
A STUDY OF THE GENERAL ELECTRIC SYNTHETIC JADEITE

By Kurt Nassau and James E. Shigley

The gemological properties of synthetic green and lavender jadeite, which has been manufactured by the General Electric Company on an experimental basis, are summarized. The synthetic jadeites examined appear as flattened or rounded disks that have indices of refraction of about 1.66 and specific gravities of 3.28–3.34. They are also similar in many other respects to natural jadeites, except for a slightly greater hardness (7½–8) and differences in luster, translucency, and appearance. The synthetic jadeites are the result of an experimental study, and at present there are no plans for commercial production.

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In examining the prospects for the future of synthetic gemstones, Nassau (1980) noted that "Another field providing scope for further work is that of the polycrystalline materials. . . . With their toughness derived from tiny interlocking crystals . . . the jades should provide interesting preparation problems to the materials scientist." We now know that at that time R. C. DeVries and J. F. Fleischer, of the General Electric (G.E.) Research Center in Schenectady, New York, had already completed the bulk of their research on the synthesis of jadeite by a high-pressure technique, although this work was not published until 1984 (DeVries and Fleischer, 1984 a and b).

In the course of their experiments, DeVries and Fleischer produced white, various shades of green to black, and lavender jadeite, in cylindrical pieces up to 12 mm in diameter and 3 mm thick (figure 1). Although this product can be considered gem material, it does not match the highly translucent, almost transparent, quality of what is known in the trade as "Imperial" jadeite. Both total synthesis, as well as reconstruction of crushed natural jadeite with additional colorants added, were used to produce uniform as well as mottled and layered structures. It appears that at present the General Electric Company has no intent to continue this research or to market a synthetic jadeite. A brief preliminary description of this material was provided by Pough (1985).

The following report describes the synthesis experiments and, on the basis of the authors' examination of a set of samples obtained courtesy of Dr. DeVries, presents a comprehensive gemological description of this synthetic jadeite.

THE JADEITE "PROBLEM"

Jadeite is one of the pyroxene "single-chain" silicates, with ideal composition $\text{NaAlSi}_2\text{O}_6$ (Deer et al., 1978). Both jadeite and the amphibole mineral nephrite are called *jade*.



Figure 1. These nine synthetic jadeites manufactured by the General Electric Company were examined by the authors. The sample numbers of the jadeites, starting at the top row and proceeding left to right, are as follows: 7, 6; 9, 3, 1; 4, 8, 5; 2. The pieces range from 0.68 ct to 2.46 ct in weight. Photo © Tino Hammid.

The two kinds of jade consist of aggregates of tiny interlocking crystals. In the case of nephrite, these microscopic crystals are long and fibrous, whereas in jadeite they are more prismatic or platy (Zoltai, 1981). In both cases, the crystals themselves are not particularly hard ($5\frac{1}{2}$ to 7 on the Mohs scale), but in their compacted, interlocked arrangement they are collectively extremely tough. This intricate network of tiny crystals is responsible for the great toughness and excellent polishing quality of both types of jade (see Bradt et al., 1973). Like nephrite, jadeite is found in a range of colors, and has been used extensively for carvings and other ornamental purposes (for further details, see Hobbs, 1982; Webster, 1983).

Early attempts to synthesize jadeite in the laboratory have been summarized by Yoder (1950). According to Roy and Tuttle (1956), L. Coes (Norton Company) may have been the first to achieve success, in 1953.

Jadeite cannot be synthesized at atmospheric pressure, since it decomposes into a mixture of the minerals nepheline and albite when heated (see Bell and Roseboom, 1969). Pressure is required to maintain the stability of jadeite at elevated temperatures. As shown in figure 2, based on several studies as summarized in Deer et al. (1978), a pressure of about 28 kilobars at about 1330°C (and higher pressures at higher temperatures) is required so that jadeite melts without prior decomposition. Equally important, such conditions are also required for a melt of jadeite composition to form crystalline jadeite without the presence of any other phases.

