 1950.

INDIAN DIAMONDS

(Condensed from " Diamond Mining and recovery at the Majhgawan Mine in Panna, Vindhya Pradesh," by S. M. Mathur : Indian Minerals, Vol. VII, No. 1, pp. 34/42—January, 1953).

THE Panna diamond field has supported a widespread mining industry for several centuries. The gems have been obtained mainly from several conglomerate horizons in the Upper Vindhyans and from the gravels derived therefrom. Another source of these gems has been the Majhgawan deposit, situated about twelve miles South-west of Panna, where the diamonds have been recovered from a volcanic agglomerate tuff.

It was realized that the Majhgawan Deposit was not a conglomerate as early as the 18th century by Capt. J. Franklin[1] who stated that " the cavity of the chasm is filled with green mud," the habitat of the diamond " being in the green mud." These remarks lead K. P. Sinor to investigate the Majhgawan area whose examination revealed that it was a volcanic neck filled in with an agglomerate tuff. In 1930 he published a monograph on the Panna diamond pipe together with reports and analyses by foreign scientists.[2]

This mine is reported to have been flourishing as early as Akbar's reign in the 16th century. The first attempt to work it on modern lines appears to have been made nearly 65 years ago when a shaft was put down in this area. The results are not available now. Sinor put down a bore-hole through the agglomerate tuff during the late twenties and established the occurrence of this rock to a depth of 242 ft.

The Panna Diamond Mining Syndicate Ltd, the present leaseholders, reopened the mine in 1936. Until the Second World War the Syndicate sank five shafts, out of which two were not successful owing to caving in of the walls, the third was abandoned, and the fourth had to be closed during the last War. The remaining work also had to be considerably slowed down during this period and at one time almost no work was being done. The mines were rejuvenated in 1947. Systematic mining by mechanical methods has been undertaken and the hand washing of the ore has been replaced largely by machinery.

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[1] *Asiatic Researches*, Vol. XVIII, p. 111 (1829).

[2] *The Diamond Mines of Panna State in Central India*, Bombay, 1930.

Doubts were expressed in certain quarters regarding the diamondiferous nature of the pipe rock, though the past records showed this tuff to be diamond bearing. Dr. A. E. Waters, Chief Geologist, and Mr. A. Royden Harrison, Mining Engineer, of the Anglo-American Corporation of South Africa Ltd, were invited in 1950 to carry out a detailed investigation. They took about 305 cu. ft of the tuff rock lying in the mines and washed it in an 8 ft washing pan, when nine diamonds weighing a total of 3.32 carats were obtained. Subsequent work also has amply proved the diamondiferous nature of the tuff. It is, however, to be expected that the entire ore-body may not be uniformly productive. The diamond content is likely to vary from place to place even as is the case with the pipes of the Kimberley area and there may also be barren patches in the ore-body.

The pits are situated within the confines of a volcanic neck which appears to have a pear-shaped outline on the surface. The maximum length of the pipe-mouth is about 1,600 ft and the width at the broadest is about 960 ft. The total area is approximately 112,500 sq. yds.

The diamondiferous ore in the pipe has been conveniently described as an " agglomerate tuff ". In hand specimens it is dirty green in colour and its ground-mass is traversed by a closely-knit network of thin calcite stringers. Fragments of black shale (? porcellanite from the Semri Series), reddish sandstone and jaspers have been found occurring as xenoliths in the ground-mass. Under the microscope this green mass is seen to consist mainly of serpentine produced by the alteration of olivine, pseudomorphs after which are sometimes recognized in the slices. Grains of iron minerals and calcite are frequently seen distributed in the ground-mass. This rock bears superficial resemblance to certain types of South African " blue ground ". Chemical and mineralogical examinations, however, show that it is not a true Kimberlite, which is a more complex rock than the Majhgawan tuff. Kimberlite, being rich in olivine, is a type of peridotite, but the Majhgawan tuff samples so far obtained are serpentine-rich. The tuff is an earthy-looking rock and has a tendency to crumble away in the presence of water. This property was utilized in the past by miners who left it exposed in the rain after which it could be easily treated for washing.

For a long time geologists considered that the original source of the diamonds in the Panna conglomerate were the dykes of the Bijawar age. But now that the true nature of the Majhgawan deposit is known to be diamondiferous volcanic pipe rock, it appears certain that the diamonds first crystallized in a formation of this type. The Majhgawan pipe is the only one so far discovered—and it is the only evidence of volcanic activity in the Vindhyans of this area—but it is quite possible that several others lie hidden under the younger rocks or alluvium, because it is rather difficult to believe that a single pipe of such a small surface area could supply gems in large quantities to widespread conglomerates found at different horizons.

The washing of the diamondiferous materials is still carried out by primitive manual methods elsewhere in the Panna diamond field. At the Majhgawan mine, however, a mechanical plant for the recovery of the gems was installed and has resulted in treatment of a much larger volume of ore. The diamonds are recovered by what is known as the " direct treatment process," because the ore is treated as soon as it comes from the mines without any intermediate preparation like exposing it to the weathering agencies for natural disintegration. This process in outline consists of breaking the ore by mechanical crushers, washing and concentration in a specially designed pan, classification of this concentrate through vibrating screens, and the final recovery of the diamonds on specially constructed grease tables. All the material from the grease tables is further checked by highly experienced hand sorters. At present the grease used is not proving very effective in holding the diamonds, but experiments are in progress to evolve a grease having suitable properties to which the Majhgawan diamonds would adhere. This is the reason why it is necessary to check all the concentrate by hand sorting. When dried by the natural heat of the sun, a team of nimble-fingered and sharp-eyed girls go through the concentrate. These girls have highly trained eyes and it is rare indeed for them to miss a diamond even if it be a dark coloured bort the size of a sand grain.

Since 1936 the production has deen fairly steady though not on a scale even remotely resembling the output of a similar mine in Africa. The figures available include the production both from the tuff proper and the overlying alluvium. It is not certain, therefore, what is the actual yield from the pipe rock itself. It is essential to find out the actual weight of the diamonds won per unit[1] of ore in order to assess with a fair degree of accuracy the average diamond content of the ore and therefore the potential value of the property. Unfortunately no such data was collected in the past, but I am informed that this information is being now recorded.

The result of concentration by Waters and Royden Harrison has already been mentioned. It gives the yield at 15.2 carats per 100 loads.[2] As the test was an isolated one it is essential to emphasize that this figure should not be taken as an indication of the true value which can only be obtained by production figures collected over a fairly lengthy period.

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1. The usual unit in diamond mining is a " load " which is equivalent to 0.8 short tons or 1600 pounds.
2. Extracted from a privately circulated Progress Report of the Panna Diamond Mining Syndicate Ltd. (1951).

NOTES from AMERICA

The appearance of almost colourless pieces of glass, brilliant cut, which have a refractive index of 1.785 and hardness of 5½, is reported by G. Robert Crowingshield in Vol. VI, No. 6, 1954, of the Gemological Institute of America's students publication. The material has been variously advertised as " new German synthetic " or " new synthetic from Japan ". The dispersion of the glass is said to be high.

The G.I.A. also reports examination of material made from strontium titanite (*see Journ. Gemmology*, Vol. III (7), 1952). The material, which is singly refractive, has refractive index about 2.00 and a dispersion slightly greater than diamond. Although the material is soft, it is suggested that confusion with diamond might arise. The new product has not yet been marketed commercially.

RANDOM NOTES

by J. R. H. CHISHOLM, M.A., F.G.A.

ONE of the gemmologist's most satisfactory techniques, which he shares with the mineralogist and the petrographer, is the determination of specific gravity by means of heavy liquids, and the satisfaction which it gives is qualified only by the rather uncongenial nature of the liquids used for specific gravities over 3.33. For densities over that of methylene iodide the gemmologist usually relies upon Clerici solution, which by dilution with water covers the whole range from about 4.15 downwards but is unpleasant to handle (as well as being expensive). Johannsen[1] lists various liquids in this range together with their disadvantages, such as Klein's solution (aqueous solution of cadmium borotungstate —max. s.g. 3.55) and Rohrbach's solution (aqueous solution of barium mercuric iodide—max. s.g. 3.58), and there are a few other media mentioned in the literature with warnings of their high toxicity or other disagreeable attributes—such as molten silver thallium nitrate (Retgers's Salt[2]) and Clerici solution itself. A reference in the Industrial Diamond Review[3] to " antimony tribromide which melts at 96.6 deg. C. to give a liquid of sg. of about 3.6 and in a crude way can be used to separate alumina from diamond " therefore set me wondering whether this might not provide a useful aid for the gemmologist. I optimistically discounted the statement that " antimony tribromide is quite toxic and gives off toxic fumes at its melting point," in the light of the accompanying reference to " conflicting reports on the toxicity of methylene iodide," and decided to put the use of molten $SbBr_3$ for density-determination of gemstones to the test. In the result, I certainly cannot recommend its use, though it may be regarded as a possibility for some purposes, if no better medium is obtainable. Like Clerici solution, antimony tribromide is a Schedule I poison and its sole advantage over Clerici solution is that of price: it cannot be diluted with water and has other unamiable characteristics. These appear in the following account of my experiment in its use, which I append as a warning to any who may be similarly tempted to try it.

About 30 gms of antimony tribromide were placed in a test-tube held by means of a laboratory stand and clamp in a beaker of water, placed on a stand over a Bunsen burner. The height of the test-tube was so arranged that the surface-level of the water in the beaker was somewhat higher than the $SbBr_3$ in the test-tube; a second clamp held a thermometer in the water alongside the test-tube. The Bunsen burner was lit and the water gradually heated. When the heat of the water was between 92° and 93° C. the $SbBr_3$ began to melt and between 96° and 97° it melted completely to a clear pale-yellow liquid. Thereafter the water was kept at about 97° to 98°—just " off the boil ".

A topaz crystal was dropped into the liquid $SbBr_3$ and floated until, owing to the comparative cold of the stone, the liquid congealed on its surface and made it sink: after remaining at the bottom of the test-tube for some little time and re-heating, the $SbBr_3$ coating melted off and the topaz rose again to the surface.

Similarly a spinel crystal just floated, but an almandine cabochon sank straight to the bottom and remained there. In order to avoid what had happened to the topaz, the spinel and the almandine were both first heated in the Bunsen flame. The almandine, which had been chosen for the experiment because it was cracked and chipped, split into two pieces in the heat of the flame. It was also necessary to heat the corn-tongs in the flame before using them to take the stone out of the liquid, because otherwise the liquid congealed on the tongs in thick " gloves " (like the " Persian slippers " of Socrates's flea[4]) and made them unusable. (The " gloves " could be broken off with a knife or, more easily, melted off in the flame).

On removing the stone from the liquid it was found to be covered with a thin film of antimony tribromide, which of course immediately congealed. An attempt to remove this with boiling water failed, because, as I ought to have foreseen, the $SbBr_3$ reacted with the water to form a greyish-white coating of antimony oxybromide ($SbBr_3 + H_2O \rightarrow SbOBr + 2HBr$), which could, however, though with some difficulty, be rubbed or scraped off. More effective cleaning methods were to melt off the film of antimony tribromide in the Bunsen flame—a procedure not without its attendant risk, for the almandine unfortunately disintegrated still further—or to wash it off in a hot solution of common salt: the salt prevents hydrolysis of the bromide, or at least forms a water-soluble complex with the oxybromide and so enables the stone to be washed clean.

As it was by then clear that antimony tribromide could not be regarded seriously as a rival to Clerici solution, it did not seem worthwhile to proceed further or to attempt to define its density more precisely.

