Taaffeite, a new beryllium mineral, found as a cut gemstone.[1]

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In October 1945 Count Taaffe,[2] a brilliant if unorthodox Dublin gemmologist, in the course of examining a motley collection of gemstones, came across a small mauve stone which puzzled him greatly. The stone had the appearance, and most of the characters, of spinel, but afforded clear evidence of double refraction. As recounted below, this stone was later found to belong to an entirely new mineral species—the only case hitherto known where a mineral has been first encountered as a faceted gem.

Since the precise circumstances of such a discovery have both human and technical interest, it seemed best to obtain from Count Taaffe his own account of the event. This is accordingly given below before proceeding to the more formal presentation of the data on the new mineral, which has been named taaffeite in honour of its discoverer.

> On one of my rounds in search of gems I came to Mr. Robert Dobbie, watchmaker and working jeweller in Fleet Street, Dublin; he allowed me in his genial way to go through all his boxes in which he kept stones, to pick out any that were real—most of them were glass—and to make him an offer for them. He only needed the pastes for jobbing. That was one day in October 1945. I started right away in his workshop where he had cleared part of his bench and I sorted out what looked like stones, one by one. Most of the stones and pastes were crudely divided according to colour. The pastes were mostly new, but the stones were without exception broken out of jewellery, badly rubbed or chipped in many cases. They had been in the workshop since the times of Mr. Robert Dobbie's father, some for twenty years.

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[1] Preliminary accounts appeared in Nature, London, 1951, vol. 167, p. 438; Gemmologist, 1951, vol. 20, pp. 75–77 (p. 76, 'Taaffeite', Anderson); Journ. Gemmology, 1951, vol. 3, pp. 75–77. [M.A. 11-309.]

[2] Count Edward Charles Richard Taaffe, born in Bohemia 1898, only son of late Henry, Count Taaffe (12th Viscount Taaffe of Corran, Baron of Ballymote, Co. Sligo) and of Magda, Countess Taaffe.

I found there blue zircons, opals, garnets (even demantoids), citrines, amethysts, spinels, very few Siam rubies, some poor emeralds and sapphires, in fact stones of the usual mixture as they accumulate with working jewellers—their origin as manifold as their appearance. After several hours I showed Mr. Dobbie what I had selected so far; maybe there were 50 or 100 stones. I paid and arranged to continue the next day, and took the 'bag' home. I continued till I had gone through every stone in the house; it took two or three days I think. The total purchase price was £14; it was very easy to come to terms with Mr. Dobbie.

Now, at home, I washed the stones, which were very dirty, and started sorting them and testing each one of them, because I am always afraid of a wrong identification if I go only by appearance. First I sorted according to colour. The taaffeite was put into the little box containing violet and lilac stones; then viewed under my Bausch and Lomb binocular Greenough microscope, without stage, on white paper, with illumination from above, using a flexible table-lamp with tin reflector, ordinary 100-watt bulb with a flexible lens-holder as condenser. Magnification is 21 × (objective 1·4 ×, ocular 15 ×). Holding each stone in tweezers, and viewing it under different angles and from several sides, I look for double refraction and evidence of the stone's identity, e.g., cracks in the surface on opposite 'poles' denoting corundum, &c. Mind you, I do that with every stone, and only in the rarest cases have I to apply other methods to see whether the stone is doubly refractive or not. One of the stones in which I can sometimes not detect double refraction is topaz; I do not understand why. I have to twist and twist and look into every facet until I can see it. But not so with the taaffeite. In a certain direction every speck of dust on the back and every scratch appeared double like on a badly wobbled snapshot.

Next step: specific gravity. Sinking in bromoform. Sinking in methylene iodide, but more slowly than corundum. Clerici solution was unobtainable then. My only balance was a pocket diamond balance which I had to hold by the tassel. As B. W. Anderson taught me in his book 'Gem testing', I determined the S.G. by hydrostatic weighing in water, holding the tassel and repeating the observation ten times. The average of ten results was 3·62.