To prepare a mixture of the correct composition for high-temperature studies of jadeite, it has been customary to mix the ingredients (e.g., $\text{Al}_2\text{O}_3 + \text{Na}_2\text{CO}_3 + 4\text{SiO}_2$) and melt the mixture at a high temperature in air. Typically, this is done at 1550°C in a platinum crucible. The CO_2 is released and the result on cooling is a glass of jadeite composition. The crystallization of such a glass at high temperature and pressure then readily produces synthetic crystalline jadeite, although this had previously been done only with very tiny

Figure 2. Temperature-pressure relations of jadeite, showing the stability fields of jadeite and other phase assemblages in this compositional range (after Bell and Roseboom, 1969).

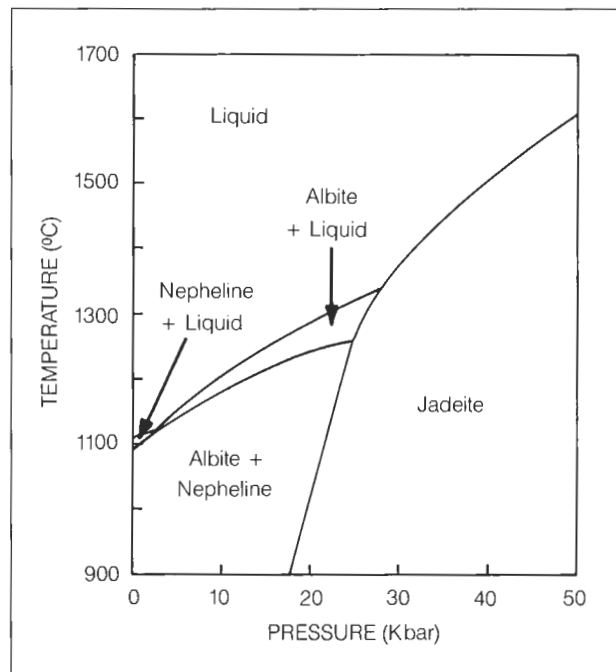




Figure 3. In this photograph of the high-pressure apparatus used to synthesize jadeite, R.C. DeVries is loading a sample into the apparatus while J.F. Fleischer looks on. Photo courtesy of the General Electric Company.

specimens, for example, by Williams and Kennedy (1970).

THE GENERAL ELECTRIC EXPERIMENT

In the latter of the two descriptive accounts published by DeVries and Fleischer (1984 a and b) on their synthetic-jadeite experiments, they provide tabulated data giving the 61 compositions used and some details of the 189 high-pressure synthesis experiments.* These data indicate that the work was begun in 1974, not long after G.E. accomplished the production of gem-quality synthetic diamonds (see, e.g., Nassau, 1980), and that it was basically completed in 1979. The final 14 high-pressure experiments, involving five compositions, were performed between 1979 and 1982.

According to DeVries and Fleischer (1984 a and b), three major types of starting material were used in the G.E. experiment. Most of the starting materials were glass, prepared as described above, but subjected to several crushing and remelting steps to achieve a high level of homogeneity; these were found to be the best type of starting material and were the ones used to produce the samples examined here. The G.E. researchers also performed some experiments using crushed white or gray natural jadeite, sometimes with colorants added. This method has the advantage that there is

no significant volume change on crystallization as there is with glass, but the overall results were not as good. Finally, some compositions were prepared by a sol-gel method (Sakka, 1982) to improve homogeneity, but there were no particular benefits in the final product. Exact compositional data on the starting materials used to produce the group of synthetic jadeites examined herein are not available.