* * *

Historical accuracy requires a correction of the statement made in this *Journal*[5] (following Dr. Gubelin[6]) that it was in 1835 that Sir David Brewster distinguished two types of liquid inclusions detailing his observations in a letter to Sir Walter Scott. Scott died on 21st September, 1832. On 24th April, 1832 Brewster had finished writing his " Letters on Natural Magic addressed to Sir Water Scott, Bart ", which were subsequently published in 1834 as Vol. XXXIII of the " The Family Library ". " My dear Sir Walter," Brewster wrote in the first of these "Letters", "as it was at your suggestion that I undertook to draw up a popular account of those prodigies of the material world which have received the appelation of *Natural Magic*, I have availed myself of the privilege of introducing it under the shelter of your name." The passage on inclusions reproduced in this *Journal*[5] is an excerpt from Letter XIII. It did not represent new work even in 1832, but was a much abbreviated and popularized account of investigations begun in 1818, of which a detailed record was embodied in a paper read before the Royal Society of Edinburgh in 1823, followed by a further paper in 1826, both being published in that Society's Transactions.[7] It is interesting to observe that among the many beautifully engraved illustrations of inclusions which accompanied the original papers—of which only a few were rather poorly reproduced in 1834—there is one of a three-phase inclusion (two liquids, a bubble and a cubic crystal) and two of two immiscible liquids with a cubic crystal—all three being in topazes—but reference to the included cubes (" small squares . . . within the cavities, which seem to be filled up with crystallized matter ") is made only in a footnote[8], and, although there is a description elsewhere of three-phase inclusions in quartz[9] containing " spherical groups of whitish crystals," Brewster had evidently not observed three-phase inclusions in emerald, since of emerald and beryl he wrote: " The degree of foulness which is so common in these gems arises generally from strata of cavities containing a single fluid and an air-bubble, which does not perceptibly decrease with a temperature of 150°."[10] It is also interesting to note that in his investigations into the nature of inclusions Brewster for the most part used only techniques available to the gemmologist: except by an occasional accident, like my own with the almandine, he seldom destroyed the objects of his research. " Though I have employed only the microscope, and the agency of heat and light," he wrote[11], "I have been led to results of considerable . . . interest. This physical method of determining the properties of minute quantities of matter, though often very difficult and sometimes perplexing in its manipulations, carries with it a degree of evidence not inferior to that of chemical analysis; while it possesses the advantage of examining the substance in its original and unchanged condition, and may be applied, in many cases, where the chemist cannot avail himself of any of the resources of his art."

* * *

On the subject of inclusions I have recently been reading F. G. Smith's *Historical Development of Inclusion Thermometry*[12] borrowed, through my County Library, from the Library of the Science Museum. It is divided into three sections; the first 85 pages record the published data on the subject in chronological order from 1818 to 1953, after which follows a 25-page critical summary of the present state of knowledge and the remaining 36 pages contain a bibliography in two parts, the first classified by authors' names and the second by subjects. The survey covers a period of 135 years—among the earliest workers in this field being Sir Humphrey Davy[13] and Sir David Brewster[7]—and includes a reference to Dr. Gubelin's article in this *Journal* in 1948.[14] Mr. Smith's book is of course in no way comparable with Dr. Gubelin's *Inclusions as a Means of Gemstone Identification*[15]; it deals with inclusions in other minerals as well as gem-minerals and its purpose is not the diagnosis of different species but the determination of the temperature and pressure of formation: it is nevertheless full of interest to the gemmologist.

We are all familiar with " flies in amber ", but to me it was new that " sometimes quartz has been found enclosing undoubted fossils. A good example of well-formed, doubly-terminated crystals enclosing stromatoporoid fossils was described and illustrated by Erdmannsdorffer "[16]; and how delightful it is even to read of " a clear quartz crystal containing a liquid inclusion with a bubble and a movable crystal of gold."[17]

* * *

In South Africa diamond and pyrope garnet are found together, as in Brazil are diamond and quartz: South African diamonds frequently contain included garnets, and quartz is found as an inclusion in Brazilian diamonds. Diamonds themselves occur as inclusions in other diamonds and it would be interesting to know whether diamond inclusions have ever been found in pyrope or quartz—or in any other mineral. One would hardly think that included diamonds, if they in fact occur, could escape attention, since they would obviously present something of a problem to the lapidary. Yet, if they do not in fact occur, what can be the reason? The answer may provide a further clue to the still unknown origin of diamond. Dr. Gubelin appears to be in two minds on the question whether diamond inclusions in other minerals exist or not, since on page 91 of his book[15], he wrote, " Included diamond crystals . . . will be found only in diamond," while on page 173 we find, " It is to be expected that many garnets from South African diamond deposits will contain diamond inclusions, with the reverse being true also since during the secondary phase both gems were formed at the same time in these deposits."

* * *

The diamond pipe mines of South Africa are, of course, well known and provide an indication of the primary source of diamond so far as that continent is concerned. North America is not usually thought of as a diamond-producing area, but in fact it is a producer on a modest scale, and there too a diamond pipe was discovered at Murfreesboro, Arkansas, in 1906; while the Australian diamond fields presumably also owe their origin to similar sources, a diamantiferous pipe having been found at Ruby Hill, near Bingara, N.S.W.[18] Until recently however there was no evidence to show whether the primary sources of Brazilian and Indian diamonds could also be ascribed to volcanic pipe rocks: it remained an open question whether all diamonds (other than those comparatively few of meteoric origin) had reached the surface of the earth by means of volcanic pipes, having been formed in the depths of the earth, or whether some had been so formed and transported while others had been formed elsewhere and otherwise transported. The question perhaps still remains open, and no pipes have yet been discovered in Brazil, but the clue to the primary source of Indian diamonds may now reasonably be concluded also to be found in volcanic pipes. In 1950 this *Journal*[19] reported the discovery of a diamond-bearing pipe near Panna in Central India, although another report[20] appeared to indicate that the pipe was barren of diamonds—as many kimberlite pipes in South Africa are said to be. Since then little further information has appeared in this country, but a full account of the Majhgawan Mine in Panna, which is indeed a volcanic diamantiferous pipe was published in India in 1953.[21]

In addition to its scientific interest the Majhgawan pipe is of course of commercial significance. In the *Times* of 20th September, 1954 the following report from Delhi appeared:—

> " Three Russian technicians have arrived here as the advance party of a construction team employed to instal machinery for a diamond mine in Vindhya Pradesh, the *Statesman* reported this morning.
>
> The company, the Panna Diamond Mining Syndicate, is said to have negotiated a contract with the Russian embassy here which has been accepted by the Indian Government. The machinery is to be ready for operation by 1956 and will be used to develop a newly discovered mine called the Majgawan pipe. Indian and foreign experts are reported to have said

that the Panna region should be a rich source of high-quality diamonds."

It would appear therefore that the Russians have been quick to seize the opportunity of " getting in on the ground floor " in respect of this new source of one of the few raw materials in which the U.S.S.R. and its satellites are notably deficient.[22] I am informed on good authority that the present output is 3,000 carats per annum and the pipe contains on the average two carats per 10 cubic yards, the output being industrial diamonds.

* * *

Those who are lucky enough to attend Mr. Anderson's " school " at Chelsea know that scientists may be divided into the " splitters " and the " lumpers ". The " splitters " are those who are ever on the lookout for some small difference to reveal a new species, always trying to sub-divide into smaller and more exclusive categories; they may sometimes be suspected of an inability to see the wood for the trees. The " lumpers " on the other hand see resemblances in the most dissimilar objects, and like to classify in large and comprehensive families. The splitters love to discover, for instance, a new type of garnet—to distinguish a " spandite " or to differentiate a " rhodolite " from a " pyrandine "—while the lumpers delight in welcoming a new mineral as a member of an old family—seeing taaffeite ($BeMgAl_4O_8$) as an intermediate member of a group which also includes chrysoberyl ($BeAl_2O_4$) and spinel ($MgAl_2O_4$).

In 1934 the splitters got to work on diamond. In a classic paper[23] Robertson Fox and Martin split the diamond into two, designated respectively Type 1 and Type 2, with the following distinguishing features:—

Type 1: Band at 8μ, complete absorption at λ 3000, less isotropic optically, lamellar structure not typical;

Type 2: No band at 8μ, complete absorption at λ 2250, more isotropic optically, typical lamellar or mosaic structure.

Just ten years later Sir C. V. Raman replied for the lumpers.[24] He propounded the theory, supported by much practical evidence[25], that there are four ideal structural types of diamond—TdI and TdII (tetrahedral positive and negative), OhI and OhII (octahedral)—which in practice commonly occur intermixed in various proportions and manners, as by interpenetrative twinning of the positive and negative tetrahedral structures on a microscopic or ultra-microscopic scale, lamellar twinning of the octahedral structures, intertwinning of the tetrahedral and octahedral structures or dispersion of one structure in another in microscopically or ultra-microscopically small volume-elements. Type I and Type 2 then fitted easily into this grouping as members respectively of the tetrahedral and octahedral structure-groups.

Now, another ten years on, Dr. J. F. H. Custers, after referring to Raman's work on the subject only to say that perhaps it had not received the attention it deserved, has told us[26] of the discovery of another new type, so that Type 2 has itself been split into Type 2a and Type 2b. It appears at least possible that this new Type 2b is only another small sub-group whose characteristics (electrical conductivity, phosphorescence when activated by short-wave ultra-violet) are peculiar to a particular range of combination (whether in manner or proportion) of Raman's structure groups.

And what of Raman's latest work? Is he going over to the splitters? I think not. For although he and his associates are satisfied that amethyst (unlike rock crystal) is optically biaxial and crystallographically monoclinic[27], he insists on its close relationship to colourless quartz, finding that the change of structure from trigonal (colourless quartz) to monoclinic (amethyst) occurs during the growth of the crystal from material containing ferric impurities and is consequential on the progressive elimination of those impurities, which are finally deposited as a dome of discrete particles on the boundary between the amethyst and the colourless quartz.[28]

Monoclinic amethyst will take some getting used to; but so science progresses. The answer that received no marks in last year's Preliminary Examination may help to win next year's Tully Medal.

REFERENCES.

1. A. Johannsen, *Manual of Petrographic Methods*, 2nd ed., New York and London, 1918, p. 528.

2. A. Johannsen, *op. cit.*, p. 546.
J. F. H. Smith, *Gemstones*, 12th ed., London, 1952, p. 117.

3. J. Swimmer, *Separating Diamond from Aluminium Oxide and Silicon Carbide*, Industr. Diam. Rev., 1953, **13**, 225.

4. Aristophanes, *Clouds*, 149–151.

5. Journ. Gemmology, 1953, **4**, 56.

6. E. J. Gübelin, *The Chemical Compound of Some Liquid Inclusions*, Watchmaker, Jeweller and Silversmith (Journ. Gemmology), January, 1946, 24–25.

7. Sir D. Brewster, *On the existence of two new fluids in the cavities of minerals which are immiscible and possess remarkable physical properties*, Trans. Roy. Soc., Edinb., 1826, **10**, 1–41 ; *On the refractive power of the two new fluids in minerals with additional observations on the nature and properties of these substances*, Trans. Roy. Soc. Edinb., 1826, **10**, 407–427.

8. *Ibid.*, p. 21.

9. *Ibid.*, pp. 29–31.

10. *Ibid.*, p. 34.

11. *Ibid.*, p. 3.

12. F. G. Smith, *Historical Development of Inclusion Thermometry*, University of Toronto Press, 1953.

13. Sir H. Davy, *On the state of water and aeriform matter in cavities found in certain crystals*, Phil. Trans., 1822, 367–376.

14. E. J. Gübelin, *Gemstone Inclusions*, Journ. Gemmology, 1948, **1** (7), 7–39.

15. E. J. Gübelin, *Inclusions as a means of Gemstone Identification*, Los Angeles, 1953.

16. O. H. Erdmannsdörffer, *Quarzkristalle mit Fossilresten*, Mber. Dtsch. Geol. Ges., 1908, 32–35.

17. E. J. Dunn, *Geology of Gold*, London, 1929, p. 175.

18. Sir H. A. Miers, *Diamond*, Ency. Brit., 1910, **8**, 161.

19. D. S. M. Field, *Diamond Pipe Discovered in India*, Journ. Gemmology, 1950, **2**, 347.

20. A. M. Bateman, *Economic Mineral Deposits*, 2nd ed., New York, 1950, p. 845.

21. S. M. Mathur, *Diamond Mining and Recovery at the Majhgawan Mine in Panna, Vindhya Pradesh*, Indian Minerals, 1953, **7**, 34–42.
(A condensed version of this paper follows these Notes).

22. A. M. Bateman, *International Implications of Mineral Resources*, Indian Minerals, 1954, **8**, 16.

23. Sir R. Robertson, J. J. Fox and A. E. Martin, *Two Types of Diamond*, Phil. Trans. A., 1934, **232**, 463–535.

24. Sir C. V. Raman, *The Crystal Symmetry and Structure of Diamond*, Proc. Ind. Acad. Sci. A., 1944, **19**, 189–197 ; *The Nature and Origin of the Luminescence in Diamond*, Proc. Ind. Acad. Sci. A., 1944, **19**, 199–215.

