XV. " Researches on Emeralds and Beryls.—Part I. On the Colouring-matter of the Emerald." By GREVILLE WILLIAMS, F.R.S.   Received May 9, 1873.

A considerable amount of discussion has taken place at various times regarding the cause of the colour of the emerald.   Klaproth concluded from his earlier analyses that it was due to iron*; but the results of his later experiments †, made after he became aware of Vauquelin's discovery of the presence of chromium in emeralds ‡, confirmed the observations of that chemist.

From the time of Vauquelin's analyses, the colour of the emerald was always regarded as due to the presence of oxide of chromium, until the publication of the memoir of Lewy §, who, having burnt emeralds in oxygen in a similar apparatus to that employed by M. Dumas in his researches on the atomic weight of carbon, ascertained that they contained that element, and concluded that the colour was due to the presence of some organic substance.   Lewy also affirmed that the deepest-tinted emeralds contained the most carbon.   The small quantity of chromium contained in emeralds he considered to be insufficient to account for the colour.   Wöhler and Rose ||, on the other hand, having exposed emeralds to a temperature equal to the fusing-point of copper for one hour without their losing colour, and also having fused colourless glass with minute quantities of oxide of chromium and obtained a fine green glass, considered chromium and not organic matter to be the cause of the colour.

Boussingault ¶, in the course of an investigation of the " morallons " **, arrived at the same conclusion as Wöhler and Rose ; and although admitting them to contain carbon, denied that it was the cause of their colour, inasmuch as they endured heating to redness for one hour without loss of colour.   This result has been confirmed by Hofmeister ††, who found that an emerald endured a red heat for hours without destruction of the colour, except at the edges, and concludes this small bleaching to arise from the destruction of the crystalline character of the stone.   I have carefully repeated and extended these experiments.   The emeralds employed were canutillos from Santa Fé de Bogota ; they were kindly given to me by Professor Church.   The following values were obtained in a determination of their specific gravity :—

* Klaproth, Chem. Essays, vol. i. p. 325 (London, 1801).
† Klaproth, *loc. cit.* vol. ii. p. 172 *et seq.* (1804).
‡ Vauquelin, Ann. de Chim. vol. xxvi. [1] p. 262 (1798).
§ Comptes Rendus, vol. xlv. p. 877 (1857).
|| Chem. News, vol. x. p. 22.
¶ Comptes Rendus, vol. lxix. p. 1249 (1869).
** The emeralds from the mines of New Granada are divided, according to Boussingault, into classes, two of the most important being the " canutillos," or finely crystallized, and the " morallons," or amorphous emeralds.
†† Journ. für prakt. Chem. vol. lxxvi. p. 1 (1859).

Specific gravity of Emeralds (Canulillos) before fusion.

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	4·4964	2·8293	16·5	·998921	2·69
II.	4·4961	2·8294	17·0	·998841	2·69
III.	1·6655	1·0486	16·0	·999002	2·70

The formula used was

$$D = \rho t\, \frac{W}{W - W'},$$

where

W   is the weight in air,
W' the weight in water,
ρt the specific gravity of water at $t°$,
t the temperature of the water,
D   the specific gravity.

One of the above emeralds was exposed for three hours in a platinum crucible to a bright reddish-yellow heat. At the end of the operation it was rendered opaque on the edges, but the green colour was not destroyed. This experiment completely confirms those of Wöhler and Rose and Hofmeister. It is, I think, quite evident that no organic colouring-matter could withstand such a temperature for so long a time. The announcement by Lewy that the depth of colour of emeralds is in proportion to the amount of carbon present, made it at first appear improbable that colourless opaque beryls would contain any of that element. The power of the colouring-matter to resist a red heat having, however, made me inclined to disconnect the question of the colour from that of the presence of carbon, I made experiments to determine whether beryls contained that element, and, if so, to what amount. An experiment was made at this stage of the inquiry (see p. 414), the result of which showed that the beryl analyzed* contained the same amount of carbon as Lewy's emerald. As it was just possible that the small increase in weight of the potash-tubes used by Lewy, Boussingault, and myself, in determining the carbon, might not have been really due to the absorption of carbonic anhydride, but to some volatile inorganic acid produced on heating the emeralds and beryls to redness in an atmosphere of oxygen, I felt it necessary to settle this question definitely. With this intention I burnt 1·2 grm. of beryl A in a platinum boat in a current of oxygen. The water produced was received in a U-tube filled with fragments of asbestos moistened with sulphuric acid. The carbonic anhydride was received in a Geissler's potash-