In the absence of color-active impurities, the synthetic jadeite produced was white. Colorants used included chromium as Cr_2O_3 , which gave the typical light to dark green jadeite colors when present in the 0.5 to 2.0 wt.% range, but produced black at higher concentrations. Manganese, best added in the form of Mn_2O_3 as 1.5 to 3 mol.%, gave medium to dark purple (lavender) colors. Titanium added as TiO_2 at similar concentrations provided a measure of whiteness (rather than gray) and translucency. Additional impurities tried included erbium, europium, iron, nickel, samarium, uranium, and vanadium, as oxides, as well as some combinations, such as iron with chromium and iron with vanadium. However, the results usually were either not reproducible or provided no improvement over the use of chromium or manganese alone.

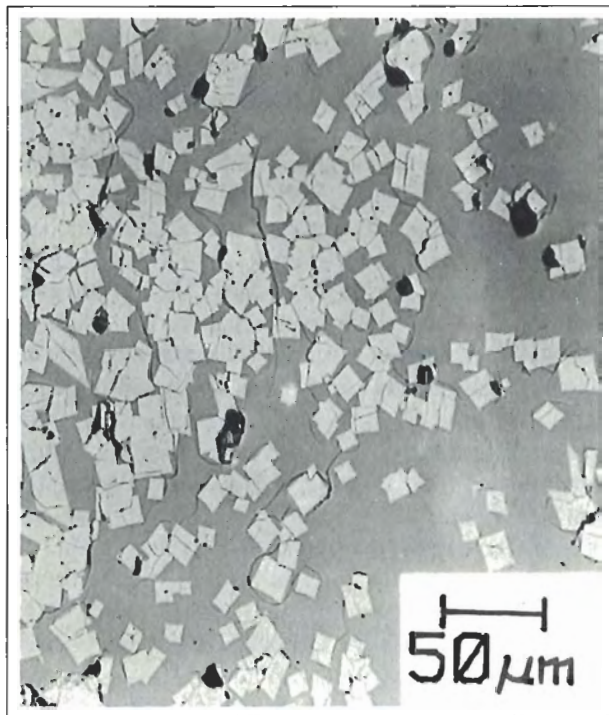
The high-pressure experiments were carried out in a belt apparatus (for details, see Nassau, 1980) within a graphite heater (figure 3). Processing was performed for one-half to 24 hours at 30 to 50 kilobars pressure and 1200° to 1400°C; values

* Please note that there are a number of typographical errors in this report, some of which are not obvious.

near the higher end of all of these ranges gave the better results. Finally, the temperature was reduced before the pressure was released in the manner normally used to preserve the high-pressure equilibrium phases. Crystallization occurred at the high pressure and temperature, possibly with some strain recrystallization as described above. Figure 4 shows jadeite crystals grown in a glass taken from an experimental run that was quenched by cooling prior to complete crystallization.

The experimental product, consisting of flat or rounded circular disks up to 12 mm across and 3 mm thick (figure 5), was principally jadeite as determined on the basis of X-ray and optical characterization by the G.E. researchers. The sizes and shapes obtained were limited by the apparatus used. Given the known high-pressure technology, there is little doubt that uniform pieces up to the size of a 10-mm cube and even larger could be

Figure 4. This photomicrograph shows euhedral synthetic jadeite crystals that have grown in a glass. The glass sample was removed from an experimental run that had been quenched to room temperature prior to complete crystallization of the glass. Photo courtesy of the General Electric Company.



produced if large tetrahedral or cubic presses were used (Nassau, 1980). One problem also probably avoided by the use of these alternative configuration presses would be the laminar structure often observed, which is caused by the uniaxial pressure present in a belt-type apparatus.

A variety of other problems were noted by the G.E. researchers, including the frequent occurrence of a residual glassy phase. Again, there is little doubt that with a suitable development effort, should one wish to market synthetic jadeite, such problems could be solved. General knowledge of high-pressure technology suggests that a price on the order of \$100 per disk would be feasible, with a significant reduction for larger-scale production.

GEMOLOGICAL PROPERTIES

We examined nine specimens of synthetic jadeite (figure 1), seven of which range from medium light green to dark grayish green, with the remaining two medium and dark purple. Three are rounded "cabochons" and six are flat disks; all are approximately 5–10 mm in diameter. The cabochons range up to 3 mm thick, and the flat disks are approximately 1 mm thick.