25. R. S. Krishnan, *Experimental Evidence for the Existence of the Four Possible Structures of Diamond*, Proc. Ind. Acad. Sci. A., 1944, **19**, 298–303.

26. J. F. H. Custers, *Talk on Recent Researches on Diamond*, Journ. Gemmology, 1954, **4**, 305.

27. Sir C. V. Raman and A. Jayaraman, *The Structure of Amethyst and the Origin of its Pleochroism*, Proc. Ind. Acad. Sci. A., 1954, **40**, 189–196.
S. Pancharatnam, *On the Pleochroism of Amethyst Quartz and its Absorption Spectra*, Proc. Ind Acad. Sci. A., 1954, **40**, 196–210.

28. Sir C. V. Raman and A. Jayaraman, *On the Structure of Amethyst and its Genesis in Nature*, Proc. Ind. Acad. Sci. A., 1954, **40**, 221–229.

AN UNCOMMON GEMSTONE

by SIR JAMES WALTON, K.C.V.O., F.G.A.

IN working as curator through the specimens in the Gemmological Association's collection there has recently come to light a very beautiful specimen which, although well known to mineralogists, appears to be, in this country, uncommon as a gemstone. It is the only specimen of its sort in the museum and not only have I no example in my own collection but I am unacquainted with one in any other private collection. It is not mentioned in Herbert Smith's treatise nor in the works of Anderson or Spencer.

Webster, however, mentions it in the glossary of his compendium and it is briefly described by Kraus and Slawson and their remarks are quoted in Shipley's Dictionary of Gems and Gemology.

It is a variety of feldspar known as peristerite. Dana, Ford and Read (Rutley's Mineralogy) describe it as being a variety of pure albite, although the latter states that albite rocks may contain up to 10% of anorthite. The present specimen certainly has all the physical characters of pure albite. It apparently occurs in very varied geological formations, in the alkaline igneous rocks, syenite and diorite, and in the feldspathic lavas, in the more acid rocks such as granite, in the metamorphic gneiss and schists, in pegmatite veins, and is also deposited in veins and rock cavities from superheated aqueous solutions.

Kraus and Slawson state that attractive varieties occur in Ontario, Quebec and Madagascar while Dana, Ford state that it occurs in Bathurst, Lanark Co., Ontario. It is probably because of its site of origin that greater attention has been given to it in American rather than British text books of gemmology. Unfortunately the full details of origin of the present specimen have been lost, the notes simply stating that it came from Ontario, Canada.

Most of the above authorities lay stress upon the fact that peristerite shows a play of colours resembling that of labradorite but this stone is a mixture of albite (30%-50%) and anorthite. In the present specimen there is a beautiful schiller resembling "moonstone", but again this name is usually given to an intergrowth of orthoclase and albite.

The specimen under discussion is an oblong rectangular cut stone with slightly rounded edges. It measures 18 × 12 × 8 mm. and weighs 18·7 carats. It is opaque and milk white but in certain lights has a definite pink tinge. Perhaps its chief characteristic is that it has a most beautiful pearl-like iridescence much resembling that shown by the feathers on the breast and neck of a pigeon, in fact Dana Ford state that the name comes from the Greek περιδτερά (a pigeon). In addition there is, on movement, a beautiful bright blue schiller more vivid and to my mind considerably surpassing that of most moonstones.

With the naked eye and more plainly with the lens there are seen multiple parallel laminae and also fine glittering specks, which may be of quartz, for Rutley states that this variety often contains disseminated grains of quartz.

Under the microscope the specimen is too thick and opaque to observe the structure and for a similar reason, although the lamination is almost certainly due to polysynthetic twinning according to the albite law on (010), the vibration directions cannot be determined between crossed nicols, although under these conditions the specimen remains light in all directions on rotation showing that it is composed of multiple minute crystals rather than of a single one.

There is no dichroism and under the Chelsea filter the stone remains white; with reflected light no absorption bands can be seen in the spectrum.

The refractive indices are α 1·525 and γ 1·536. Attempts to obtain β (which for albite should be 1·529) by the method of double reading were unsuccessful but these two readings with a birefringence of ·011 are characteristic of pure albite and differ considerably from the other feldspars (see Dana Ford & Herbert Smith). It has a fair polish and lustre. The specific gravity is 2·62 and the hardness 6·5.

Here, then, is a beautiful mineral capable of being formed into most attractive gemstones and worthy of a much greater interest by jewellers than appears to be shown. It is white and at best only translucent, but its pink tinge, its pearly opalescence and its lovely blue schiller are a delight to the eye. Mounted singly in a brooch, a pin, in earrings, or with others to form a necklace or bracelet it should form attractive jewellery. It is true that it is relatively soft, but at 6·5 it is as hard as other gems used for a similar purpose, e.g. garnet and nephrite, and harder than many others, e.g. turquoise,opal, scapolite and lapis lazuli, so that with moderate care it should maintain its lustre and polish.

Gemmological Abstracts

Sutherland (G.B.B.M.), Blackwell (D. E.) and Simeral (W. G.). *The problem of the two types of Diamond.* Nature, Vol. 174, pp. 901-904, 1954.

Prof. Sutherland and Dr. Blackwell are already well known for their researches on diamond, and this is an important summary of their most recent work. It is now twenty years since Robertson, Fox and Martin first reported the existence of two types of diamond, showing marked differences in their absorptive properties in the infra-red and ultra-violet regions. Further differences were subsequently noted by other workers, and a summary of the main features of the two types can be given as follows:—

Physical property.	*Type I.*	*Type II.*
Infra-red absorption.	Bands at 4-5. Absorption 8-10.	Bands at 4-5. None between 8-10.
Ultra-violet absorption.	Complete beyond 3000A.	Transparent to 2250A.
X-ray diffraction.	Shows " extra " spots and streaks.	Normal.
Photo-conductivity.	Poor.	Good.
Birefringence.	Present.	Absent.

Since that time, the distinctions between Type I, to which almost all gem diamonds belong, and the rarer Type II stones, has been found to be far less clear-cut than was originally thought to be the case. Type I diamonds vary widely in the strength of their absorption in the 8-10 region, and Raman and his co-workers have found that strongly blue-fluorescent diamonds are transparent to well below the 3000A limit. A similar gradation has been found in the intensity of the extra spots in the X-ray diffraction patterns, and Grenville-Wells, who listed various physical properties of thirty-eight diamonds found four stones which exhibited anomalous X-ray streaks were transparent beyond 2400A.

It thus seems necessary to speak not merely of Type I stones but of extreme Type I, medium Type I, and weak Type I. Type II stones can also be sub-divided in accordance with differences in the 3-5 region absorption, according to Blackwell and Sutherland, while Custers recently suggested a division into Type IIa and Type IIb on the basis of luminescence and photo-conductivity. To complicate matters still further, the factors causing the X-ray variations are not necessarily the same as those causing differences in absorption. The present authors have therefore coined the symbols IS and IIS to indicate diamonds which are Type I or II so far as their spectroscopic properties are concerned, and IX and IIX for those in which it is the X-ray evidence that is being considered.

A study of the ultra-violet absorption of highly-branched saturated hydrocarbons (in particular that of adamantane, $C_{10}H_{16}$, which has a structure very similar to diamond in its distribution of bonds) shows that a cut-off at about 2200A is to be expected. In this respect Type II diamonds can be said to have perfectly normal ultra-violet absorption. Similarly, calculation of the fundamental frequency spectrum of the diamond lattice, combinations of which may be expected to give rise to infra-red absorption bands between 3500 $cm.^{-1}$ and 1800 $cm.^{-1}$ which are in fact to be found in IIS diamonds again show type II diamonds to be completely normal in their behaviour.

The surprising conclusion is thus reached that it is Type I diamonds that are abnormal and Type II which approximate to the ideal diamond from the crystallographic point of view.

It is suggested that " impurity centres " exist in Type I diamonds which account for their anomalous absorptive properties. These centres may consist of foreign atoms, missing carbon atoms, or carbon atoms which are not in the same electronic state as the majority of carbon atoms in the diamond lattice. Since most Type II diamonds are manifestly inferior in appearance to Type I stones, to which most gem diamonds belong, it would almost seem as though a large single crystal having the ideal Bragg structure is unstable and requires certain impurity centres to be incorporated to give stability. Such effects are by no means unknown in crystals of other substances. B.W.A.

COOMBS (D. S.) *Ferriferous orthoclase from Madagascar.* Mineralogical Magazine, Vol. 30, pp. 409-427, 1954.

The paper is chiefly concerned with the optic axial angles and the optic axial planes found in Madagascan yellow orthoclase, which vary in a puzzling manner apparently little related to the iron content. Of more interest to the gemmologist are the refractive index data for these gem-quality feldspars which are given for analysed specimens in Dr. Coombs' paper. Some of these are arranged below, and show very well the gradual rise in the indices with the tenor of Fe_2O_3.

Fe_2O_3%	α	β	γ	γ-α
0.62	1.5194	1.5237	1.5241	0.0047
0.9	1.521	1.5255	1.5255	0.0045
1.25	1.522	1.5265	1.5265	0.0045
1.45	1.523	1.5275	1.5277	0.0047
2.0	1.5245	1.529	1.5295	0.0050
2.56	1.5265	1.531	1.5315	0.0050
3.25	1.526	1.530	1.531	0.005

The optic axial plane was found to be perpendicular to the (010) plane in the first two and the fourth specimen in the above list, and parallel to (010) in the remainder. No density figures are given in the paper.
B.W.A.

WEBSTER (R.). *Glass imitation gemstones.* Gemmologist, Vol. XXIV No. 282, pp. 8-9, January, 1955.

A short discussion on the range of refractive indices for glass imitation gemstones of different colours. An appended table shows the distribution of colour and refractive index of some three hundred specimens. Most colourless glass stones had refractive indices between 1.60 and 1.65: most reds between 1.60 to 1.70: dark blues between 1.60 to 1.65: pale blues 1.50 to 1.54: purple and violet colours between 1.50 to 1.60: greens 1.60 to 1.70: yellow and brown colours between 1.48 and 1.54: black glass between 1.60 and 1.65. Only four glass imitation stones have been reported as having refractive indices greater than 1.70. The Author advises caution in accepting the table, except as a guide, owing to the relatively small number of determinations.
P.B.

MARCHER (G. H.). *Detection of faceted glass gemstones.* Gemmologist, Vol. XXIII, No. 281, pp. 229-232, December, 1954.

A reprint of an article first published in the *Mineralogist.* (*Journ. Gemmology Abstracts,* Vol. V. No. 1, p. 34, January, 1955).
R.W.

PAYNE (C. J.). *Kornerupine.* Gemmologist, Vol. XXIII, No. 281, pp. 215-219, December, 1954.

Discussion of the localities in which kornerupine has been found: some notes on the properties of the species, and short biographical notes on J. Lorenzen, who first published a paper on the mineral, and on A. N. Kornerup, after whom the mineral is named. Kornerupine was first described from the locality at Fiskernaes in Greenland in 1884. In 1886 a new mineral named *prismatine* found in Saxony was proved to be kornerupine. A further source of the mineral was found, in 1912, at Betroka, Madagascar, and later, in 1922, another find was made at Itrongay in the same island, the stones from Madagascar being sage green in colour. About 1936 a number of browny-green stones from the illam of Ceylon were identified as kornerupine. A very opaque grey variety of kornerupine has been reported from Port Shepstone, Natal. Although an unidentified emerald-green stone was known about 1937, the occurrence of the emerald-green kornerupine, of which the earlier unidentified stone was a specimen, from the Mogok district of Burma, was not clearly known until the collector A. C. D. Pain produced another such stone in 1952. In 1949 two varieties, one dark green and the other yellow or greenish-yellow, were found in the Province of Quebec. The characters of kornerupine are given in the text and in a very full table.
R.W.

ANON. *Electro-static separation.* Gemmologist, Vol. XXIII, No. 281, p. 232, December, 1954.