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* As this beryl will be repeatedly alluded to in this paper, and especially in the second part, I shall, for convenience of reference, call it "beryl A." It was found in Ireland.

tube containing lime-water; this form of potash-tube was employed in this and the other experiments to be described further on, as it enables the operator to see whether the carbonic anhydride is all absorbed in the first bulb. The carefully purified oxygen was allowed to stream through the lime-water for half an hour to prove its freedom from carbonic anhydride. At the end of that time there was no trace of turbidity. The beryl was then heated to redness, and in a few seconds the lime-water in the first bulb of the potash-apparatus became milky. Thus not only proving the presence of carbon in a colourless beryl, but, taken in conjunction with the quantitative determinations, showing conclusively that the depth of colour is not, in this class of stones, in the ratio of the amount of carbon present.

But although demonstration had been obtained of the presence of carbon in the beryl A, it was still possible that it might have been derived from the decomposition of a carbonate. To settle this question, I arranged an apparatus in the following manner:—

A current of air from a gas-holder was sent in the direction indicated by the arrow (see p. 413); it passed through a solution of potassium hydrate in A and B. The three-necked bottle C contained lime-water, freshly prepared and perfectly clear. The current of air then passed into the three-necked flask D, containing 3 grms. of beryl A, finely levigated in an agate mortar, and covered to about one inch with pure distilled water. The flask E was empty, and served to arrest any thing which might have spirted over. The potash-apparatus F was filled to the height indicated with lime-water. The pipette G contained concentrated sulphuric acid. The arrangement being complete, a current of air was sent through for half an hour; not the slightest turbidity was found in C or F; the air was consequently free from carbonic anhydride. Its freedom from any other substance containing carbon had been previously determined by sending it mixed with oxygen, first into a red-hot combustion-tube, and then into a previously weighed potash-apparatus. After passage of the gas for half an hour, the potash-apparatus was reweighed and found to be absolutely unaltered. The purity of the air employed having thus been rigorously ascertained, the stopcock of the pipette G was turned, and sulphuric acid admitted into D until the water in the latter had become very hot; still no turbidity was observed in F. The fluid in D was then boiled with the same result. It was evident, therefore, that the carbon found in the beryl was not derived from the decomposition of a carbonate. The stopper at H was then removed, and about 4 grms. of pure recently fused acid chromate of potassium were added; there was still no turbidity observed in F for twenty minutes, during all which time the fluid in D was gently boiled. At the end of this time a cloudiness began to appear in the first bulb of F, and after half an hour in the second bulb: finally, a decided precipitate was obtained; it was collected, washed, and on analysis proved to be carbonate of calcium. The expe-

riment was repeated in a modified manner several times. It having been found that a faint turbidity in the lime-water was sometimes obtained before the addition of the beryl, it was traced to the presence of minute quantities of organic matter in the chromate and sulphuric acid. To eliminate this source of error, the chromate and acid were mixed at the commencement of the operation, and the current of air was kept up until every trace of carbonic anhydride was removed; at this point the beryl was added, and the effect noted. The results, both with emeralds or the beryl A, were, however, always precisely the same.

The apparatus was then recharged, and when half an hour's passage of the air produced no milkiness in F, 5 milligrammes of charcoal were introduced into D; in two minutes the first bulb, and in four minutes all the bulbs were rendered milky.

In another experiment, after the usual precautions, 5 milligrammes of graphite were acted on. In four minutes the first bulb, and in eight minutes all three bulbs were rendered milky.

The above experiments show, therefore, that the beryl A contains carbon, not in the state of a carbonate, but in a condition which is more slowly attacked than either free charcoal or graphite; and it is, I think, probably in the form of diamond, as has been shown to occur with the carbon contained in artificially crystallized boron[*]. The power of free chromic acid to attack the diamond with liberation of carbonic acid has been shown by the Messrs. Rodgers[†].