The color of natural jadeites can vary greatly in terms of hue, saturation, tone, and uniformity of appearance. The synthetic jadeites correspond closely to natural jadeites in many of these respects, and thus color provides little assistance as a distinguishing feature. However, the synthetic lavender jadeites and some of the synthetic green jadeites do have a more intense color than is commonly seen in natural jadeites. In addition, the color of the synthetic lavender jadeites is quite mottled, and appears to be concentrated in distinct areas. One of the synthetic jadeite disks also exhibits aventurescence, which is caused by the reflection of light from numerous tiny grains (figure 6).

All of the synthetic jadeites are semitranslucent to almost opaque, with a deep green or purple color being visible when the green and purple samples, respectively, are placed over a strong light source. Polished samples of the synthetic jadeite exhibit a vitreous luster and an appearance exactly like that of natural jadeites. We were not permitted to prepare optical thin sections of the synthetic jadeite for examination with the microscope, so features such as the nature of the granular texture, aventurescence, and the sometimes irregular color



Figure 5. The crushed glass on the left was used as starting material in some of the synthesis experiments, and is shown here with one of the synthetic jadeite disks that resulted. Photo courtesy of the General Electric Company.

distribution could not be investigated further; nor could we cut the samples for use in preparing spectrophotometric absorption curves. However, the infrared reflectance spectra of the synthetic jadeites (DeVries and Fleischer, unpublished data) agree with those of natural jadeites.

The nine specimens were examined using standard gemological methods and instruments. The measured gemological properties for all of the synthetic jadeites are tabulated in table 1 along with values for natural jadeites. The values for most of the physical properties are very similar to those reported for natural jadeites. However, the synthetic jadeites were all found to have a somewhat greater hardness ($7\frac{1}{2}$ –8, as measured using hardness points) than natural jadeites (7). The cause of this difference is not known, but it may be due to the size, degree of compaction, or orientation of the jadeite grains themselves, or it may be a result of the method of synthesis employed in these experiments that gave rise to the pronounced lamellar structure. For the synthetic jadeites, we attribute the somewhat lower density values measured by the hydrostatic method, as compared to those obtained by the heavy liquid method (both measured in repeated trials), to the fact that the flat shape, light weight, and small size of the disks leads to greater buoyancy, to the trapping of air bubbles along surface cracks and irregularities, and to the lesser wetting characteristics of water as compared to those of the immersion oil (meth-

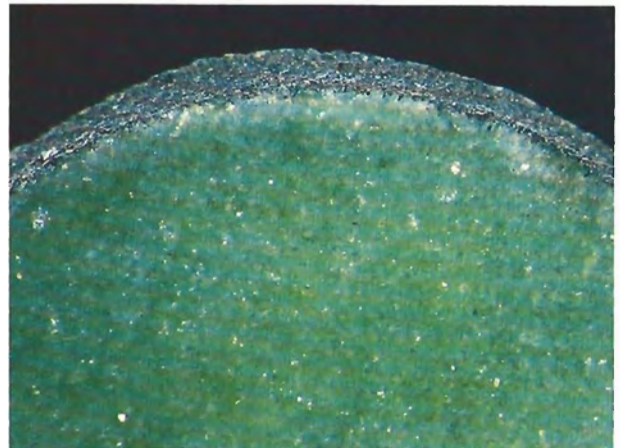


Figure 6. The upper surface of this synthetic jadeite disk (no. 6) shows granular texture, mottled color distribution, and an aventurine-like appearance caused by light reflecting from numerous tiny grains. In contrast to the other samples, this disk has a black rim; it has probably not yet been cleaned. Reflected light, magnified $20\times$. Photomicrograph by John Koivula.

ylene iodide diluted as needed with benzyl benzoate) used as the heavy liquid.