Abstract of a report on a new process to recover diamonds that are too small to be separated satisfactorily by grease belts. First installed at the central recovery plant of the Consolidated Diamond Mines of South West Africa Ltd, in November, 1952. Following initial difficulties satisfactory results now obtained. Electro-static separation depends upon the differential electro-conductivity of the various particles of the mixture. Diamonds are poor conductors but most of the gangue minerals are better. The separator consists essentially of an earthed electrode and a positively charged electrode, placed opposite and fairly close to one another. A high tension electrical field is maintained between the two electrodes. When a diamondiferous gravity-concentrate is passed through the high-tension field all particles obtain an induced charge. The particles of gravel, being relatively good conductors, allow their charge to leak away to earth as they pass over the grounded electrode. Thus, they acquire the negative earth potential and are attracted towards the positive electrode. As diamonds are poor conductors the induced charge on their surface does not leak away to earth and are therefore repelled by the positive electrode. Thus a separation is achieved, but this is not quite complete. Diamond recovery is said to be as high as 99%.

R.W.

SMITH (R. J.). *Jade artifacts of Puerto Rico.* The Mineralogist (Oregon), January, 1955.

This is an interesting article describing two jade artifacts discovered on the small island of Puerto Rico which is at the eastern end of the Great Antilles group—part of the Commonwealth of the U.S.A.—and was visited by the author. These artifacts he establishes as jadeite and makes reference to the other jadeite localities of the world. The author lists China, Tibet, Burma, Costa Rica, and California, though only the third and fifth have been established. No known occurrence of jadeite has yet been confirmed in either China or Tibet. A known occurrence in Costa Rica would be welcomed by all interested in The Jade Question. The author's statement that " the Maori tribes of New Zealand are making axes from nephrite rocks today " is without foundation.

E.R.

ANON. *Adaptor for use with Rayner refractometer.* Gemmologist, Vol. XXIV, No. 283, p. 28, February, 1955.

A useful refractometer stand consisting of a base plate and two inclined wing slides with concave surfaces, devised by T. P. Solomon. The intention, for which the piece of apparatus seems most suitable, is to facilitate the control of bracelets, etc., which tend to slip off the refractometer when the stones are being tested. The modification is similar to the hand rests often incorporated in the stage of dissecting microscopes.

1 illus. R.W.

ANDERSON (B. W.); PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXIII, No. 281, pp. 222-225, December, 1954; Vol. XXIV, Nos. 28/23, pp. 5-8 and 31-33, January and February, 1955 (Parts 16, 17 and 18.)

The continuation of the series (Part 16) discusses the absorption spectrum of jadeite, Jadeite shows, in the case of the green-coloured material, fine lines in the red due to chromium, but the species as a whole has a more distinctive absorption band in the violet region (4375A) due to iron. It is intended that this will be further discussed when stones showing spectra due to iron are dealt with. The chromium lines seen in green jadeite consist of one centred near 6915A, which is possibly an unresolved doublet, a weaker line at 6550A and a vague band at 6300A and increase in strength with Cr content. These bands have a certain similarity to the bands seen in emerald in showing transparency patches alongside them. The prominent iron band at 4375A is masked if the chromium content is strong, but in practically all other specimens of jadeite is intense and diagnostic. This band in the violet is present in the yellow and green spodumene—an allied pyroxene mineral—but the appearance of spodumene is so different from that of jadeite that no confusion is possible. The absorption spectrum of nephrite is discussed. Some nephrite contains traces of chromium but any trace of this in the spectrum is vague and weak, and, despite the iron coloration, nephrite does not show the 4375A line seen in jadeite. Comments are made on the chromium-rich type of jadeite, possibly the so-called " Yunnan Jade." A summary of the jade spectra is given, which mentions also that jadeite, unlike emerald, does not show red under the colour filter, and reiterates the usefulness of employing a copper sulphate filter before the bright light source as an aid to observing the absorption spectra. Part 17 describes the spectrum of demantoid garnet. The name of this gemstone and the misnomers which have been applied to it are discussed. The " horsetail " inclusions of fine asbestos fibres in demantoid are mentioned as an aid to identification. Demantoid garnet shows an intense absorption band at the beginning of the violet with its centre about 4430A which in the pale greenish specimens is sharply delineated and not very broad, but in the finer green specimens the chromium absorption is superimposed on that due to iron and a general absorption of the violet occurs so that the 4430A line may appear simply as a cut-off. The copper sulphate filter and the widening of the slit of the spectroscope will assist visibility of the band in the violet. In the richer chromium types the lines in the red are seen, but are not so clearly seen as in emerald and alexandrite. These lines in the red are at 6930A, 6400A and 6220A, the last two some 100A broad, and one in the deep red which has not, as yet, been possible to measure. Weak bands have also been measured in the blue part of the spectrum at 4850A and 4640A. Demantoid garnet shows pinkish through the colour filter. The comparison with gems similar in appearance to demantoid is discussed. These are green zircon, green sphene, green diamond, peridot, green sapphire, chrysoberyl, andalusite, enstatite, and emerald. Part 18 discusses the chromium spectra of such minerals as hiddenite, euclase, kyanite, enstatite, chrome diopside, the peridot from Hawaii, stained chalcedony, green glass, green aventurine quartz, variscite and scapolite. It is remarked that the prescence of a chromium spectrum is presumptive evidence that the mineral concerned contains aluminium.

2 illus. R.W.

PARKINSON (K.). *The open polariscope in gemmology.* Gemmologist, Vol. XXIV, No. 282, pp. 1-4, January, 1955.

Describes a polariscopic apparatus which is not combined with a microscope (an American instrument is illustrated). The vibration directions of nicols and polaroid plates are discussed in relation to the " crossed position." The comments on the effects seen when the analyser is rotated are not very clearly expressed ; the "crossed position" occurs at every 180° of rotation, that is twice in a full circle—not 90° as printed. The effects seen with doubly refractive stones and crypto-crystalline material and anomalous double refraction are discussed. The employment of such a polariscope to detect dichroism is touched upon. Methods for observing the interference figures are discussed. In view of the the fact that the open polariscope does not have a condenser, it is suggested that a drop of highly refractive liquid placed on the surface of a facet which is normal to the optic axis will assist in obtaining the interference figure.

2 illus. R.W.

PARSONS (C. J.). *How to make a quartz wedge.* Gemmologist, Vol. XXIV, No. 283, pp. 21-28, February, 1955.

A continuation of the series on the polariscope by K. Parkinson, with this part written by a second author. A list of minerals with overlapping constants, in which case the determination of the optic sign will assist identification, is given. The method of making the quartz wedge is discussed, mention is made of the lapidary apparatus needed, and what can be improvised. The correct orienting of the optical directions of the rough quartz in preparation for the slicing is given. The way to grind to wedge shape and the way the wedge is finally mounted and is marked to show the Z (slow) direction are told.

4 illus. R.W.

ROSENBLOOM (W. E.). *Paua Shell—The Marine Opal.* Lapidary Journal, Vol. 8 (6), 1955, pp. 498-508.

Paua is a Maori name for a mollusc occurring around the coasts of New Zealand and Pacific waters. The Maoris used the shell as working tools, for hunting and fishing purposes and for ornamentation, such as inlaying of eyes for *tikis*. Little of the shell is dived for today and the only worthwhile material has to be obtained from a live mollusc. Iridescence or play of colours is apparently on inner surface of shell and greatly enhanced when polished, and the author regards it as superior to that of the *abalone* shell. Details are given for removal of outer limey deposit and for cutting and grinding the shell into suitable shapes for use in jewellery and ornamental articles.

S.P.

BOOK REVIEWS

HANSFORD (HOWARD S.). *A Glossary of Chinese Art and Archaelogy.* The China Society, London, 1954. 104 pp. 15/-.

Mr. Hansford, who is lecturer in Chinese Art and Archaeology at the Courtauld Institute of Art, has already earned the gratitude of all students of jade by his book, "Chinese Jade Carving," published in 1950. This gave a scholarly and up-to-date account of the nature and origins of jadeite and nephrite, and of the tools and techniques whereby the Chinese artist-craftsmen have fashioned these obdurate materials into objects of enduring beauty from the earliest days until recent times.

The small book now under review is much less general in its appeal. It is designed to fill a very special need—a need felt by the author himself many years ago when he was resident in China and studying those subjects in which he is now an acknowledged authority. It is addressed (to use the author's own words) " both to readers of Chinese who require precise definitions of technical and conventional terms met with in current writings on art and archaeology, and also to those already familiar with Chinese arts, crafts and antiquities, who have embarked on a study of the written language."

The glossary is divided into six separate headings: metals, gems, and gem-stones, sculpture in stone, painting, ceramics, and " miscellaneous." The last term covers such materials as lacquer, ivory, wood, glass, etc. Near the end of the book there are several pages of beautifully-executed line drawings depicting ritual bronzes and weapons. typical ceramic shapes and ritual jades. These are numbered and are referred to in the text, but a key adjoining the illustrations themselves might usefully have been provided.

The Chinese language is not rich in specific names for minerals, and two pages suffice to cover the Chinese names for gemstones. Under this general heading, however, there are other pages dealing with the lapidary's craft and various aspects of jade. Some of the names for gems are hardly inspired—Lu pao shih for emerald and hung pao shih for ruby, for instance, literally mean nothing more than "green precious stone" and " red precious stone " respectively. Others, such as ch'a ching—" tea crystal "—for cairngorm and tan-pai shih—" white-of-egg stone," for (common) opal—are delight-fully apt. The term for diamond, chin-kang shih, or "gold-steel stone," may seem puzzling until expanded into " a stone which is as precious as gold and as hard as steel."

In the text, the Chinese characters for all the terms are given first, followed by the romanised version. It would have assisted the complete beginner in Chinese if a literal translation of the multi-syllable expressions could also have been appended. The book concludes with an index of the romanized version of all the terms given in the text.

The " Glossary " is admittedly a book for the specialist, but serious students of Chinese art and archaeology will undoubtedly welcome its appearance. Parallel works on architecture and calligraphy are planned by Mr. Hansford for future publication by the China Society.

B.W.A.

ANON. *The polarizing microscope.* Handbook (Publication No. M7000Z), Cooke, Troughton & Simms, Ltd, York.

This extremely well-written handbook is for use in conjunction with a miniature film on the subject, which is distributed by the well-known microscope manufacturers, Messrs Cooke, Troughton & Simms, of Haxby Road, York. The booklet, which is Part I (Part II it is understood will be in colour and will be issued later), deals with all aspects of the polarizing microscope and polarized light. The difference in visibility of the structure of transparent and opaque substances as seen through the microscope in ordinary light and in polarized light is dealt with. A clear dissertation is made on the nature of ordinary and polarized light and its production by Nicol prism and by artificial polarizing filters, and on the action of the Bertrand lens. Pleochroism and the behaviour of light in anisotropic substances are clearly explained with reference to the "parallelogram of forces" of the vibration directions. The Becke line method for the determination of refractive index and for the determination of birefringence is interestingly told, as is the " path difference " or " retardation " of the two vibration directions. The determination of the extinction angle is referred to and the use and action of the quartz wedge are discussed. Much valuable information in small space. No less than 63 illustrations help to make the text understandable.

R.W.

STRONTIUM TITANATE

A new synthetic gemstone

by DAN E. MAYERS

EVER since the introduction of synthetic rutile some years ago there have been rumours of a newer and whiter synthetic stone, but until very recently samples of it did not come upon the market. Recently the writer obtained a sample of the new material and had some stones cut from it; in addition a prism was made for the precise determination of refractive index measurements.

The new material is said by the producer to be composed of strontium titanate, $SrTiO_3$. It is entirely white, without any trace of the slightly yellowish rutile colour, and, most important of all, is isometric, hence there is none of the characteristic doubling of the back facets of cut stones as in the case of uniaxial rutile. Perhaps it is owing to this comparatively simple isometric structure that the material shows virtually none of the strain, layer structure, or other optical inhomogeneities which invariably occur in rutile.

The index of refraction and dispersion of strontium titanate very closely approximate to those of diamond, as can be seen from the following table of optical constants, for whose measurement I am much indebted to Dr. G. Calsow, of Carl Zeiss:—

Measurements made upon a prism of $34°9' \, 7.3'' \pm 2''$.

n_C—2.40647 $\pm 5 \times 10^{-5}$ Mean Dispersion, $n_F - n_C = 0.10104$
n_D—2.42513
n_d—2.42603 Abbe Number, $v_D = \frac{nd - 1}{nF - nC} = 14.1$
n_e—2.45187
n_F—2.50751
n_g—2.58613 Dispersive Power $= 1/v_D$—0.0709
n_h—2.66692

From the purely commercial standpoint, and leaving gemmology aside, the striking thing about this material is the fact that it does, for the first time in man's long struggle in this direction, closely resemble the diamond. Cut strontium titanate shows the characteristic lustre, fire, and transparency of the diamond; the play of colours is a trifle more pronounced than in the diamond but by no means as much as in the case of rutile.