The presence of carbon in beryls does not appear to be invariable. After repeated experiments upon another large beryl from Haddam County, North America, I was unable to satisfy myself that it contained carbon. It is true that traces were found in the experiment; but they were so minute that they might have been due to the difficulty of entirely excluding the presence of organic dust during the necessary manipulations[‡].

The next point I wished to ascertain was the relation borne by the quantity of carbon in the beryl A to that in the emerald. For this purpose I employed a similar apparatus to that used by Dumas in his researches on the atomic weight of carbon previously alluded to. The minute error due to the apparatus was carefully determined by going through the whole process of heating the combustion-tube to redness for the same time as in the analysis, the current of oxygen passing through at the same speed, and finally replacing the oxygen in the system of tubes by a current of pure dry air. No appreciable error was found to affect

[*] Wöhler and Sainte-Claire Deville, Comptes Rendus, February 16, 1857.

[†] R. E. Rodgers and W. B. Rodgers, Chem. Gaz. vol. vi. p. 356 (1848).

[‡] Since the above paragraphs were written, an interesting paper has been published by Prof. Silliman, " On the Probable Existence of Microscopic Diamonds with Zircons and Topaz in the Sands of Hydraulic Washings in California," Chem. News, vol. xxvii. p. 212.
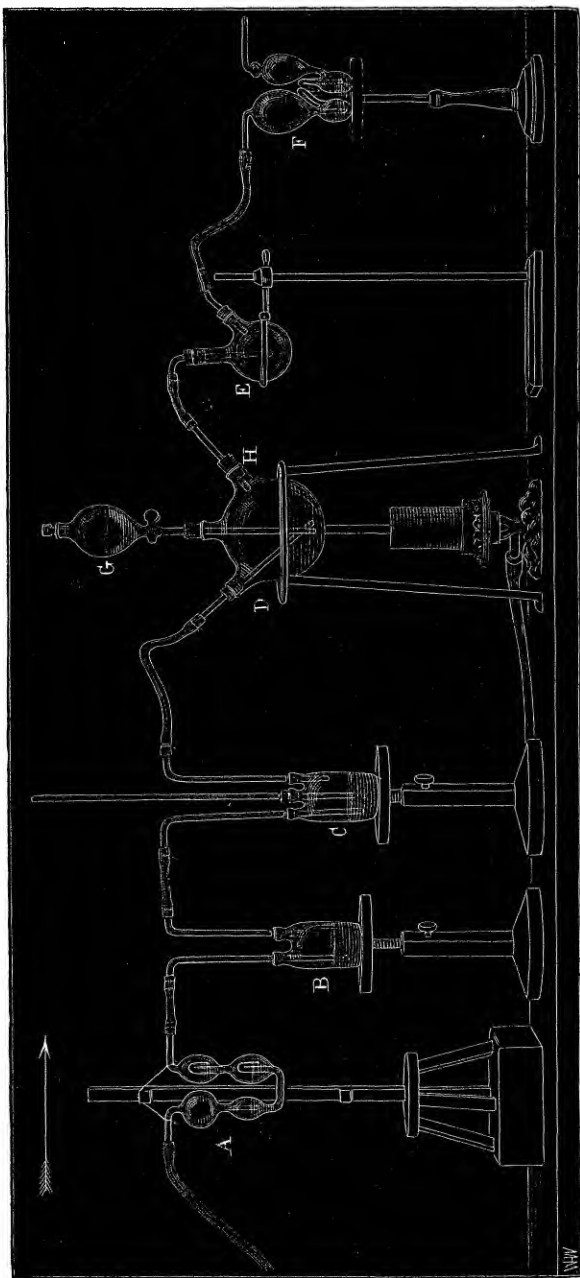
the carbon determination, but a correction had to be applied to the hydrogen. The necessity for minute precaution will be evident when it is considered that 1 grm. of beryl A, or emerald, only yielded 3 milligrammes of carbonic anhydride.

Estimation of Carbon and Hydrogen in Peruvian Emerald and Beryl A.