Natural green jadeites exhibit a range of behavior when exposed to ultraviolet radiation. Our own observations indicate that they can either be inert or fluoresce in various colors (366 nm long-wave—yellow, yellowish green, or yellowish white; 254 nm short-wave—yellow, orangy yellow, orange). The intensity of this fluorescence varies greatly from extremely weak to moderate, and it can have a “chalky” or an uneven, mottled appearance. The synthetic green jadeites vary from inert to weak in their fluorescence (see table 1), and the fluorescence is often visible either at the edges or at the center of a disk, perhaps related to the textural difference described below. This range of behavior falls within the fluorescence range observed in natural green jadeites, and thus is not a distinguishing feature.

Natural lavender jadeites also vary in their reaction to ultraviolet radiation. If the color of the jadeite is mottled, so is the fluorescence. The fluorescence ranges from very weak to strong in intensity, and may occur in many colors (366 nm long-wave—grayish white, yellowish white, violetish white, reddish orange, orange; 254 nm short-wave—yellowish white, greenish white, reddish orange, orange). Again, the color is often “chalky.”

In contrast, the two synthetic lavender jadeites displayed only weak fluorescence, but they exhibited small distinct spots of brighter orange fluorescence. Because only a few synthetic jadeites were available for study, it is difficult to assess the significance of these observations. In general, though, it does not appear that natural jadeites can be distinguished from the synthetic stones on the basis of their fluorescence behavior.

Observations with the Microscope. Each of the synthetic jadeite samples was examined with the microscope in transmitted and in reflected light. The three "cabochons" (nos. 4, 5, and 8) appear to have been partly polished, but the flat disks have surfaces that vary from rough to rather smooth. All of the samples display a granular texture, especially along their outer edges and along broken areas (figure 7). Even on flat or semi-polished areas, this granular texture was apparent from slight differences in surface luster, in the appearance of

vague grain outlines, and in minor variations in surface relief suggesting hardness differences. Some of the synthetic jadeites exhibit a "dimpled" surface caused by a slight undercutting during polishing. Broken edges display no evidence of cleavage but represent irregular fracture surfaces. The rims of many of the disk-shaped specimens are lighter and more grayish in color, which is caused either by a compositional inhomogeneity or, more likely, by textural differences, since the rim areas are highly fractured (figure 8).

One of the more interesting observations concerns the pronounced lamellar structure present in most of the disks. When viewed along their edges, the disks exhibit numerous, parallel fractures that give the material a distinct layered appearance (figure 9). Around the edge of a disk or cabochon, there frequently is some breakage of the outermost layers (figure 10). It is likely that this layered (or delaminated) structure of the synthetic jadeite is related to the method of synthesis under uniaxial

TABLE 1. Gemological properties of natural and nine General Electric synthetic jadeites.

Property	Natural jadeite		Synthetic jadeite				
	Deer et al. (1978) ^a	Webster (1983) ^a	1	2	3	4	5
Shape	—	—	Disk	Disk	Disk	Cabochon	Cabochon
Diameter (mm)	—	—	9.5	9.4	10.6	10.3	5.7
Thickness (mm)	—	—	2.4	1.2	0.9	2.5	3.0
Weight (ct)	—	—	2.21	1.17	1.31	2.46	0.68
Color	— ^c	— ^c	Dk. grayish ^d green	Dk. green	Med. green	Med. dk. green	Med. green
Color description ^b	—	—	—	vsbG 6/2	G 5/2	vsbG 5/2	G 5/2
ColorMaster reading	—	—	—	C 2/29/7	C 7/73/16	C 6/74/21	C 7/73/16
Hardness (Mohs scale)	6	7	8	7½	8	7½–8	7½–8
Refractive index							
α	1.640–1.681						
β	1.645–1.684	1.66	1.653	1.652	1.654	1.655	1.655
γ	1.652–1.692						
Specific gravity							
Heavy liquid (3.32)	—	3.30–3.36	3.34	3.34	3.31	3.34	3.28
Hydrostatic	3.24–3.43	—	3.31	3.27	3.25	3.28	3.28
Fluorescence							
Long-wave UV	— ^c	— ^c	Inert	Inert	Ex. wk. greenish at edges	Ex. wk. greenish at edges	Ex. wk. greenish at edges
Short-wave UV	— ^c	— ^c	Inert	Inert	Ex. wk. chalky orange	Ex. wk. chalky orange	Ex. wk. chalky orange
X-ray	—	Yellowish white	None	None	None	None	None

^a Compilation of data.