Facets were scarcely visible in methylene iodide, so I gathered that the refractive index was near spinel. Refractometer not obtainable. But the double refraction? I checked it with crossed nicols and got normal extinction at 90 degrees. I became puzzled. I could see no bands in the spectrum. The two spectroscopes I had at the time were not very good and the lighting system quite inadequate. I panicked, sent the stone to B. W. Anderson at the Laboratory of the London Chamber of Commerce, and begged for help. I wrote on November 1 1945: 'This time a new riddle: what is this mauve stone? It seems to me to answer all characteristics of spinel, yet it shows double refraction: doubling of facets visible under the Greenough, extinction when polarized, though with queer colour effects. Could anomalous double refraction be so strong? R.I. too high for topaz, S.G. too low for corundum. What is it?'

B. W. Anderson replied on November 5: 'You have sent a *most* interesting stone in that mauve spinel (*I* call it that on the basis of its absorption spectrum: my colleague is so horrified at its anomalous optics that he doubts whether it is spinel). The indices are 1·717 and 1·721, clear double refraction, giving a clear uniaxial interference figure through the table facet. The stone is so remarkable that I should like your permission to have an X-ray analysis made, if possible without harming the stone. I should also like to write it up for the Gemmologist, giving full credit to you for discovering it. Would you agree?'

Optical and density determinations (B. W. A. and C. J. P.).

It will be seen from the above account how an acute, experienced, and painstaking observer can obtain most of the data needed to identify gemstones with the simplest of apparatus; even without the aid of a refractometer, which is rightly regarded as 'essential' by most gemmologists.

The mauve-coloured stone when it arrived weighed 1·419 carats. Its shape suggested that probably it had been cut in Ceylon. The refractive indices given in the first reply to Taaffe were not quite accurate. A little later quite good readings for the ordinary ray were obtained by the minimum deviation method using a prism angle (provided by the facets) of 48°. The indices were determined for lithium (6708 Å.) light and for Fraunhofer's g line (4226 Å.), as well as for sodium light, in order to measure the dispersion of the stone. The results were:

λ . .	6708	5893	4226Å.
ω . .	1·7191	1·7230	1·7390

This gave a Li–g dispersion figure of 0·0199, corresponding to approximately 0·019 (for the standard B–G range). This compares quite closely with the dispersion of spinel, which is 0·0205 to 0·0207 for stones having a refractive index of 1·715 for sodium light.[1] Later still, an opportunity arose to measure both refractive indices on a Zeiss Abbe-Pulfrich refractometer, which gave the following figures: ω 1·7230, ϵ 1·7182, $\omega-\epsilon$ 0·00475.

The density, as determined by hydrostatic weighing in ethylene dibromide, was measured as 3·621 at 15° C. Later, a more accurate estimate was achieved by finding blue spinel pebbles which matched the taaffeite closely in density as evidenced by their behaviour in Clerici solution. These were of sufficient size to enable reliable determinations to be made by hydrostatic weighing in ethylene dibromide. By choosing one specimen which was slightly denser and the other slightly less dense than the taaffeite, limiting values were obtained. On the basis of these experiments $3{\cdot}613\pm0{\cdot}002$ emerges as the most probable figure.

The absorption spectrum was very weak, but bore a distinct resemblance to that of blue spinel, particularly two weak bands in the green at 5530 and 5580 Å., corresponding bands in spinel being 5520 and 5570 Å., which is within the limits of error for such diffuse bands. The strongest bands in blue spinel, a broad absorption centred near 4590 Å. and a narrower band at 4800 Å. are replaced by a very weak narrowish

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[1] B. W. Anderson and C. J. Payne, Min. Mag., 1937, vol. 24, p. 548.

band at about 4750 and a diffuse region centred near 4600 Å. Recently, a photograph taken on a small diffraction grating spectograph revealed the unexpected presence of a narrow and fairly intense band in the near ultra-violet at approximately 3820 Å., entirely absent in a corresponding spectrogram of blue spinel.

To enable X-ray and chemical work to be carried out, Count Taaffe generously assented to portions of the stone being removed. It will be realized that this was a crucial business since at that time there was only this one specimen of the mineral known. The work was skilfully carried out by Charles Mathews (Lapidaries) Ltd., in two stages, reducing the stone first to 0·95 carat, and then 0·56 carat which is its present weight. The stone was refaceted and polished in order to preserve its appearance as an attractive gemstone.