The stone is not yet on the market commercially and distribution plans are far from settled; it is to be hoped that the experience gained by gem dealers in connexion with the sale of rutile will enable them to avoid some of the errors in distributing strontium titanate which marred the sale of rutile, particularly as strontium titanate is slightly softer than rutile and even less suitable for use as a ring stone.

Note by B. W. Anderson

I was naturally very interested to see the two small cut specimens of strontium titanate which Mr. Meyers handed to me in order that a density determination might be made. Hydrostatic weighing in ethylene dibromide gave the high density value 5·13. The stones only weighed 1·35 cts and 0·68 cts respectively, so that no great accuracy can be claimed for this result, which may need slight modification when larger pieces are available for experiment.

The refractive index figures obtained for Mr. Mayers by Dr. Calsow are obviously highly accurate, but it is a pity that wavelength figures were not quoted in addition to the Fraunhofer letters. In British works of reference, for instance " e " is not given, and if this is taken to mean Fraunhofer's E line = 5270 A this does not lie conformably with the curve formed by the other figures stated when the dispersion is plotted graphically.

Mr. Mayers' statement that the *dispersion* of strontium titanate closely approximates that of diamond is obviously a slip of the pen, since the C–F figure of 0·101 given in his table is about four times the corresponding value for diamond, and the greater degree of fire shown by the new material is sufficiently obvious to the eye.

COLOURED MINERALS and the DICHROSCOPE

by NIGEL W. KENNEDY, F.R.S.A., F.G.A.

HUMAN ingenuity in the exploitation of natural phenomena in the service of mankind has produced many optical instruments of particular interest to the gemmologist, but not every student of gemmology is able to make the best use of them.

Among these are two in the use of which few students are really proficient; these are the Chelsea filter and the dichroscope. It is probable that variation in eyesight is partly responsible, as in my own case, since with the filter I can rarely distinguish any other tone than black or brown of varying intensity. How I envy observers like Mr. L. C. Trumper whose keen colour sensitivity detects tone differences which are completely concealed from me.

This is due partially to a form of colour-blindness, but many other students admit their inability to see most of the characteristic appearances which should be observed. It is probable that this is largely due to inexperience, and the form and intensity of the light source is of great importance, particularly as a standard of comparison between stones examined at different times. Although I suffer from a defective colour-sense, this refers mainly to tones of red under adverse conditions. Under suitable illumination I can detect very slight differences between shades and tones.

These observations apply equally to the dichroscope, or rather, to the use of the various patterns of the instrument now available, of which some are simpler and easier to use than others.

In principle the instrument is easy to manipulate, but in actual practice this is not usually so. The normal instrument is a tube with the usual shaped calcite rhomb, and optically ground glass ends. With this type the user must support a stone in some way in order to examine it, and this introduces undesirable variations in technique, which easily lead to varied results. To avoid this some dichroscopes have a support or holder for the stone, or in one instance, a rotatable table. These are intended to simplify operation and to eliminate errors that may occur by incorrect manipulation. The table model seems ideal—yet I am not the only user who sometimes removes the instrument in order to make an observation.

It is fairly obvious on consideration, that in order to make any accurate comparison between one stone and another, the conditions of examination should so far as possible be identical—lighting, distance from light, and uniformity in the angle of vision, not to omit the essential factor that it is best to use artificial light, since this eliminates any possibility of taking one observation in daylight and another in artificial light. Unless and until one is very skilled in this technique it is certainly advisable to record observations for future reference and comparison. In practice, when handling large numbers of stones, this may be virtually impossible, but as a principle it should be adhered to by the careful worker, and always with unusual stones.

It is not always realized that blue sky is quite distinctly dichroic, and this can upset observations quite considerably. It is rather disconcerting to discover, for the first time, that apparently white light may be and in fact, often is, distinctly polarized, so that instead of seeing a pair of evenly illuminated white squares in the instrument, one sees a white and pale blue square at times. If the reader has never examined blue sky through a dichroscope, it will be interesting to do so. Observations should be made from two points (a) back to the sun on a bright day, and (b) at right-angles to the direction of sunlight. The difference is, of course, due to the polarizing effect of minute crystals of ice high up in the sky, and the blue colour of the sky is directly due to this cause. When one rises high above the clouds on a bright day, the sun is a brilliant object set in a sky of velvety blue-black, studded with myriads of stars.

With due care, this effect is not present when using artificial light, but it is well, in recording observations (especially in the case of some unusual effect), to record the light in which it was made. Observations of quite common stones may differ quite considerably when taken by different forms of illumination.

The student may also be loosely aware that there is a polarizing angle for light incident to a reflecting surface, as in the case of the sun's rays on water, and that therefore, one should be prepared to see this effect in the dichroscope, and to avoid it.

Some instruments are provided with a rotating table for the stone, and this has a semi-polished black surface, which under suitable conditions may slightly polarize light falling on it and reflected into the aperture, resulting in quite different tints being seen. This has puzzled observers, and has assisted in promoting a feeling of distrust for the instrument, as the reason for the differences noted was quite unsuspected.

Another similar effect which also puzzled me has been traced to total reflection from the inner surface of one of the glass ends cemented to the calcite rhomb in the instrument, and seen when, by accident, a stone is viewed in a direction oblique to the optical axis of the instrument.

Once these simple difficulties have been realized and avoided, the observer can make better use of the instrument, and will understand how essential it is that observations should be made so far as possible under identical conditions.

Before proceeding to a discussion of the use of the dichroscope, and of the method of recording phenomena observed, it may not be out of place to run briefly through the theory of the optical behaviour of matter which is transparent to light having wavelengths within the limits of the visible spectrum. In this connexion one is, of course, thinking in terms of composite (white) light, transmitted through material possessing the property of selective absorption, transmitting or reflecting vibrations which are interpreted by our sensory system in terms of colour.

A beam of composite light traversing an isotropic medium, that is, amorphous material such as glass, or anything crystallizing in the cubic (isometric) system, travels with equal velocity in all directions because it meets with equal retardation. If the two surfaces of the material traversed by the beam are parallel, the angle of incidence, or entry, and the angle of exit will be the same, and the emergent beam will take a path parallel with the incident beam, still maintaining its identity as white light. Such material is, of course, singly refractive.

On the other hand, a similar beam traversing anisotropic material—that is, material crystallizing in any other system than the cubic system—is split up on entering into two rays vibrating in planes at right angles to each other which emerge as separate rays, such material being doubly refractive. The refractive index of each ray has a maximum and minimum value, according to the direction of propagation, and in some directions the rays have equal velocity and the same refractive index. Such a direction is referred to as an optic axis, and uniaxial crystals (the dimetric systems comprising the tetragonal and hexagonal) possess *one* optic axis, while the biaxial crystals (crystallizing in the trimetric systems, namely, orthorhombic, monoclinic, and triclinic) have *two* optic axes. In dimetric (uniaxial) systems, the two rays are known respectively as the ordinary ray (denoted by the letter " o " or Greek letter "ω"), and the extraordinary ray (denoted by the letter " e " or Greek letter "ε") because of their optical behaviour. The ordinary ray has a constant refractive index, while the extraordinary ray has a variable index according to its direction.

A beam of white light transmitted in the direction of an optic axis suffers equal retardation, has uniform velocity, and therefore, has one index of refraction, that is to say, in such a direction all minerals are singly refractive.

In uniaxial crystals the optic axis corresponds with the principal or "c" crystallographic axis, hence basal sections in dimetric (uniaxial) minerals are isotropic. It must be remembered that optic axes are purely directional and in biaxial (trimetric) minerals the concept of the optic axes becomes increasingly complicated as one proceeds from orthorhombic minerals to crystals of the monoclinic and triclinic systems. In fact, even H. G. Smith(1) states in referring to this " The symmetry of the triclinic system being so low, it would be profitless to attempt a statement of optic orientation."

Light is transmitted through biaxial (trimetric) crystals by rays having maximum (gamma ray) and minimum (alpha ray) indices of refraction, with a third ray (beta) having an intermediate velocity and refractive index. Light travelling through such media is split into two rays vibrating at right-angles to each other, and travelling in pairs according to the direction of propagation, namely, as alpha-beta, alpha-gamma, or beta-gamma, and in intermediate directions.

The colour of minerals by reflected or transmitted light, is due to the selective absorption of certain rays by the material, while the unabsorbed rays travel on to the eye. The effect, in the case of coloured glass, and other amorphous material, and substances crystallizing in the cubic system, is to transmit the same colour uniformly in all directions, as one would expect.

In the case of coloured varieties of anisotropic minerals, the pairs of rays into which composite light is resolved, differ in wavelength, and are differently absorbed during transmission. As a result the transmitted colour as interpreted by the eye may be a combination of differently absorbed wavelengths, and in some striking examples, a purple stone, for example, viewed at different angles, is seen by the unaided eye to be both red and blue, producing the effect known as dichroism. An example of this effect is seen in the lovely so-called " Alexandrine " sapphires from Ceylon, which display this optical effect most strikingly. In the case of biaxial minerals, in which the colour differs according to which of three directions light is transmitted in, possibly the most beautiful example of this effect is the lovely kunzite, or lilac spodumene, which is lilac in one direction, pale pink in another, and pale blue in a third. In light-hued stones the effect may be clearly seen, but in others the strong body colour may mask the effect.

By the use of suitable rhombs from the colourless and very strongly doubly-refractive mineral calcite, or "Iceland Spar", a complete separation of the two polarized rays may be achieved and compared in the dichroscope, by which a beam of composite light after traversing a transparent medium is doubly refracted, producing two adjacent square images of the aperture, which may thus be easily compared. Coloured isotropic material will, of course, produce two images of identical tint and intensity, when examined by light transmitted in any direction, and similar images will be seen when any doubly refractive mineral is examined in the direction of an optic axis.

All coloured glasses, being amorphous in nature, are optically isotropic, and in most cases their optical behaviour is normal, but there is one special type of glass which behaves rather differently when examined by the dichroscope. The only example I have encountered so far was in the form of small cut pastes in ear drops, made possibly forty years ago, and believed to have been of German origin, and sold as " Rhinestones." These have no connexion with, or resemblance to, the cheap paste trinkets of garish colours and cut, coming from the United States of America just now, but to quite a different type of paste. I have not yet discovered the origin of the name " Rhinestone " nor whether, in fact, similar stones were ever found in the Rhine, and this would be interesting information. These little stones of about 1.5 ct are semi-transparent, and in one direction they appear to be pinkish, while in another the colour is brown. When examined by the dichroscope, two squares of the same colour are seen, but from another angle the transmitted light produces a pair of images of a different colour, thus differing from normal isotropic material, which gives identical colours in all directions. This phenomenon is known as dichromatism, and is not to be confused with dichroism; and is characteristic of a number of organic substances.

Solutions of some organic dyes may exhibit this effect to a remarkable extent. By transmitted light across the solution the colour reaching the eye may be a bright red, but when looking down at the surface of the liquid the reflected light may be blue owing to differential absorption.

Since the power of selective absorption varies in different directions in doubly refractive minerals, when coloured varieties of these crystals are viewed through a dichroscope by transmitted light in any direction except that of an optic axis, a pair of differently coloured images is usually seen. Not all doubly refractive coloured minerals display this phenomenon to any marked extent, for example some quite strongly coloured varieties of quartz and zircon; but conversely, pale varieties of some minerals show remarkable dichroism, for example, Burmese blue apatite. Maxixe beryl, brown tourmaline, ruby, and andalusite are a few examples of gems showing strong and delightful dichroism.

If observations should be made when by accident a strong light illuminates the stone at right angles to the axis of the instrument, the interior of the stone may be flooded by light of quite a different wave-length, resulting in the formation of images quite different from those normally transmitted. This effect is seen when examining a fairly large specimen in different directions in strong sunlight. This is why it is so essential to standardize the method of observation, in order that a direct comparison may be made between two specimens, even after an interval of time between observations. If, for any reason, an examination should be made under other than normal conditions, the fact should be recorded for future reference.