^b Color description terminology taken from the GIA Colored Stone Grading System; colors for sample nos. 1 and 7 do not fall within the system.

^c See discussion in the text.

^d Abbreviations: dk. = dark, med. = medium, lt. = light, ex. = extremely, wk. = weak, v. = very, mod. = moderate, st. = strong.

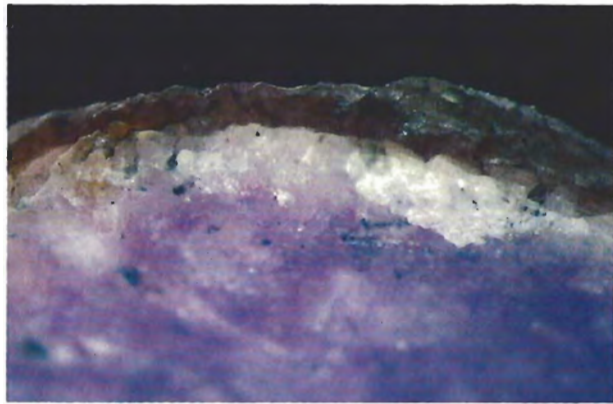


Figure 7. The edge of one of the synthetic jadeite disks (no. 9) shows granular texture along with the irregular surface and fracture. Also note the blotchy color that is typical of these synthetic jadeite samples and the presence of small black grains of unknown identity. Reflected light, magnified 25 \times . Photomicrograph by John Koivula.

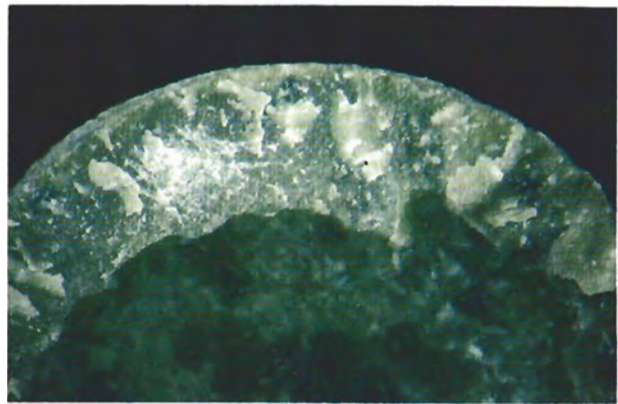


Figure 8. The rim area of this jadeite disk (no. 2) illustrates the fractured lighter-colored edge evident on most of the synthetic jadeites examined. Reflected light, magnified 15 \times . Photomicrograph by John Koivula.

Synthetic jadeite			
6	7	8	9
Disk	Disk	Cabochon	Disk
11.1	10.8	7.3	9.3
1.7	1.5	1.6	1.1
2.11	2.08	0.70	1.14
Med. lt. green	Dk. grayish green	Med. purple	Med. dk. purple
G 5/2	—	bP 5/1	V 5/2
C 7/73/16	—	C 14/45/52	C 14/44/74
8	7 $\frac{1}{2}$ -8	7 $\frac{1}{2}$ -8	7 $\frac{1}{2}$ -8
1.65	1.655	1.65	1.655
3.33	3.34	3.28	3.32
3.27	3.29	3.22	3.24
V. wk. yellowish green	Inert	Wk. reddish orange	Reddish orange with orange spots
Ex. wk. chalky orange	Inert	V. wk. reddish orange	Wk. reddish orange
None	None	St. yellow	Mod. yellow