   I. 0·9725 grm. beryl A gave 0·0030 carbonic anhydride and 0·0131 water.
  II. 1·0082 ,,   ,,   ,, 0·0031   ,,   ,,   0·0174 ,,
 III. 1·1690 ,, emerald ,, 0·0030   ,,   ,,   0·0140 ,,

or, per cent.:—

	Beryl A.		Emerald.	Lewy's Emerald (mean).
	I.	II.		
Carbonic anhydride	0·31	0·31	0·26	0·28
Water	1·35	1·73	1·20	1·89

In working on such minute quantities, it is not easy to speak with certainty as to the proportion of hydrogen contained in emeralds and beryls which is not due to the water present; and the difficulty is increased by the fact, insisted upon by Boussingault[*], that these stones do not give off all their water below a red heat. If it be considered permissible, which I cannot admit, to calculate the hydrogen on the principle of deducting the water found on ignition in a crucible from that formed during the combustion in oxygen, and then calculating the percentage of hydrogen on the difference, as Lewy has done, the results would be as follows:—

	Beryl A.		Emerald.	Lewy's Emerald (mean).
	I.	II.		
Carbon.............................	0·08	0·08	0·07	0·08
Hydrogen	0·06	0·11		0·04

The smallness of the values obtained, and even the very fact of their close approximation, make me offer them with a certain amount of reserve, and I shall endeavour to repeat them upon much larger quantities as soon as I have found a method of avoiding all possible sources of error.

I have not inserted the numbers given by Boussingault, as there appears to be some mistake in them. He found 0·24 per cent. of carbon in the morallons, and yet says that this number agrees with two of Lewy's determinations, one of which (he says) gave 0·21, and another 0·25 ; whereas I find, on reference to Lewy's memoir, that that chemist obtained in the two experiments alluded to 0·21 and 0·25, not of carbon, *but carbonic anhydride.*

As it was possible that some of the carbon found in these experiments might have been derived from the steel mortar used in the preliminary crush-

ing of the emeralds and beryls, I pulverized some emeralds in a porcelain mortar, every precaution I could devise being taken to prevent any contact of organic matter.   On burning in oxygen, and passing the products of the combustion into lime-water, a copious precipitate of carbonate of calcium was obtained.

ON THE EFFECTS OF FUSION UPON EMERALDS AND BERYLS.

On the Effects of Fusion upon Opaque Beryls.—In order to study the effects of fusion upon beryls or emeralds, I found it necessary to use the oxyhydrogen blowpipe.   Beryls and emeralds were amongst the numerous substances fused with this instrument by Clarke [*] as long ago as 1816.   He states that the Siberian beryl fuses to a clear glass containing bubbles.   The Peruvian emerald he found to melt very easily to a round, extremely beautiful bead free from bubbles; it lost its green colour, and became like a white sapphire.

My first experiments were made upon the beryl A; it weighed 62·54 grms., and its density was taken with great care previous to fusion. In the first experiment the whole crystal was suspended from the balance-pan, and weighed in water; in the second a few fragments were weighed in a Regnault's flask with the usual precautions.   The values obtained were as follows:—

Specific Gravity of Beryl A *before fusion.*

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	62·5400	39·0000	21°·5	·997936	2·65
II.	1·6838	1·0512	20·0	·998259	2·66

In order satisfactorily to submit beryls to the action of the oxyhydrogen blowpipe, it was necessary to find a support capable of enduring the high temperature without burning away too rapidly, and also not containing sufficient inorganic constituents to complicate the results. After a few trials I selected square prisms of gas-retort carbon, taking care to ascertain by experiment that they were adapted to the purpose. Some specimens burn away very readily, and others yield too much ash to permit of their being employed successfully.   The oxyhydrogen blowpipe employed was of the ordinary construction; and, with the exception of having several nozzles of various calibres to adapt it to different quantities of the substance to be experimented upon, needs no particular description.   These nozzles (which supply the oxygen) should be well formed, and free from internal irregularities.   Instead of hydrogen, coal-gas was generally employed, as I have not found, for the purposes

* Schweigger's Journ. vol. xviii. p. 237 (1816).

described in this paper, hydrogen to possess advantages sufficient to counterbalance the inconvenience of storing it in the large quantities required.

