become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

[*To be concluded.*]

CARBORUNDUM: ITS HISTORY, MANUFACTURE AND USES.

BY E. G. ACHESON.

[*Read at the stated meeting of the Institute, held June 21, 1893.*]

B represents the less attacked mixture of sand, carbon and salt. This mixture surrounds the other shells. An analysis of a sample taken from the top of the mass gave the following composition:

	Per Cent.
(I) Salts soluble in water,	11·19
(II) Carbon, free,	32·96
(III) Ash (insoluble in water),	55·85

The analysis of part I gave the following results:

	Per Cent.
P_2O_5,	0·02
SO_3,	2·43
MgO,	0·04
CaO,	0·19
Al_2O_3,	0·04
Fe_2O_3,	0·71
NaCl,	96·57

Part III had the composition:

	Per Cent.
SiO_2,	94·28
Fe_2O_3,	1·75
Al_2O_3,	4·24
CaO,	0·21
MgO,	0·14

The composition of this—the outer mass—would, however, be a variable quantity, depending upon the original mixture.

While it is not my intention, nor the purpose of this paper, to enter into any exact statements regarding the cost of manufacturing carborundum, I deem the subject one of sufficient interest to justify some few remarks and figures.

The quantity produced at the present time will average 150 pounds per day of twenty-four hours, requiring an expenditure of seventy-eight horse-power for a like period, or 1,872 horse-power hours, amounting to twelve horse-power hours for each pound produced. Improvements now being introduced, relating to the design of the furnace and current regulations, will, it is expected, reduce this expenditure about twenty per cent. or thirty per cent. The location of the works—in the centre of the great coal fields of Western Pennsylvania—permits of obtaining cheap fuel, for the steam plant, and cheap coke for the use of the carborundum furnaces. The value of this location is not, however, of so great significance at the present time, as it will prove to be with largely increased production, for, while with an output of 150 pounds per day, the fuel constitutes but one-third of the total cost of the power, with an output amounting to ten times that amount, or 1,500 pounds, it would be approximately two-thirds of the cost. The present practice entails a loss of a considerable quantity of the coke, sand and salt, used in charging the furnaces; the amounts required for producing one pound of carborundum being, approximately, four pounds of mixture containing 1·82 pounds of sand, 1·46 pounds of coke, and ·72 pound of salt. Much of this waste is due to difficulties encountered in re-using portions of the mixture left from former charges, this applies particularly to that portion designated in the diagram as *W*, and that portion of the mixture *B* immediately surrounding it.

The furnace as now used does not materially differ from the early form as shown in the diagram. The advisability of furnishing a ready escape for the gases produced, together with the necessity of having refractory and electrically non-conducting walls, has resulted in the continued use of fire-brick for its construction. These are knocked down after each run and built up fresh for the succeeding one, it having been found that repeated use, without re-building, reduced the output, owing to the walls becoming, in a measure, conducting from incrustations forming thereon. Four carbon electrodes are used at each end, their size being 2 inches in diameter by 12 inches in length. These carbons are, as in the furnace shown, adjustable lengthwise, permitting of the tightening up of their contacts with the mixture and core. The dimensions of the furnace are 18 inches in width by 12 inches in depth and 6 feet in length. The core consists of granular carbon, placed in the form of a sheet, having a width of about 10 inches, depth 1 inch, and in length, extending the distance intervening between the electrodes, about 5½ feet.

A furnace of this construction and capacity requires from seven and one-half to eight hours' time to complete the transformation of a portion of the charge into fifty pounds of carborundum, and three of them are operated every twenty-four hours. The labor required for the preparation of the mixture, building and charging the furnace, operating and discharging the same, for twenty-four hours, consists of the services of two men and two boys. This same amount of labor would, however, be able to attend to the production of probably four times the amount now made.

From these figures and data, it will be concluded that the cost of manufacturing carborundum, on a large scale, need not exceed, and possibly not equal, the present cost of mining corundum and preparing it for the market.

Carborundum, when removed from the furnace, is a mass of crystals, of varying sizes, the greater number being of a size sufficiently small to pass through a sieve having 2,500 meshes to the square inch, and too large to pass through one having 40,000 meshes. These crystals cling together in so loose a manner that comparatively little effort is required to separate them. In the factory this separation is accomplished by throwing the crude lump material into an iron pan, and causing two heavy iron wheels to roll over it—water being introduced to facilitate the action—and the mass is stirred up continually during the grinding process.