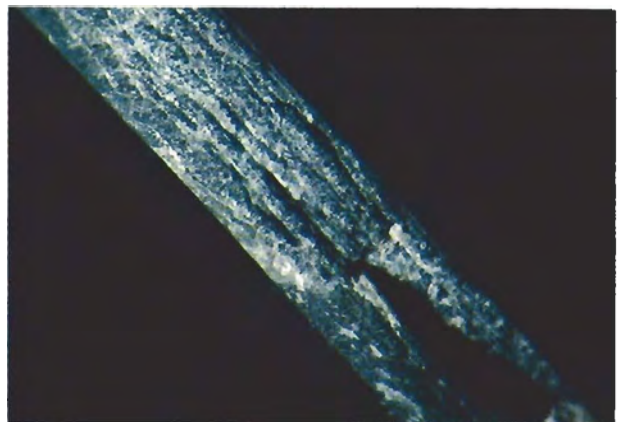


Figure 9. This view of the edge of one of the synthetic jadeite disks (no. 7) shows numerous fractures that run parallel to the upper and lower surfaces of the disk. Reflected light, magnified 25 \times . Photomicrograph by John Koivula.

pressure and, as discussed earlier, could probably be avoided.

Chemistry. Chemical compositions of the synthetic jadeites were obtained by electron microprobe analysis. Table 2 summarizes the chemical compositions of two representative specimens. These analyses are consistent with reported data on the chemistry of natural jadeite with the exception of the greater amounts of manganese in the synthetic lavender samples and the absence of



Figure 10. This view of the upper surface of one of the synthetic jadeite cabochons (no. 4) shows the broken edges of several of the thin layers that make up the material. Reflected light, magnified 20×. Photomicrograph by John Koivula.

magnesium and calcium in both the synthetic green and lavender samples. Minor differences in concentrations of the color-causing transition elements (Fe, Cr, Mn) give rise to the variations in color among the samples. Further chemical analysis by X-ray fluorescence (XRF) confirmed the presence of the major elements shown in table 2 and also indicated the presence of trace amounts of zirconium, nickel, zinc, tin, and strontium in almost all of the synthetic jadeites. The reason for the presence of these trace elements is uncertain, but their presence does provide a good indication of synthetic origin and thus distinguishes these specific samples from natural jadeites.

Spectroscopy. Viewed with a hand spectroscope and transmitted illumination, the synthetic green samples exhibit general absorption from 400 to 500 nm, a narrow region of transmission from about 500 to 600 nm, and then absorption from 600 to 700 nm. The degree of absorption in these two regions increases as the synthetic jadeites become more blackish green in color. In some instances, the green samples exhibit three absorption bands, at about 630, 655, and 690 nm, which vary in intensity from one sample to the next. These three bands are also present in natural deep green jadeites. However, the sharp band at 437 nm typically observed in the spectrum of any translucent color of natural jadeite (except for some darker green natural jadeites, in which the 437 nm band is masked by general absorption in this region of the

spectrum) was not seen in the spectrum of any of the synthetic jadeites. While the darker green natural jadeites are colored by chromium, the principal coloring agent of most natural green jadeites is iron (Rossman, 1974). In natural jadeite, iron gives rise to the 437 nm band and to weaker bands at 573 and 610 nm, while chromium is responsible for the 630, 655, and 690 nm bands. Because of its high content, chromium appears to be responsible for the green color in the synthetic jadeites. An exception is sample no. 6, which does not show the 437 nm iron line despite a high iron content. No features in the spectra of the synthetic jadeites could be attributed to iron.

There is little written in the gemological literature on the spectra of lavender jadeites. The absorption spectrum of a natural lavender jadeite shown in Rossman (1974) has a sharp band at 437 nm that is due to iron, and a very broad, prominent band at 573 nm which is responsible for the lavender color. Rossman attributed this latter band to a mechanism involving $Fe^{2+}-Fe^{3+}$ intervalence charge transfer. In the hand spectra of both the synthetic lavender jadeites, in contrast, there is a broad absorption band from approximately 530 to 630 nm but no other features. The low iron content but high manganese content of these two samples suggests that manganese is the likely cause of this broad band in synthetic lavender jadeite.