The phenomena observed on submitting a fragment of beryl to the action of the flame are very beautiful; but to obtain the best results, many precautions and some little practice are necessary. The coal-gas having been lighted and the oxygen turned on, the beryl at once begins to melt, and froths or, rather, boils violently. By careful regulation of the supply of oxygen, the boiling entirely disappears; but the slightest excess of oxygen causes it to be renewed. This property of oxygen, which is found to occur with other substances besides beryls and emeralds, I hope to study in greater detail. Having so adjusted the flame that the beryl fuses tranquilly, and is yet at the exact point of maximum heat (if the substance is not too large for the apparatus), it no longer lies as a shapeless mass on the carbon support, but gathers together, rises up, and forms a perfect bead—round, clear, and brilliant. To obtain the adjustment of position necessary for this result, it is indispensable to wear very dark glasses, so dark, indeed, that objects can scarcely be discerned through them in bright daylight. Without this precaution, the minute details of the globule cannot be observed; and it would be impossible to drive away the bubbles which form instantly when the bead is moved in the slightest degree from the proper position. The heat and glare would also soon seriously affect the sight; and, with every precaution, I have found, after the preparation of one or two hundred globules, that my sight appears (even after an interval of some months) to be slightly but decidedly deteriorated. If all is working properly, the bead should be quite mobile; and advantage of this must be taken to keep it incessantly rolling, and yet not remove it from the point where it gives out the most brilliant light. By this means the whole globule is rendered transparent. If, on the other hand, it is allowed to remain without motion on the carbon (unless the globule be very minute), it will be found, when cold, to have a white opaque base, passing into the centre of the bead in a conical form, and entirely destroying its beauty. This exact adjustment of the position of the bead at the point of maximum heat, combined with constant movement of the carbon support and perfect regulation of the proportions of oxygen and hydrogen, are indispensable to the production of the glasses, specimens of which accompany this paper.

When thus fused, the globules obtained from the beryl A were clear and colourless, but generally contained a few minute air-globules and striæ, which become obvious under the lens. Towards the end of this part of the investigation I succeeded in almost entirely avoiding these defects; but I have been compelled for a time to abandon experiments in this direction in consequence of the strain thrown upon the eyes.

When chromic oxide is added to the beads, and they are again carefully fused, they acquire a fine green colour; the tint, however, is infe-

rior to that of the emerald. The green beads may, by an intense and prolonged heat, be rendered colourless. With cobalt oxide the beads afford beautiful blue glasses of any desired shade; and in all cases the results are the same as with the artificial mixture of beryl ingredients to be described further on.

The effect of fusion upon the beryl is to lessen the hardness and lower the specific gravity. The globules may be scratched by quartz. The following numbers were obtained in a determination of the specific gravity :—

Specific Gravity of Beryl A *after fusion.*

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	2·3376	1·3710	27·2°	·996603	2·41
II.	2·3376	1·3699	27·0	·996603	2·41

The beryls have, therefore, lost nine per cent. of their density in passing from the crystalline to the vitreous state.

I was desirous of carefully comparing this loss of density undergone by beryls with that of rock-crystal fused under the same circumstances. According to an experiment quoted by Forbes[*], the specific gravity of quartz of undoubted aqueous origin, and also that from granites, is 2·6, and that of rock-crystal, fused before the oxyhydrogen blowpipe to an amorphous glass, 2·2. According to the experiment of Le Royer and Dumas[†], the specific gravity of rock-crystal determined at 4° *in vacuo* was 2·652. The value found by the Austrian Commission was 2·651223[‡]. I have repeated with great care the determination of the specific gravity of rock-crystal, both before and after fusion, with the annexed results :—

Specific Gravity of Rock-crystal before fusion.

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	1·9493	1·2154	21°	·998047	2·65

The above number is practically identical with those of Le Royer and Dumas and the Austrian Commission. Rock-crystal fuses very readily before the oxyhydrogen blowpipe, and, if care be taken, the beads obtained are beautifully clear and free from bubbles.

[*] Chem. Soc. Journ., new series, vol. vi. p. 225.

[†] Gmelin's 'Handbook of Chemistry,' vol. iii. p. 354.

[‡] Ueber das Verhältniss des Bergkrystall-Kilogrammes zum Kilogramme der K. Archive zu Paris (Wien, 1870). I am indebted to Prof. W. H. Miller for this reference.

Specific Gravity of Rock-crystal after fusion.