After removal from the grinding pan, the carborundum is placed in stone tanks, and treated with dilute sulphuric acid, for a period of seven days, the object of this treatment being the removal of all iron, it having been found necessary to remove this impurity before firing in the kiln, during the manufacture of wheels, as a destruction of the crystals would result from its presence.

The intrinsic value of carborundum is a quantity yet to be determined. That it will find varied uses in the arts and manufactures cannot be doubted, its three prominent characteristics—great hardness, infusibility and incombustibility—are sufficient to warrant its extensive introduction into special lines. Perhaps no other use to which it can be put will equal in importance that as an abrasive material, and should it find no other, this alone would be sufficient to class it as one of the most valuable of the materials used by the artisan. The use of emery and corundum in the form of wheels and special shapes, while of comparatively recent introduction, has grown to wonderful proportions. At no period in the world's history has the value of time been more highly appreciated than at the present day. Economy of time, increased output with a given amount of labor, and the resultant cheapening of production and consequent lower selling price of the article produced, are the demands of the times. This is being met by the manufacturer by the introduction of improved machinery and more efficient devices for rapid work and quick production. It is probable that the introduction of no other single tool into our factories, mills and shops, has produced so great a saving in labor as the emery wheel. I have not been able to obtain figures giving even an approximate value for the consumption of emery in the United States, and while I am, therefore, not prepared to say what it would actually amount to, I believe that it is several million dollars annually. These figures will convey some idea of the astonishing consumption of the material, but they will scarcely suggest the much greater amount that is, each year, saved in time and labor by its use. If emery has accomplished so much, "What," you will ask, "is left for carborundum to do?"

The amount it will do and save will depend wholly upon its hardness and fitness as an abrasive, over and above these qualities as manifested in emery. The statement has frequently been made by myself and others, that carborundum was equal in hardness to the diamond, while, perhaps, a greater number of persons—who are apparently in a position to know, have stated quite the contrary—that it is not as hard as the diamond. The final determination of this important question, in a manner satisfactory to all interested parties, remains to be made. My own conclusions were arrived at from what, to me, seemed positive tests, made without prejudice, the material having been used on diamond cutters' laps for the practical cutting and polishing of diamonds. The first test for diamond cutting was made by myself. A disc of iron was mounted in a fast running lathe, and the surface having been charged with fine carborundum crystals, a diamond contained in a ring was pressed against the revolving disc, and in from four to five minutes the facet, which had been presented to the disc, was found to be devoid of lustre, of a milky color and scored with lines. The second test was in a diamond-polishing establishment in New York. Here the proprietor was asked to re-polish the diamond above referred to, using, as the polishing agent, carborundum powder. The gentleman kindly consented to make the experiment, under the following conditions: A new lap, free from all diamond powder, should be used; my material would be tried first, and if successful, no charge would be made for the re-polishing, while if not successful, diamond powder would be substituted, and I should pay him $5 for his trouble. He added that in his opinion the $5 was just as good as earned. The new lap was mounted, and a workman supplied with one-half karat of carborundum powder, with which he was instructed to charge the lap and polish the lustreless facet. The diamond had, in the meantime been removed from its setting and mounted in lead, as is the practice in diamond polishing. Much to the surprise of the workman, the proprietor, and in some measure of myself, an application of the diamond to the lap for a period of twenty minutes removed all lines from the facet and restored it to its former beauty. Since these first tests, I have, at odd times, spent many hours in watching the operation of diamond polishing with carborundum powder, in three different diamond-polishing establishments in New York City. These various tests served to prove that the hardness of carborundum was sufficient to cut diamond surfaces—removing deep lines from them and producing a fine polish—this work being done, in the opinion of some workmen, in a shorter time than could be performed with diamond powder. They also demonstrated that carborundum was not equal to diamond powder, in the first work of cutting the rough diamond and shaping the facet. Its failure to do this first work has been used, by some diamond cutters and others interested in diamonds and their commercial value, as a conclusive argument that it is not as hard as the diamond. While I do not wish to be understood as denying their statements, I am inclined to accept the proofs I have received with my own eyes, as conclusive evidence, that in the form of a very fine powder it compares favorably, in hardness and cutting qualities, to diamond powder of equal fineness, and to account for its failure when applied to the rougher work, it is necessary to take into consideration the brittleness of the crystals, this brittleness being, apparently, very much greater than in the case of the diamond crystal.