It seems to me that in order to use the dichroscope to the best advantage, the student should be encouraged to use the instrument intelligently, and to record the results of his observations in his note book in a carefully tabulated manner. This would be facilitated if it were possible to obtain special pages, say quarto size, on which were printed pairs of blank frames representing the pairs of images seen in the instrument, which could be suitable coloured by the observer. I think that these frames should be printed in groups, each occupying a line across the folio.

The first should consist of, say, four pairs arranged horizontally, and the next, of four pairs, the first being horizontal, the next oblique, the third vertical, and the fourth horizontal. This arrangement should be repeated down the folio, space being left between each group for abbreviated notes. These should state the source of light, for example, a 40 w. " Pearl " electric light, at a distance of 8 ins. The vibration directions of the rays should be indicated where known. A system of shading lines could be used in place of colour if desired, although colour is more desirable.

I feel that it would be well worth while to study coloured minerals in the manner suggested, and the keen gemmologist will not find it a waste of time to keep a record of observations on various coloured media by means of the dichroscope. Much of the trouble in keeping such records would be in having to rule a large number of neat frames, but I believe that, subject to the demand arising, these ruled folios would soon be available to the student.

REFERENCE.

1. H. G. Smith, *Minerals and the Microscope*, Thomas Murby, London, 4th edition, 1949.

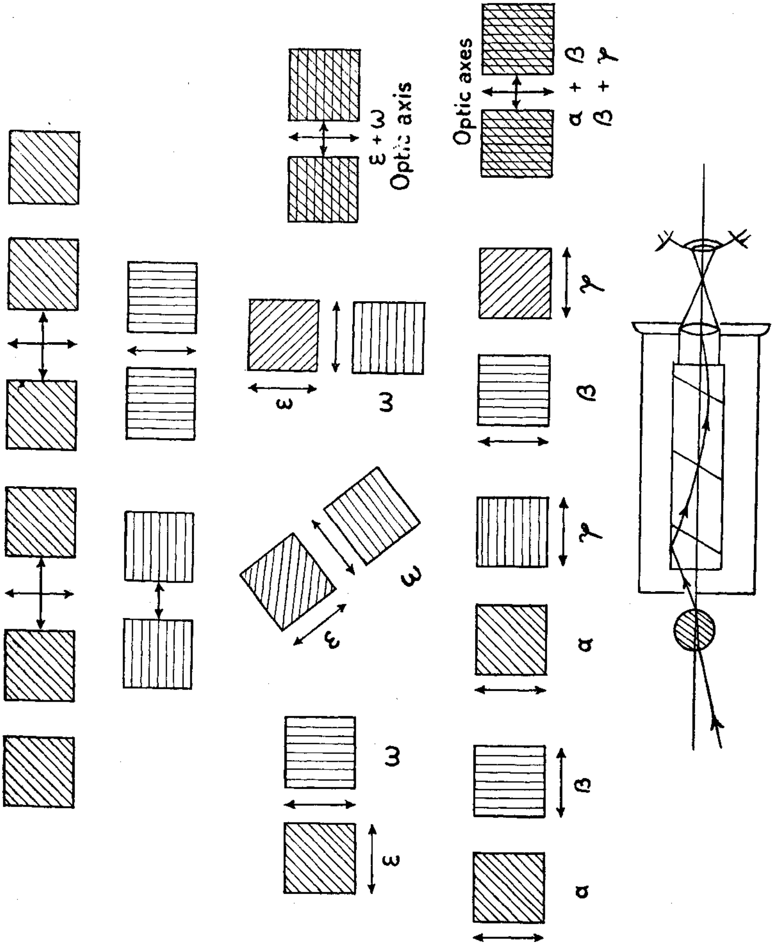

FIG. 1

ASSOCIATION NOTICES

CHANGE OF ADDRESS OF ASSOCIATION OFFICES

After 29th April, 1955, the address of the Association's registered offices will be SAINT DUNSTAN'S HOUSE, CAREY LANE, LONDON, E.C.2. Telephone: Monarch 5025/26.

Carey Lane runs at right angles to Gutter Lane, so that visitors to the new offices should easily find the new building. The Association occupies offices on the second floor, and members are invited to call whenever they are in the district.

A GEMMOLOGICAL BRAINS TRUST

Three experts in gemmology, Mr. Robert Webster, Mr. Fred Ullman and Mr. D. G. Kent, faced other experts in the same subject at the Association " Any Questions? " meeting on January 21, 1955, when it may be said that both sides gave a very good account of themselves. Questioners and the questioned were good, with interesting information being suggested, asked for and obtained.

In the absence of the Chairman owing to illness, the Secretary, Mr. G. F. Andrews, took the Chair.

The first question came from Mr. A. E. Farn who wanted to know why chrysoberyl and spinel were so little used in jewellery. Mr. Ullman responded with the reason that they were rare stones and from the public point of view their colour was on the dull side compared with sapphire or ruby, and Mr. Kent considered that the synthetic spinel out-classed the natural. Mr. Webster added that the yellow chrysoberyl had been fashionable in Victorian days. It might come back as the amethyst was coming back.

Dr. E. H. Rutland wanted to know how rare was really good spinel, say of a red colour, to which Mr. Ullman admitted that such stones were rarely seen in parcels today.

Entertaining discussion followed the additional query from Mr. A. E. Farn as to whether it was correct to term a stone colourless or white.

Mr. Ullman plumped for " colourless " as the more correct because white suggested a " colour " and Mr. Webster agreed, saying that to him white meant a milk-like colour that could be applied, for instance, to ivory or jade. He admitted that some people might say that as black was the absence of colour, so its opposite should be white, though in fact that represented all the colours of the spectrum.

Opposition came from Dr. Rutland who said the term " colourless " involved the denigration of good stones, and the Chairman asked how a colourless diamond could be called blue-white? Mr. Ullman said that diamond experts would say that the blue was due to fluorescence and was not a physical property of the stone.

Mr. M. D. S. Lewis asked if the interior of good paste had ever been found featureless and without " swirl " marks?

Mr. Webster said this was so as far as ordinary magnification was concerned. The more modern lead glass seemed less liable to interior imperfections than the old glass though they might show up under high magnification of eighty or more. Dr. W. Stern volunteered the theory that present methods of manufacture got rid of the bubbles, possibly by supersonic means.

Still on the topic of interior features, Mr. Lewis wanted to know if their absence suggested a natural or synthetic stone. Mr. Webster said such a stone was more likely to be natural Most of the synthetic corundums showed features, though the yellow was remarkably clean. Spinels were another matter. Sometimes these were clean when synthetic. The worst thing they could encounter was the natural stone which sometimes turned up and showed no features.

Mr. B. W. Anderson asked the panel what was the most difficult gemmological problem that they had encountered.

Mr. Ullman said it was the identification of natural or synthetic sapphire which required laboratory experience and professional skill in certain cases. Mr. Kent quoted the identification of danburite crystals or coloured tourmaline with an .030 double refraction, and Mr. Webster said he considered the hardest stone to distinguish was turquoise.

Another question of nomenclature was introduced by Mr. Farn who asked whether the panel favoured the changing of the description quartz-topaz which was well understood by the trade.

Mr. Ullman said it would be a good thing if the trade did accept and call things by their correct descriptions and he was supported by Mr. Webster who pointed out that at one time there was ruby-spinel, though he added that the term " ruby glass " was still used by the glass trade. However, that was a colour adjective and topaz might be used in the same way. The Chairman pointed out that since the Merchandise Marks Act, 1953 the description of a quartz as a quartz-topaz might make a dealer liable to prosecution. It was no defence, as had already been laid down in the Courts, to say that this was an established trade practice. Mr. J. R. H. Chisholm agreed and Mr. Anderson thought that the trade used the name because it sounded better. It would have to go in the cause of honesty. These terms were losing ground and eventually one name should stand for one stone.

Another question that was cleared up was why the jeweller's loupe was so-called. It was agreed that this came from the French word meaning magnifying-glass and was sometimes wrongly applied to the watch lens more commonly used by the jeweller.

Mr. Anderson propounded a question that rather stumped the panel when he asked if there are any blue cobalt minerals and if not, why not? Mr. Webster admitted that all the natural ones he knew were pink. He could not say why but Mr. H. Lee came forward with the suggestion that it was perhaps due to the relative speed of their formation.

An interesting discussion followed on the fate of the diamonds that were in the fire that followed the recent air crash at Prestwick. Mr. S. F. Redknap said he had heard that some of the diamonds had fused. Was there anything that could be done to make them commercially usable?

Mr. Webster said that he had heard from someone who had been engaged in the search for them that they were quite unusable. The stones were cracked and pitted. Most of the stones were in the rough state and the crystals had apparently corroded and fused as if something outside had pressed into them, that was how it had been described—it was almost as if they has been made plastic and then something pressed against them.

There were several questions concerning modern paste stones. Mention was made of an American paste with a refractive index of over 1.7 and a hardness of about six and there was a discussion about "case-hardened" paste from France. Other speakers thought these stones were of equal hardness throughout being toughened possibly as a result of an annealing process.

COUNCIL MEETING

At a meeting of the Council of the Association held at 19/25, Gutter Lane, London, E.C.2, Sir James Walton presided in place of the Chairman, Mr. F. H. Knowles-Brown, who was indisposed.

The following were elected to membership:—

FELLOWSHIP.	ORDINARY.
C. I. Belcher, Johannesburg.	L. J. van Ameringen, London.
S. S. Bradbury, London.	G. M. Beauchamp, Bournemouth.
A. B. Chinn, Jersey.	R. E. H. Jeffreys, London.
J. Stamnaess, Oslo.	E. J. Soukup, San Diego.

The Council heard with regret that Mr. Knowles-Brown wished to resign as Chairman because of ill-health and other reasons. The Council made the following nominations for submission to the Twenty-fourth annual general meeting:—Chairman, Sir James Walton, K.C.V.O., F.G.A.; Vice-Chairman, Mr. Norman Harper (Birmingham); Treasurer, Mr. F. E. Lawson Clarke (London). The Council further decided to nominate the retiring Chairman for election to the Council.

It was reported that Messrs. R. K. Mitchell and E. H. Rutland retired from the Council, in accordance with the Articles of Association, and, being eligible, were willing to offer themselves for re-election.

The question of including more work on diamond in the practical examination was considered, and deferred to a subsequent meeting.

Messrs. Watson, Collin & Co. were willing to continue as Auditors to the Association.

HERBERT SMITH LECTURES.

The Council agreed to establish annual lectures, to be known as the Herbert Smith Lectures, as a suitable means of commemorating the great services to gemmology of the late President. It was further agreed that these lectures should be given in March of each year.

TALKS BY MEMBERS

PARRY, Mrs. G. I.: "Precious stones." Cardiff and District Branch of Federation of Soroptimists Clubs, 24th November, 1954 ; *id.* S. Wales Domestic Science Teachers' Association, 9th December, 1954.

BLYTHE, G.: " Gemstones." Crowstone Young Wives' Group, Westcliff-on-Sea, Essex, 28th January, 1955 ; *id.* Benfleet Young Wives' Group, Essex, 1st February, 1955.

SOLOMON, S. T. : "Gemstones." Plymouth City Townswomen's Guild, 21st March, 1955.

LEAK, F. E. : " The Science of Gemmology." Redfield Youth Centre, Bristol, 12th January, 1955.

id. Wives' Comradeship, Tyndall's Baptist Church, Clifton, Bristol, 17th February, 1955.

id. Men's Contact Club, Westbury-on-Trym Baptist Church, Bristol, 18th February, 1955.

id. Companion's Club, St. Mary's Church, Stoke Bishop, Bristol, 26th February, 1955.

id. Townswomen's Guild, Warmley, Glos., 1st April, 1955.

LETTERS TO THE EDITOR

DEAR SIR,

However well-equipped laboratory a gemmologist may have, he sometimes finds it that a method without use of apparatus is a boon. When accurate statements are not necessary and only qualitative proofs are enough, the following method will be found very suitable.

Hold the table-facet of the stone to be tested just near your eye and look through the stone at a lighted clear-glass electric bulb. There will be as many images of the bulb as there are back facets on the stone, and there will be some spectrum in some images. But besides these two common sights, there will be a very interesting thing seen if the vision is fixed on one of the many images. Within the image of the bulb there will be a double image of the incandescent filament. The double image will be distinctly a little apart from each other even in stones like quartz, emerald, corundum, topaz, whose double refraction is low, even though the stone is small—say one carat size. But if the stone is deep-cut and large the doubling is enhanced. In stones like tourmaline, peridot, zircon, the doubling is larger and larger respectively, and the filaments appear far apart from each other.