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	·4116	·2240	24°	·997367	2·19
II.	·4116	·2261	25	·997120	2·21
III.	·4116	·2228	24	·997367	2·17
IV.	·3376	·1832	25	·997120	2·18
V.	·1796	·0977	11	·999655	2·19

Mean .... 2·19

Rock-crystal loses, therefore, no less than seventeen per cent. of its specific gravity on passing from the crystalline to the amorphous state, or about a half per cent. less than is undergone by garnets, according to the observations of Magnus ; whereas the beryl A only lost nine per cent., or little more than half as much.

On the Effects of Fusion upon Emeralds.—On heating alone before the oxyhydrogen blowpipe these emeralds bear a bright red heat without losing their colour ; and at a heat which causes incipient fusion, the edges turn colourless and opaque, while the centre remains green. After fusion for a short time they yield an opalescent greenish glass, which, kept for a long time at the maximum temperature of the blowpipe, becomes quite transparent and almost colourless. The addition of chromic oxide causes the bead to become of a dull green colour, which is not improved by moderate heating. The fact that emeralds endure a temperature capable of fusing the edges without the centre losing colour, appears conclusive against the idea of the colouring-matter being organic. The beads produced by the fusion of emeralds resemble those formed in the same manner from beryls ; the phenomena during the fusion are also nearly alike ; but it takes longer and a higher temperature to produce a colourless transparent bead with emeralds than with colourless beryls. The beads can be scratched by quartz, and the density is reduced to the same extent as with the beryl.

Specific Gravity of Emeralds (Canutillos) after fusion.

No. of experiment.	W.	W'.	t.	ρt.	D.
I.	·7432	·4334	13°	·999430	2·40

The density of fused emeralds is therefore almost exactly the same as the globules obtained in a similar manner from the beryl A.

Beryls, from the most various sources and of the greatest difference in appearance, vary but little in specific gravity ; thus a large crystal of beryl from Haddam County, North America, weighing 1089 grms., had its specific gravity determined by suspension, and the number obtained was

2·67.   The beryl A from Ireland gave 2·66 ; and a beautiful transparent yellow crystal, the locality of which is doubtful, gave 2·69, or exactly the same as the emeralds from Santa Fé.

On the Effects of Fusion upon an Artificial Mixture of Beryl Ingredients.
—Being desirous of trying the effects of fusion upon an artificial mixture of the same composition as that of a beryl, I made a series of careful analyses of the beryl A.   The results of these analyses have led me to a laborious examination of the processes at present in use for the separation of alumina from glucina.   The study of the original carbonate-of-ammonia process of Vauquelin, and the modifications of Rose, Joy, Hofmeister, and others, has taken twelve months of constant work ; but even my earlier analyses enabled me to obtain a sufficiently close approximation to the composition of the beryl A.   The following were the proportions used :—

<div align="center">

Silica .... 67·5
Alumina.. 18·5
Glucina .... 14·0
                                                        ——
                                                       100·0

</div>

I did not introduce any iron or magnesia, as I regard them as accidental impurities varying in amount.

When a mixture of the above composition is exposed to the flame of the oxyhydrogen blowpipe, it fuses with almost exactly the same phenomena as with the natural beryl.   It is, however, as might be anticipated from the absence of iron and chromium, much easier to get a colourless transparent bead with the mixture than with either emeralds or beryls. The greatest difficulty in this respect is, of course, found with emeralds. The specific gravity of the fused globules was determined with the following result :—

Specific Gravity of Artificial Amorphous Beryls.

No. of experiment.	W.	W′.	$t.$	$\rho t.$	D.
I.	·5774	·3394	$13\overset{\circ}{}$	·999430	2·42

or almost exactly the same as the density of native emeralds and beryls after fusion.

When a small portion of chromic oxide is added to the artificial mixture and the whole is subjected to fusion, the resulting bead is of a rich yellowish green, and in many experiments approached to the emerald tint ; but, as a rule, the colour is more of a faded leaf-green ; and although I have never obtained a globule of the vivid tint of a fine emerald, the glasses, when well cut, are quite beautiful enough to serve as jewels.

Prolonged heating gradually diminishes the colour, the bead gradually becoming of the palest bottle-green, and, finally, nearly colourless. This result is the same as with the emerald.