A summary of the properties of Taaffe's original specimen can now be given:

ϵ.	ω.	$\omega-\epsilon$.	Density.	Hardness.
1·7182	1·7230	0·00475	3·613	8

It was not until October 1949 that a second specimen was found. This stone weighed 0·87 carat and was of a very pale mauve colour, in fact it was almost colourless. The stone was sent to the Laboratory in Hatton Garden together with a hundred other stones in a case (presumably belonging to a collector). They were sent in to be tested in the ordinary way of business by a Hatton Garden merchant. Not much information about the origin of the stones could be gleaned from the nature of the collection. It was obvious that none of the stones had been cut in Asia: though not very well cut or polished they had regular facets and were all symmetrical in styles which are included in the general term 'mixed cut'. The collection consisted mostly of green sapphires, though one of them was found to be a Ceylon kornerupine (Ceylon was probably also the source of the sapphires), and spinels many of which were small, pale-coloured stones. These spinels were very typical, having n_D 1·715. They were tested on a refractometer which was in a bad condition, as owing to external circumstances no other instrument was available at the time. One stone, however, had n_D 1·721 or 1·720: it was impossible to see birefringence owing to the small and badly polished table facet and the worn surface of the refractometer glass. It did, however, show a uniaxial negative interference figure of a size which suggested a small birefringence. The tester (C. J. P.) then realized that he had found a second taaffeite. The birefringence was confirmed when other refractometers were available, and finally the stone was sent to a lapidary to have the table facet enlarged, well polished, and truly plane. More elaborate optical work was done and the stone was found to have the following properties:

ϵ.	ω.	$\omega - \epsilon$.	Density.	Hardness.
1·7167	1·7208	0·00412	3·60	8

It was confirmed by X-ray analysis that this stone was of the same species as that of Count Taaffe.

The hardness of the first taaffeite was cautiously tested by trying its edge against polished surfaces of quartz and topaz, and was found to be nearly equal to the latter. On the second specimen, confirmation of this was kindly provided by Dr. W. Stern of the Diamond Information Bureau, who carried out micro-indentation tests with a double cone indenter, and found the hardness of taaffeite by this method to be slightly greater than natural spinel and slightly less than synthetic spinel, when these were tested at the same time and under the same conditions.

Before passing on to a discussion of the composition and structure of the mineral, there is one more property that may be mentioned: its luminescence. Under ultra-violet radiation of both 2536 Å. and 3650 Å. the stones remained inert; but under X-rays both showed a distinct green fluorescence. In Taaffe's stone this was not nearly so brilliant as in the second stone, presumably due to the presence of rather more iron in its composition, to which the enhancement in colour, density, and refractive indices may also reasonably be ascribed. The X-ray luminescence might provide a rapid test for the mineral were it not that spinel of similar appearance gives an almost identical green glow under the rays.

X-ray determinations (G. F. C.) and chemical analysis (M. H. H.).

A preliminary examination by X-ray methods was made of Count Taaffe's stone as originally submitted for testing; this confirmed the optical indications that it could not be spinel. It was therefore decided to make a more detailed study and for this a small portion sawn from the region of the culet was used. The fragment so obtained was lightly crushed in a diamond mortar and one of the resulting smaller fragments powdered and photographed. The measurements obtained (table I and fig. 1A) were used to search for comparable data in the literature and in the British Museum records of unpublished X-ray photographs. No such data were traced. The powder spacings were subsequently indexed by first determining the *l* indices by the superposition of a powder photograph upon a *c*-axis rotation photograph taken in the same camera and