It is probable that methods will be worked out for reducing this brittleness, such for instance, as a process of annealing. This question, as to the exact place of carborundum in the scale of hardness, is, after all, one of scientific rather than commercial importance. Sufficient is now known to rate it very much above the abrasives ordinarily used, and as it is in the steel, iron, glass, porcelain and similar industries that the several million dollars worth of emery is yearly consumed, and not in diamond cutting, the question of first importance is, "Can carborundum be used with greater economy than emery?" To put the question in another form, "How will the cost of a given amount of work performed with carborundum compare with the cost of the same work done with emery?"

We will take a case of brass valve grinding; this being a case, where owing to the metal being comparatively soft, the test will favor the softer abrasive. A number of establishments are now using carborundum powder for this class of work. In one factory they formerly used a fine emery which cost them twenty cents per pound, while the carborundum powder cost them twenty times that amount, or $4.00 per pound. The experience of months has demonstrated to them, that in the hands of a good, careful workman, one-eighth of an ounce is sufficient for one day's work, and that with such a quantity the workman will perform not less than twice the amount of work that he could have done with any amount of emery.

The wages of the workmen are $2.50 per day. We here have, as the result of using one-eighth of an ounce of carborundum, costing six and one-fourth cents, an additional output amounting to the labor of one workman at $2.50, and assuming the emery to cost nothing, we have a value for the carborundum used of $2.43¾, and this without counting the value of the larger production turned out from the same machinery, floor space, etc. It must be admitted that this result is not attainable in all cases, for it is evident that a careless workmen could, and does, very materially reduce this saving by his wasteful use of the carborundum powder. This does not, however, change the relative values of the two abrasives, which we know it is possible to obtain. In glass cutting, tests that have been made, indicate that a given amount of work can be performed in one-fourth the time required when emery is used. Much the same conditi ns regarding time are found to exist in the case of carborundum on hard steel or chilled iron, and the sum of the results thus far obtained indicate an average saving of labor amounting to at least twenty-five per cent.

The value of the other two characteristics referred to—infusibility and incombustibility—as applied to industrial uses, it is at present impossible to determine. It was these qualities that made carborundum a material equal to and perhaps surpassing all others, from which to construct the small buttons used in the Tesla lamps, as shown in his lecture before the Franklin Institute last February.

The crystallographic formation of carborundum is a subject that has not received any attention at my hands, nor in the works of the Carborundum Company. I am pleased to be able to state, however, that this subject has received the attention of Professors Frazer and Richards.

The specific gravity of green carborundum crystals was found by Dr. Mulhaeuser to be 3·22.

It will be probably as interesting to you as it was at first disturbing to me, to learn that a compound, responding to the formula SiC, has been produced by another without any known knowledge of my investigations. In the transactions of the Academy of Sciences of France (session of Monday, May 16, 1892), will be found a communication under the title, "Contribution to the History of Carbo-silicious Compounds," by Mr. P. Schützenberger. In his communication, Mr. Schützenberger described at length the manufacture of a new chemical compound of simple formula, the symbol being SiC. Briefly stated, his method was to enclose a mixture of silicon and silica in a bone-black crucible, the latter being securely covered with a lid of like material and embedded in lampblack contained in a larger crucible of graphite. This, again, was embedded in a third crucible, and the resulting nest was placed in a suitable furnace and brought up to, and held at, a high heat for some hours. Upon cooling and opening, the contained silicon was found to have been changed to a green substance and to have gained in weight an amount equal to one-half of its original weight, the silica remaining unchanged. An analysis showed the green material to be carbide of silicon with the formula SiC. No reference was made to the presence of crystals, and as it is probable the silicon used was a powder, the carbide was probably, also, in the same form. The disturbed state of mind—not to specify it more definitely—which I first experienced upon learning of Mr Schützenberger's work, was completely relieved when I found the date of his communication was three months later than the date on which Mr. Nikola Tesla exhibited a lamp containing carborundum, before the assembled scientific societies of France. The composition of what I had called carborundum was not, however, known at that date. Mr. Tesla could not state what it was, nor did any one else, to my knowledge, know that it was carbide of silicon responding to the formula SiC.

APPENDIX.

REPORT OF AN EXAMINATION OF CRYSTALS FURNISHED BY MR. E. G. ACHESON, PRESIDENT OF THE CARBORUNDUM COMPANY.

The specimens examined were aggregations of crystals, the individual crystals, usually more or less disc shaped, varying in their largest dimensions from a fraction of a millimetre to about three millimetres. The faces were usually smooth with brilliant, adamantine lustre. The images reflected from them in the goniometer were frequently double or multiple, sometimes blurred, and sometimes broadened by diffraction. Occasionally, however, single, somewhat sharply defined, images were obtained.

The color of some of the crystals was a yellowish-green; that of others varied from a bluish-green to blue.