By practice at home on stones of the gemmologist's collection, the amount of separation of filament-images of individual species can be ascertained.

Stones which do not produce such effects are diamond, spinel, garnet and a few uncommon stones. Paste also does not produce such effect, but it can be easily identified by feeling its low thermal conductivity. A spinel cannot be mistaken for ruby, neither garnet, however fine it may be. Diamond cannot be mistaken for any other stone.

A large faceted bead from a rosary, suspected to be of glass by a devout owner, on account of low price he had paid, was thus tested. Other beads were similarly tested and the rosary was confidently declared to be of rock-crystal, and about four pounds in value. The owner had paid four shillings, for which only glass rosaries are obtainable. The devotee was so pleased. So the feel for heat, colour of the stone and qualitative double refraction by this method will enable a person to identify many stones without much eye-strain and from an easy chair.

Yours faithfully,
J. N. DAVE (India).

DEAR SIR,

A passage in Sir Mortimer Wheeler's " Rome Beyond the Imperial Frontiers " has somewhat puzzled me, and I wonder if any of your readers have an explanation to offer.

Speaking of trade from the Red Sea to India, he quotes from the Periplus of the Erythraean Sea, a geographical treatise of the first century A.D. written in (poor) Greek by a Roman subject living in Egypt. The treatise mentions the pearling industry of the Persian Gulf, but says that the pearls from there were " inferior to those of India ".

If this was so, when did the Indian fisheries along the Malabar coast cease to be of importance, and when did the Persian fisheries first come to be recognized as producing the orient pearl?

Yours faithfully,
JUDITH BANISTER.

London, S.W.15.

ANNUAL MEETING

The 25th Annual General Meeting of the Association was significant for the retirement of Mr. F. H. Knowles-Brown, who has been the Chairman for many years and to whom a presentation was made, and the announcement that an exhibition would be held in Birmingham by the Midlands branch in October.

Mr. Knowles-Brown opened the meeting at the Goldsmiths' Hall on February 24th by welcoming the Chairman of the Midlands branch, Mr. Trevor Solomon, and the Secretary, Mr. King. He said he always felt that annual general meetings, although composed of business, were an important matter in the life of an Association and he was glad that so many had attended despite the bad weather.

Mr. F. E. Lawson Clarke presented the accounts. There was a balance of £380, partly due to the increased subscriptions now payable. These would be needed this year when the Association moved into its new premises. The income tax was up by £264 and there had been a reduction in certain expenses. He thanked the National Association of Goldsmiths for their financial support and the help they had given during the year.

Mr. Knowles-Brown in dealing with the report of the year spoke of the activities of the branches. It had always been an anxiety ot the Council to know what could be done for members who could not easily get to London for meetings. The activities of the local branches gave an opportunity and the Midlands branch had been particularly active.

The annual report and audited accounts for the year ended 31st December, 1954, were adopted.

Sir Lawrence Bragg, F.R.S., was elected President of the Association. In announcing the election, the Chairman said that it was a great honour to have Sir Lawrence accept office again.

Mr. Knowles-Brown said that since the Association was incorporated he had had the honour of being Chairman. It had been a very great pleasure to serve in that capacity but the time had come for him to hand over the office. It had been a pleasure for several reasons. First, the enthusiasm of all the members and he would like to thank them for their support. Secondly, there was the Council over which he had presided. Its members were regular in their attendance and sensible and wise in their deliberations. Thirdly, their secretary and the staff had also always been of the utmost assistance.

" It is therefore a bitter thing to say ' goodbye '," said Mr. Knowles-Brown, " as Chairman, but I can come to the sweet part in announcing that my Vice-Chairman, Sir James Walton, has consented to accept the position. You know of his enthusiasm and I know that I can hand over to him with complete confidence that he will spare no effort in the interests of the Association."

Sir James Walton in accepting the appointment said he had worked with Mr. Knowles-Brown for some time and knew of no better Chairman and he hoped he would receive his help as a member of the Council.

Mr. A. Ross Popley said they regarded Mr. Knowles-Brown as a treasured friend. He had been their Chairman since 1946 and had served on the Council since 1936. He had been a member of the Association for much longer.

As a member of the Council, said Mr. Popley, he had great pleasure in presenting Mr. Knowles-Brown with this gift from his fellow Councillors—a specially bound volume of Kenneth Snowman's book " The Art of Carl Fabergé " —as a tribute to the way he had guided and helped them through the years.

After Mr. Knowles-Brown had returned thanks for this—and later obtained in it the signatures of the Councillors—the meeting went on to elect Mr. Norman Harper of Birmingham as Vice-Chairman, and Mr. Lawson Clarke as honorary treasurer. Mr. Knowles-Brown was also elected to the Council.

Mr. J. Saunders then asked if there were going to be any special events during the year and Mr. T. Solomon said the Midlands branch would hold an exhibition at the Birmingham Museum and Art Gallery on October 11th. It would be opened by the Lord Mayor and continue for a period of three weeks. Mr. Solomon added that he hoped he would be able to get the support of all fellow members in the way of loan specimens.

NEW HOME FOR GEMOLOGICAL INSTITUTE OF AMERICA

Construction is under way on new quarters for the Gemological Institute of America in Los Angeles. The G.I.A. has been serving jewellers throughout the United States, Canada and many other nations for nearly 25 years. Although it maintains the Gem Trade Laboratory and classrooms in New York City and gives classes in Chicago and other cities, the Institute's headquarters have been in Los Angeles from its inception in 1931.

The G.I.A. outgrew its present quarters several years ago and the new structure has been in planning stages during that time. Since 1931 the Institute has grown enormously and shortly after the war the rapid growth of the organisation forced the Institute to use all of the space in the building and to go elsewhere for both office and classroom space.

The new building will have approximately twice as much space for the Institute with room for construction of additional space as required. The site chosen for the new Institute is considerably farther from the centre of the city than the original locations in the Wilshire district.

At the 1954 meeting of the Board of Governors it was decided to choose and purchase a site for the new building and to select an outstanding architect to design facilities which would meet all the unusual requirements of the Gemological Institute. The architect chosen was the famous Richard J. Neutra, author of " Survival through Design " and books on the subject of modern architecture in several languages. The new Institute will be constructed along the modern lines for which Neutra is famous. The building is built in an " L " around a patio facing a parking lot behind the building.

With the building programme under way, the Institute will be able to celebrate its 25th year by moving into a new structure planned specifically for its use.

GIFTS TO THE ASSOCIATION

The Council acknowledges with gratitude the following gifts :—

Die Achate by R. E. Liesgang, for the library, presented by Mr. T. Stern.

A brown diamond crystal, for the gem collection, given by Mr. J. H. Underdown.

MEMBERS' MEETINGS

MIDANDS :

A talk on spinels was given to members of the Midlands Branch of the Association at the Auctioneers' Institute at Birmingham, on 4th February, 1955. The Chairman, Mr. Trevor Solomon, read the paper on behalf of Mr. Neville Deane, F.G.A.

* * *

On March 4th the Midlands Branch held a further meeting at the Auctioneers' Institute and heard Mr. F. E. Goldie talk about " Preparations for an Exhibition ". Mr. Goldie told of a private exhibition he had recently organized and of his experiences in gathering together a unique collection of gemstones. A fine group of Cameos was displayed by the speaker.

* * *

A meeting of the Midlands Branch was also held on 1st April, and details will be recorded in the next issue of the *Journal of Gemmology*.

Mr. Neville Deane's talk given on the 4th February to the Midlands Branch is here recorded:

SPINELS are gem stones which somehow contrive to become overlooked both by gemmologists, jewellers and the general public. It is most unusual to see any piece of jewellery marked as containing spinels, and I have spoken to working jewellers and gem setters who never seem to have heard of the gems.

This paper is not intended to be exhaustive, nor am I an expert on spinels, but is written in the hope that some interesting comments may be contributed by fellow-members to add to the general knowledge.

Spinels may be conveniently divided into natural and synthetic spinels, and first the natural spinels will be dealt with.

Natural gem spinels are mainly considered to be a compound of one molecule of magnesium oxide with one molecule of aluminium oxide, but spinels in general are an isomorphous class of minerals in the same way as garnets, i.e., there can be a replacement of the magnesium oxide or the aluminium oxide by another and similar oxide without altering the crystalline form. Within the gem classification we have a replacement by zinc oxide, producing gahnospinel which has the same crystalline form but higher refractive index and specific gravity. Also some of the magnesia may be replaced by ferrous oxide or manganese oxide, and some of the alumina by chromic oxide or ferric oxide, which replacements have important effects on the colour of the stone. In fact so rarely is colourless natural spinel found, that it may be considered that practically all natural spinels are mixtures and not chemically pure magnesia and alumina.

Obviously excess of admixed elements such as iron may take the spinel out of the gem class, as for example the iron rich Pleonaste or Ceylonite, which become practically opaque, although since they take quite a good polish they may be used for some ornamental purposes.

One of the most interesting of the spinel family which is not of gem quality is an iron ore, magnetite, which occurs in Norway and Sweden and when found in suitable specimens in mediaeval times was known as the Lodestone, used for an early form of compass.

In this mineral, the magnesium oxide has been replaced by ferrous oxide, and the aluminium oxide has been replaced by ferric oxide, so that only one metallic element is present. It is however a typical spinel and occurs as octahedra. When the ferric oxide is partially or wholly replaced by chromic oxide, the mineral becomes chromite, an important ore of chromium and again a spinel. There are also various other mineralogical names according to the replacing elements and the degree of replacement, such as hercynite which is ferrous oxide and aluminium oxide, franklinite which is zinc and manganese oxide combined with ferric oxide, and so on.

If, however, the magnesium oxide is replaced by beryllium oxide as in chrysoberyl, and partially in taaffeite, the crystal is no longer of the cubic or isometric system, but becomes orthorhombic in the case of chrysoberyl and hexagonal in the case of taafeite and so these minerals are not true spinels although they are related to them by composition.

Spinels seem to be regarded as rather common stones, somewhat in the same class as amethysts and citrines, but actually the sources of supply are quite limited, being mainly from the Ceylon gem gravels, as more or less water-worn pebbles, or from Burma where they are found in conjunction with rubies often as quite good octahedra. A few originate in Siam. A former source, although probably not available at present, was Afghanistan and another minor source was the U.S.A., in New York State and Montana.

The distribution is therefore very limited indeed and this is what might be expected from their composition, which is wholly basic, containing no silica and therefore most unlikely to be found in the more acid rocks containing much silica. In fact the most usual sources of gem spinels are crystalline limestones, that is, limestones which have been exposed to heat under the earth thus allowing the constituent parts to crystallize or the gravels which have resulted from their decomposition. Spinel also occurs in some basic and ultra-basic igneous rocks.

Spinel belongs to the cubic system, and the most common form is the octahedron, very similar to the diamond, but the shapes are much deformed, and in many cases it would be hard to identify the spinel by its crystalline form. It is in fact rather a matter for surprise that the Singalese can so often accurately pick out the spinels from the gravel, rather than that they sometimes make mistakes. I have myself found a couple of small purple corundums amongst a parcel of small rough spinels, but these were quite indistinguishable until, after cutting, the usual method of polishing spinels with ruby powder on a tin lap made no impression on them and they were polished with diamond dust instead. After cutting and polishing they could of course, be readily detected by means of the refractive index.

Spinels occur in a variety of colours, but on the whole, the colours might be called " subdued ". The richest colours are undoubtedly the brighter reds but these hardly reach the richness of colour of the best rubies, though they can equal or even surpass the colour of the pale Ceylon rubies or pink sapphires. As to other colours, there are rather cold blues, various mixtures of blue and red resulting in shades of purple and amethyst, greenish-blues and rather dark greens. Sometimes the colours are so dark that the rough stones might be considered black, and it is very difficult to know whether to cut them or not. Perhaps a hollow cabochon similar to a garnet might yield useful results, although personally I have not tried it as yet. There are reports of yellow and colourless spinels, but these are undoubtedly rare in spite of the fact that the chemical combination of pure magnesia and alumina is colourless. A pale lavender-colour is fairly common and the nearest to colourless that occurs freely. Various names have been used such as ruby-spinel, balas ruby, rubicelle, almandine spinel, sapphirine and chlorospinel, but they are better discarded.