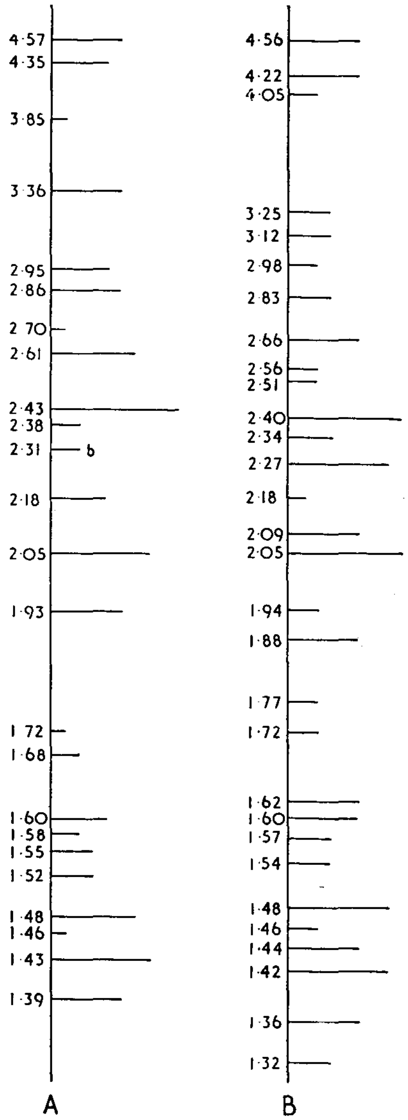

FIG. 1. Spacing-intensity plots of X-ray powder data of: (A) taaffeite. (B) artificial compound presumed to be $MgO.BeO.2Al_2O_3$ (H. F. McMurdie in R. F. Geller et al., 1946).

The *d*-spacings are plotted as reciprocals and their approximate values in Ångström units are given against each line, the length of which is an indication of intensity. b = broad.

then determining the remaining indices by reference to the appropriate Bunn chart. A second chip was set up to rotate about the optic (*c*) axis and a rotation photograph in this position gave a lattice spacing

TABLE I. Powder data for taaffeite. (Film no. X 3559b.)

hkil.	*I.*	*d.*
0004	m	4·57
$10\bar{1}2$	mw	4·35
$10\bar{1}3$	vvw	3·85
$10\bar{1}4$	m	3·36
$10\bar{1}5$	mw	2·95
$11\bar{2}0$	m	2·86
$11\bar{2}2$	vvw	2·70
$10\bar{1}6$	ms	2·61
$11\bar{2}4$	vvs	2·43
$20\bar{2}2$	vw	2·38
$20\bar{2}3$ $10\bar{1}7$	vwb	2·31
$20\bar{2}4$	mw	2·18
$20\bar{2}5$	s	2·05
$20\bar{2}6$	m	1·925
$20\bar{2}8$	vvw	1·720
$21\bar{3}5$	vw	1·684
$21\bar{3}6$	mw	1·596
$20\bar{2}9$	vw	1·576
$30\bar{3}4$	w	1·554
$21\bar{3}7$	w	1·522
$2.0.\bar{2}.10$	ms	1·476
	vvw	1·455
$22\bar{4}0$	s	1·428
$2.0.\bar{2}.11$	m	1·387

Strongest lines 2·43, 2·05, 1·43.

6 cm. diam. camera, Cu-$K\alpha$ (λ = 1·542Å.) radiation.

Intensity scale in decreasing order: vvs, vs, s, ms, m, mw, w, vw, vvw; b, broad.

along the axis of 18·38 Å. The chip was then set up by trial about another axis normal to the first (and subsequently found to be *b*) and a Laue photograph taken along the optic axial direction. The dihexagonal (6*mm*) symmetry of this is clearly seen in fig. 2, and serves to distinguish the mineral from spinel, the only possible comparable axis of which is ditrigonal. Measurement of the *b* rotation and sets of oscillation photographs about *b* and *c* axes gave *a* 5·72 Å. The diffraction symmetry from the Laue and oscillation photographs is 6/*mmm*, and this, together with the absence of all odd orders of (000*l*), leads to the unequivocal space-group D_6^6 — $C6_32$. The axial ratio *c*/*a* is 3·21.