TABLE 2. Chemical data on natural and G.E. synthetic jadeites.

Oxide	Natural green ^a	G.E. synthetic green (no. 3) ^b	Natural lavender ^a	G.E. synthetic lavender (no. 8) ^b
SiO ₂	59.65	60.2	60.40	59.3
TiO ₂	0.02	ND ^c	0.07	ND
Al ₂ O ₃	24.07	25.3	24.22	23.5
FeO	0.63	— ^d	0.43	—
MnO	0.02	ND	ND	2.0
MgO	0.71	ND	0.66	ND
CaO	1.08	ND	1.02	ND
Na ₂ O	14.01	14.9	13.83	15.2
K ₂ O	NR ^c	ND	NR	ND
Cr ₂ O ₃	0.01	0.5	ND	ND
Total	100.20	100.9	100.63	100.0

^a Data taken from Rossman (1974) for jadeite samples from Burma. Average of two electron microprobe analyses. Fe₂O₃ value recast as FeO.

^b Average of three electron microprobe analyses of two representative samples of the G.E. synthetic jadeite. Total iron as FeO. Analyst C. M. Stockton.

^c NR = not reported, ND = not detected.

^d Presence detected by energy-dispersive X-ray fluorescence. Analyst C. M. Stockton.

X-Ray Diffraction Analyses. Unit-cell parameters for one representative specimen (no. 4) were determined by least-squares refinement of d-spacing values measured from an X-ray powder diffraction film. Refinement of 23 measured values yielded the following parameters: $a = 9.434(6)$, $b = 8.565(5)$, $c = 5.227(3)\text{\AA}$, $\beta = 107.67(6)\text{\AA}$. These values are very close to the unit-cell parameters of natural jadeite (see Prewitt and Burnham, 1966).

CONCLUSIONS

Given the published details of these experiments, anyone with access to high-pressure equipment could probably produce synthetic jadeite. Several characteristics should permit the distinction of a product made by this process from natural jadeite. These include differences in texture and appearance as well as the greater hardness of the synthetic stones. The more intense and often mottled color of the synthetic jadeites may also be helpful. There are no significant differences in indices of refraction, absorption spectra, fluorescence, or specific gravity. Note also that the observed cracking and delamination caused by the uniaxial pressure in the belt-type synthesis apparatus can probably be avoided by the use of a tetrahedral or cubic high-pressure apparatus; thus, the absence of these features is not necessarily diagnostic.

The successful synthesis of jadeite raises the question of whether the other "jade" mineral, nephrite—a "double-chain" silicate with the ideal composition $\text{Ca}_2(\text{Mg}, \text{Fe}^{2+})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$ —could be similarly synthesized. Amphiboles have been grown in the laboratory under pressure (Gilbert et al., 1982), the aim, however, being to produce single crystals as opposed to a polycrystalline jade structure. We suspect that such a synthesis would be feasible, but it would be complicated by the need to have only ferrous iron and the difficulty of achieving a set hydroxyl content. In view of the lower value usually attributed to nephrite as compared to jadeite, a commercial synthesis would be even less likely.

It should be emphasized that the synthetic jadeite described in this report is an experimental product and is not likely to be encountered on a commercial basis. We do not know whether similar materials of improved appearance will be synthesized in the future, but it seems unlikely given the cost of the synthesis process versus the ready availability of natural jadeite for gemological purposes. Any such commercial product prepared and grown under different conditions could, of

course, have somewhat different characteristics. The General Electric experiments do, however, demonstrate that the understanding and technology exist to synthesize polycrystalline gem materials such as jadeite in the laboratory. Although G.E. has not applied for a patent on the synthetic jadeite, an essentially identical process has been patented in Japan by the Suwa Seikosha Co., Ltd. (1985).

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