A peculiar feature of the coloration is the appearance of two-coloured rough stones, i.e., a stone with a blue centre and a pinkish outside rim, or a dark greenish blue centre with a lighter blue rim or a pink rim. The appearance is fairly characteristic, not at all like the abrupt colour change in tourmaline, or the straight bars of colour in corundum, but a much more delicate effect, rather like an internal halo. Some of the rough stones shown display the effect in daylight although possibly not in artificial light. It is very difficult to capture the two colours in a cut stone as the lighter coloured outer rim is nearly always lost in cutting.

The different colours of the gem are ascribed to different metallic elements. Red is due to chromium, the yellowish-red tints to iron, and manganese may be the cause of some of the violet colours; blue is ascribed to iron, whilst copper has been referred to, perhaps incorrectly, as the cause of some greens. Zinc in gahnospinels, which are blue, apparently does not affect the colour. Quite a number of varieties of stones may be improved by heat-treating which will often change an unpleasant colour to a more pleasant one or make a too dark tint to a more usable lighter tint, but so far I have not heard of, or found any way of changing the colour of spinel with the means at my disposal.

Spinels quite often exist as twinned crystals in a shape so characteristic that it is called the spinel twin, a form of contact twinning, and these twinned crystals are often flattened and might easily be mistaken for hexagonal ruby crystals, unless the presence of the re-entrant angles is noticed. The twin is formed as if the crystal had been cut in half parallel to a face of the octahedron and one half had been turned round 180°.

The spinels which come near to ruby in colour have been called " balas rubies " in the past, although it is a term which should be discarded. The name may be derived from Balascia, now Badakshan, in Afghanistan, from where good spinels were derived in mediaeval times. Two stones which are commonly called rubies, and are of great historic interest, are actually " Balas rubies " or spinels. One is the Black Prince's Ruby in the Imperial State Crown, of which the first mention is in 1367 when it formed part of the treasure of the King of Granada, was seized by Pedro, King of Castile and given by him to the Black Prince. Henry V wore the stone in his coroneted helmet at Agincourt. During the Commonwealth the Crown Jewels were ordered to be sold and included in the inventory was the Black Prince's Ruby valued at £4 only.

The stone eventually turned up again in Charles II's reign, since in his crown there is a position which because of its peculiar shape could only have been intended for the Black Prince's Ruby. This stone is of great antiquity. I learn that the exact weight is not known as it is mounted in a very old gold setting which is not to be removed from the stone, and therefore the stone and setting are mounted together in the Imperial State Crown. However the weight is computed at 170 carats. The stone is not faceted but polished in the rough octahedral shape, as can be seen in the picture of the Imperial State Crown, and the shape is irregular, the length being nearly two inches. The colour is very rich.

The Timur Ruby is probably one of the largest spinels that is known and has engraved on it the names of Mogul and Persian Emperors. In 1912 it was in the possession of Queen Mary. The weight is 361 carats.

This splendid but rather dark red spinel, which also is not faceted, has a history dating back at least to 1398 when it came into the possession of Timur, or Tamerlane as he is more commonly known to Europeans, at the capture of Delhi. From him it passed into the possession of various Mogul and Persian Emperors, some of whom had their names engraved thereon ; some of these inscriptions were subsequently erased. Eventually it reached Lahore and remained there until the annexation of the Punjab in 1849, when together with the other State jewels it came into the possession of the East India Company. It was exhibited at the Great Exhibition in 1851. There does not seem to be any photograph or illustration of the Timur Ruby extant.

Probably in early days it was assumed that these stones were true rubies, but their real nature has been known for a very long time. It is evident therefore, that these representatives of the spinel family have had a long and honoured history. It is quite possible that some smaller cut spinels still may go under the description of rubies. Birmingham Art Gallery is said to have a good collection of spinels, but when I personally have visited the galleries they have not been on exhibition.

A striking justification of the science of gemmology was the detection of the spinel which was not a spinel by Count Taaffe of Ireland in November, 1945, reported in April, 1951. Whilst examining some spinels by means of a binocular microscope he noticed that one of a pale mauve colour showed a small but distinct doubling of the back facets. Since spinel belongs to the cubic system and has only single refraction, this, if correct, could only point to the stone being something other than a spinel, in spite of the constants of specific gravity and refractive index being within the spinel range. He sent the stone to the Laboratory at London, and it was in fact confirmed that the stone was doubly refractive and therefore was not a spinel, and the question was as to what it could be, as no known doubly refractive stone had these constants. From a small portion taken from the pavilion it was found that by composition the stone, instead of being a magnesium aluminate, was in fact a magnesium beryllium aluminate and belonged to the hexagonal system.

So far, one other specimen has turned up and from careful measurements the birefringence has been established at .0041, which is small but distinct. The second stone was slightly deeper in colour than the first. I have seen this stone in the Minerals section of the British Museum (Natural History).

Naturally these discoveries led to a scrutiny of available spinels, and personally I examined my small stock by means of the microscope between crossed polaroids to try to find some double refraction. I did in fact find one which showed a slight lightening of the darkness on revolution of the stone, and in great hopes sent this to Mr. R. Webster to see what he had to say about it. He very kindly did examine it, but, alas, stated that the appearance between crossed polaroids was an anomalous double refraction caused by strain, due to included crystallites in the stone, so it was just a spinel and not a taaffeite.

However, one can always hope, and so I try to examine any spinels I acquire, particularly light coloured ones, and as far as possible any rough spinels, to see if by good chance a taaffeite should turn up. Since only two specimens are known—although doubtless there are others unknown—the value of the stones is problematical and could hardly be commercially assessed. One wonders what would be the value of the stones, if only two diamonds were known!

Spinel is a hard stone—hardness 8—about the same as topaz, and therefore a good wearing stone. It has something of a reputation for being brittle, although personally I have not found this to be pronounced. Spinel has no definite cleavage planes, and being singly refractive, it has no dichroism and the stones may be cut in any convenient direction without the careful orientation necessary in some varieties of stones. As regards cutting they are fairly easy and the stones can be rough-ground preferably on a diamond grinding wheel, with no risk of starting flaws on cleavage planes or through local overheating. The facets cut crisply and clean on a diamond-charged bronze lap, and may be polished readily on a pure tin lap with " ruby powder ," without much risk of scratches appearing. If these should occur on the larger or table facets, the use of a lead-tin alloy lap—softer than pure tin—will usually solve the problem.

The specific gravity of gem-quality spinel is about 3.60, varying from 3.58 to 3.63 but in the types rich in zinc the specific gravity may reach 3.98, whilst in the opaque varieties such as ceylonite rich in iron, it may be 4.0 and in the mineral gahnite (zinc aluminate) it varies from 4.0 to 4.6.

The refractive index is also variable, being round about 1.72. The lowest R.I. is 1.715 and most natural gem spinels are below 1.72, but in red spinel the R.I. may rise to 1.735 according to chromium content and in blue spinel to 1.747 according to zinc content. Consequently the R.I. test will not show conclusively whether a spinel is natural or synthetic, although the majority of natural gem spinels are at or below 1.72 and synthetics above 1.72, but these figures are only a kind of guide and must be confirmed by other means.

Some red spinels exhibit fluorescence under ultra-violet light; the lighter reds show this effect to the best advantage. The darker and duller reds show more of a dull red fluorescence, disappearing as the purple-tinted stones are tested. The study of fluorescence has been dealt with very fully and ably recently in articles in the *Gemmologist* by Messrs. B. W. Anderson, C. J. Payne and R. Webster and is a very technical subject. Briefly, the fluorescence is due to five bright lines in the red portion of the spectrum of which the two strongest form a pair. Although the red fluorescence appears much the same as that of ruby to the unaided eye, the lines producing it are not of the same wave-length.

Spinels also exhibit absorption spectra, which vary, as might be expected, according to the colour. Red spinels which owe their colour to chromium show bands in the red portion and a blotting out of part of the green and yellow, but red spinels which owe their colour mainly to other elements than chromium do not fluoresce and do not show the bands in the red.

Blue spinel which contains iron, shows an absorption spectrum which may contain as many as ten bands, of which a strong band in the blue portion is very persistent and is visible in stones with only 2% of iron oxide.

Spinel has a colour dispersion of .020. This figure is not large and in natural coloured spinels has little visible effect, but in synthetic colourless spinel it does make a very bright and lively stone (much more so than colourless corundum, which has a dispersion of .018) and coupled with the hardness makes a very useful stone for articles of jewellery for which the cost of diamonds would be prohibitive and yet which are required to be more permanent and also more valuable than paste jewellery.

Synthetic spinels, as is commonly known, are produced by the inverted blowpipe method (Verneuil method) and this material, besides being commercially useful, is of great scientific interest. In nature spinels consist of equal parts of magnesia and alumina, but the synthetic can contain one molecule of magnesia to four molecules of alumina. The effect of this change is to vary the specific gravity from 3.58 to 3.62 and the refractive index from 1.719 to 1.728.

Natural spinel belongs to the cubic system but corundum, consisting of alumina, belongs to the hexagonal system. It would appear therefore that synthetic spinels with 80% of alumina ought to be hexagonal rather than cubic, but in fact this is not so, and many boules show quite a pronounced square shape indicative of the cubic system. It has now been discovered that alumina can assume in a certain modification a cubic structure, but usually this is not stable at ordinary temperatures, whereas evidently when combined with 20% of magnesia it can so retain the cubic structure at ordinary temperatures. Obviously, however, the synthetic spinels do not quite belong to the same class as the natural spinels in spite of their seeming similarity of properties.

Synthetic spinels are not as a rule made in colours the same as the natural; in fact it is not easy to make a synthetic red spinel. I believe the usual colour obtained by the addition of chromium is a green rather than a red, and it is only comparatively recently that a pink or red colour has been achieved. The usual colours are colourless or white, blue in various different shades and greens of a rather dark tint. A yellow colour is also made.

The blue colours are due to the addition of cobalt. It was due to the attempt to colour synthetic corundum by means of cobalt to imitate sapphire, and the failure to obtain a good distribution of colour without the addition of magnesia to the alumina that the synthetic spinel was first made, since the addition of magnesia lowered the hardness from 9 to 8 and changed the crystalline structure from hexagonal to cubic and the refraction from double to single refraction, i.e. the result was a spinel and not a sapphire.

Most of the blue colours are named as resembling aquamarine, of which they are a fair imitation. However, natural aquamarines are dichroic, the colours being blue and a greenish blue, whereas the synthetic blue spinel is not dichroic, and a packet of the natural stones has a subtly different appearance from a packet of synthetic stones. The darker blue colours have a very rich appearance, not like any natural stone. If they are sold for what they are, and the buyer knows the material and likes the appearance and the price; there is no harm in them. They are of course much harder and more durable than pastes, and therefore more suitable for use in jewellery, provided no attempt is made to sell them as natural gem stones.

The green colours that I have seen are not particularly meritorious, one being more of a dark green, sometimes referred to as tourmaline green. The other green is termed "emerald green", which can only be called very unconvincing.

The yellow colours may imitate chrysoberyl and the pinks may imitate topaz, tourmaline or rose-coloured beryl (morganite).

The absorption spectrum of the synthetic blue spinels is that due to cobalt, three heavy broad bands in the orange yellow and green, and these stones can be readily distinguished from aquamarines by examination through a Chelsea filter, under which the true aquamarines appear green, whereas synthetic blue spinels appear red in the darker colours to orange in the paler colours.

The appearance of the synthetic spinels under the long wave ultra-violet lamp is most interesting and attractive. Whereas the natural red spinels fluoresce red, the blue stones do not fluoresce, the presence of iron as colouring matter acting as an inhibitor of fluorescence. The blue synthetic stones fluoresce red of various tints since here the colouring matter is not iron but cobalt. The rather pale yellow synthetic fluoresces a very beautiful apple-green and the pale greens fluoresce darker green colours, again in distinction from the natural stones. In fact so beautiful are the fluorescent colours that synthetic spinels might well be used as " stage jewellery " for scenes where fluorescent effects are wanted; which the writer has seen in aquatic events.

So far no mention has been made of inclusions, and possibly these are not of so great importance as in some other stones.

Perhaps the most typical inclusions are small octahedral crystals. In the synthetic spinels, the inclusions, where present, are usually gas bubbles, but the stones are often extremely clean, and, whereas the presence of gas bubbles is an aid to identification, their absence may not indicate a natural stone.