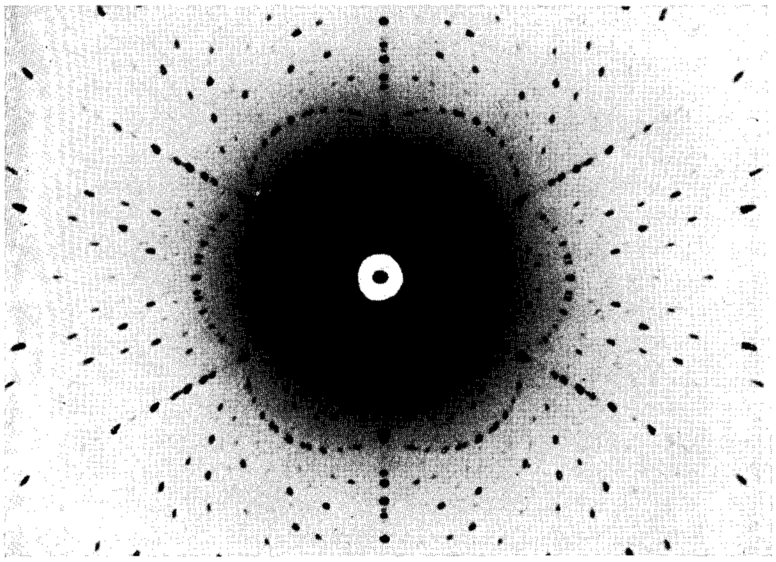

FIG. 2. X-ray Laue photograph of taaffeite along the optic (*c*) axis. Crystal plate distance 3·5 cm. Tungsten radiation.

Still another small chip was used to obtain a spectrogram in which the following elements were detected: Mg, Al, Be.

For the microchemical analysis reported below further pieces totalling about 12 mg. had been cut from the original stone. About half of this material was used for a preliminary run and the remaining 6·16 mg. for the analysis proper.

The atomic contents of the unit cell are derived from the analysis and cell dimensions (*a* 5·72 Å., *c* 18·38 Å.) with the observed density of 3·613.

The iron is assumed to be all ferric because there is an excess of divalent ions without it; the colour of the mineral is also appropriate to ferric ions.

TABLE II. Microchemical analysis and unit-cell contents of taaffeite.

Al_2O_3	70·0	Al	15·6	16·4
Fe_2O_3	5·9	Fe'''	0·8	
MgO	13·4	Mg	3·8	8·8
BeO	11·0	Be	5·0	
Analyst, M. H. Hey	100·3	O	33·4	

The figure for beryllia is thought to be somewhat high. Owing to the small amount of material analysed, the unit-cell content can only be approximate and the cell formula is given in whole numbers. Taaffeite, in which some aluminium is replaced by ferric iron, may thus be regarded as intermediate between spinel and chrysoberyl and have the ideal formula $Be_4Mg_4Al_{16}O_{32}$; it appears to be the only known mineral having both essential Be and Mg.

Assuming an approximately close-packed oxygen framework for the structure it is evident from a consideration of the cell dimensions that this framework will be built of eight close-packed oxygen sheets in hexagonal (i.e., ABAB) stacking, the distance between the centres of adjacent sheets being 18·38/8 = 2·30 Å. The distance between centres of adjacent oxygens in the sheets is found from the *a* lattice-dimension to be 5·72/2 = 2·86 Å. These figures agree closely with the corresponding dimensions for spinel[1] in which the oxygen sheets in cubic (i.e., ABCABC) stacking are 2·32 kX apart and the atoms within the sheets 2·85 kX between centres. As might be expected therefore the two structures appear to be closely related, with the hexagonal axis of taaffeite corresponding to a trigonal axis of spinel. A more detailed examination of the structure of taaffeite is in progress.

The stone found by Payne in 1949 was checked by taking a randomly oriented rotation photograph through the tip of the pavilion and superposing it on the powder photograph of Taaffe's stone.

We are indebted to Dr. J. B. Nelson for drawing our attention to the description of an artificial compound of the same essential composition and having closely related physical properties.[2] The published X-ray powder spacings for this substance stated to be 'diffraction data from patterns for the dominant phase in compositions $MgO.BeO.2Al_2O_3$ and $MgO.2BeO.2Al_2O_3$' are not, however, in good agreement with those for taaffeite although they show a rough resemblance (fig. 1B).

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[1] W. L. Bragg, The atomic structure of minerals. 1937, p. 94. [M.A. **7**-7.]

[2] R. F. Geller, P. J. Yavorsky, B. L. Steierman, and A. S. Creamer. Journal of Research of the National Bureau of Standards, 1946, vol. 36, pp. 277–312 (Research Paper R.P. 1703). [M.A. **11**-369.]