The crystals were found to be rhombohedral, their disc shape being due to the predominance of the basal pinacoid. The observed forms consisted of numerous direct and inverse rhombohedra, with the basal pinacoid and, in some crystals, the prism of the first order. The following rhombohedra were observed and determined, viz: $\frac{1}{5}$, $\frac{4}{5}$, $\frac{10}{11}$, 1, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{10}{7}$, 2, $\frac{5}{2}$, 4, $\frac{19}{4}$, 5, 10. No evident marks were discovered to distinguish direct from inverse rhombohedra. In one crystal, the following grouping was observed:

Direct rhombohedra.	*Inverse rhombohedra.*
1	$\frac{10}{11}$
$\frac{10}{7}$	2
$\frac{5}{2}$	5
10	$\frac{19}{4}$
	5

In some crystals, like that just described, the rhombohedral symmetry was evident; in others, the direct and inverse rhombohedra of the same parameters were found on the same crystal, so as to impart to it an appearance of holohedral hexagonal symmetry. This holohedral habit was observed in bluish-green and blue crystals, while in those yellowish-green crystals, which were examined in the goniometer, the habit was rhombohedral. Further investigation will be needed to decide whether this coincidence is accidental or not.

The value for the length of the vertical axis was calculated from four good measurements made on three different crystals, with the following results:

$$c = 1{\cdot}2267$$
$$1{\cdot}2261$$
$$1{\cdot}2264$$
$$1.2264$$

giving the mean value, $c = 1{\cdot}2264$.

The following are a few angles between the most frequently occurring forms observed:

	Calculated.	*Observed.*
$o \wedge \frac{10}{11}$, ...	52° 09′ 42″	52° 07½′ to 52° 14½′
$o \wedge 1$, ...	54° 46′ 22″	54° 43¼′ to 54° 50¼′
$o \wedge \frac{5}{4}$, ...	60° 32′ 15″	60° 32′ to 60° 46½′
$o \wedge \frac{?}{7}$, ...	63° 41′ 49″	63° 41½′ to 63° 43¼
$o \wedge 2$, ...	70° 33′ 12″	70° 31′ to 70° 38′
$o \wedge 5$, ...	74° 13′ 39″	74° 13½′ to 74° 15¾′
$o \wedge 10$, ...	85° 57′ 39″	85° 56¾′ to 86° 02′
$1 \wedge 1$ (terminal), ...	90° 04′ 43″	
$2 \wedge 2$ (terminal), ...	109° 29′ 43″	109° 30½′

It is worthy of notice, in view of the isometric crystallization of the diamond, that the rhombohedron chosen as the unit rhombohedron has almost the shape of the cube, while the rhombohedron 2, a frequently occurring form, in combination with the basal pinacoid has very nearly the shape of the regular octahedron.

No distinct cleavage was observed.

In one instance, a twin was observed, two disc-shaped crystals being so grouped that their basal pinacoids made an angle of 109° 29′ + with each other. This would conform to the law, twinning plane, that of the unit rhombohedron.

A flat crystal examined under the microscope in converging polarized light gave the interference figure of a uniaxial mineral, thus confirming the determination of hexagonal symmetry made by measurements with the goniometer. B. W. FRAZIER,

Professor of Mineralogy and Metallurgy, Lehigh University.
South Bethlehem, Pa., June 21, 1893.

The specific gravity of several grammes was determined by the specific gravity bottle as 3·123, at 25° C. = 60° F. When it was found that the blue crystals were apparently a di-morphic form of the green ones, a sample of each kind was put into a Sonstadt solution of sp. gr. 3·2, which was diluted down carefully until at a sp. gr. of 3·05, at which point the green crystal had sunk while the blue crystal still floated. It was thus evident that the blue variety has a lower specific gravity than the green.

JOSEPH W. RICHARDS.

ANTI-FRICTION BALL BEARINGS AND THEIR MANUFACTURE.

BY GEORGE F. SIMONDS.

[*Read at the stated meeting of the Franklin Institute, held April 19, 1893.*]

JOS. M. WILSON, President, in the chair.

MR. SIMONDS :

It was my privilege to read a paper before the members of this Institute, in June, 1888, on the "Metal Rolling Machine," and I am now pleased to bring to your attention a few facts in reference to what has been the natural outcome of that machine; anti-friction ball bearings and their manufacture.

A casual remark, heard at the Paris Exposition, in 1889, called my attention to the importance and value of ball bearings in removing friction, if they could be brought into practical use, and to make a market for the rolling machine