The metallic oxide which yields the finest tints when fused with opaque beryls, or the artificial mixture, is that of cobalt. The manner in which this oxide withstands the intense heat of the oxyhydrogen flame is remarkable. All tints, from nearly black to that of the palest sapphire, can be obtained, and the resulting glasses, when cut, are extremely beautiful, and have almost the lustre of crystallized gems.

The globules obtained by fusing the artificial mixture of beryl ingredients with didymium oxide show the characteristic absorption-spectrum of that metal in a very perfect manner, the lines being intensely black. Even when the bead is quite opalescent from insufficient heating, the black lines are beautifully distinct in the spectroscope. With a large quantity of didymium oxide the beads are of a lively pink, becoming more intense by artificial light, and, when cut, form very pretty gems. The presence of didymium in sufficient quantity raises the specific gravity.

Specific Gravity of Artificial Amorphous Beryls containing Didymium.

No. of experiment.	W.	W′.	t.	ρt.	D.
I.	·9467	·5815	$\overset{\circ}{11}$	·999655	2·59

the resulting number being almost as high as that of the emerald before fusion.

Conclusions.—The evidence given in this paper, showing that colourless beryls may contain as much carbon as the richest-tinted emerald, taken in conjunction with the ignition experiments, and the results of the fusion of chromic oxide with colourless beryls and with an artificial mixture of the same composition, leaves me no room to doubt the correctness of Vauquelin's conclusion, that the green colour of the emerald is due to the presence of chromic oxide.

The fact that emeralds and beryls lose density when fused cannot properly be cited as proving that they have been made in nature at a low temperature ; for it is quite possible that they were crystallized out of a solution in a fused mass, originally formed at a temperature high enough to keep the constituents of the emerald in a state of fusion, and that the crystals developed themselves during a slow process of cooling or evaporation. The method employed by Ebelmen * for the artificial production of chrysoberyl, namely heating alumina, glucina, and carbonate of calcium with boracic acid in a porcelain furnace until a portion of the menstruum had evaporated, yielded crystals of the true specific gravity, showing the

* Ann. Chim. Phys. [3] vol. xxii. p. 223 (1848) ; vol. xxxiii. p. 40 (1851).

density of minerals to be less dependent on the temperature at which they are produced than upon their crystalline or amorphous state.

One crystalline gem (the ruby) has undoubtedly been produced in nature at a high temperature. I have frequently repeated Gaudin's[*] experiment on the artificial formation of this stone, and can confirm most of his results. I did not, however, find the density to be quite the same as the native ruby or sapphire, which is, in different specimens, from 3·53 to 3·56. Artificial rubies of the finest colour made by me by Gaudin's process had a specific gravity of 3·45, which is not three per cent. lower than that of the ruby. The reason for this close approximation will be found in the fact that fused alumina crystallizes on cooling. The crystallization, however, is confused and imperfect, which causes the resulting product to be only partially transparent, and to have a slightly lower specific gravity than the natural gem. It is, consequently, scarcely correct to call the fused stones made by Gaudin's process " artificial rubies."

I have convinced myself that rubies have been formed in nature at a temperature equal, or nearly equal, to that of the fusing-point of alumina, from the circumstance that the reaction between chromic oxide and alumina, which results in the development of the red colour of the gem, is not effected at low or even moderately high temperatures, but requires a heat as high as that of the oxyhydrogen blowpipe. It is not necessary that the chromium should be presented to the alumina in the form of chromic acid. It appears, therefore, that the red colour of the ruby is not caused by the presence of chromic *acid*; it is, in fact, a reaction *sui generis* between alumina and chromic oxide, which, as far as my experiments have gone, only takes place at very elevated temperatures.

In my next communication I propose to give the results of a comparative study of two of the processes most generally employed for the analysis of emeralds, beryls, and other minerals containing glucina and alumina—namely, the carbonate-of-ammonia process of Vauquelin, and the caustic-potash method devised by the same chemist, but modified by Gmelin, and generally associated with his name. These studies are already far advanced.

Specimens of various beryl glasses, cut and uncut, accompany this paper.

[*] Ann. Pharm. vol. xxiii. p. 234.