attendant on blasting; the use of firemen understanding and observing the barometer; the error of supposing the wastes to fill up rapidly and entirely by subsidence; and, most of all, the hopelessness of increasing the speed of the air current, where candles are used, much beyond its present rate;—these are among the considerations which either have not occurred to those reporters, or have impressed me more strongly than they appear to have done these writers.

I end as I began; all that I have here collected and compared, all besides that I have read, all that I hear, even from those who advocate reliance on some single means of defence, convinces me that a single means is not enough. It will not do to trust alone to a strong current of air, to the superiority of "long" methods of working over "short," or "short" over "long," to the use of lamps, to frequent and minute inspection, or to regulations for workmen. Let each, or any, be observed; but let no other helps to safety, which are applicable to the situation and circumstances be neglected.

ON THE EXISTENCE OF FOUR CRYSTALLINE SPECIES OF CARBON. BY H. C. SORBY, ESQ., F.G.S.

The four species of carbon are diamond, graphite, hard coke, and charcoal. They have long been distinguished practically; and the object of the present paper is to show their various crystalline forms and mutual relationship.

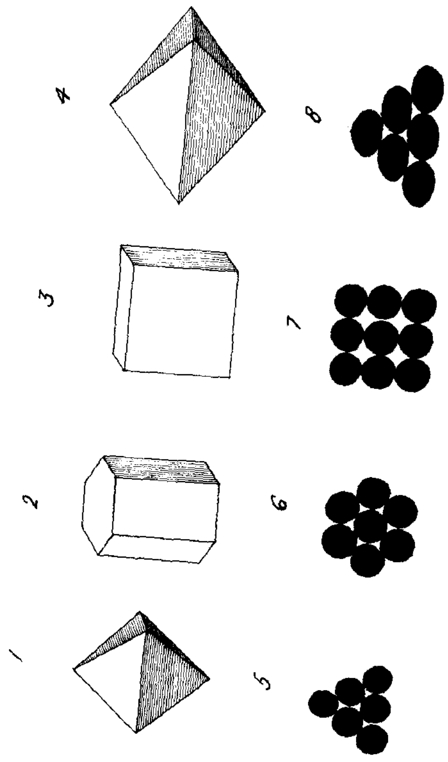
In the first place we have diamond, which is well known to be crystallized in the regular system, and to have a specific gravity of about 3.52.

Secondly, we have graphite or plumbago, which is found crystallized in regular hexagonal prisms, and has a specific gravity of about 2.18.

But besides these I find that there are two other crystalline species, viz., hard coke, *which, like diamond, belongs to* the regular system, though it has very different properties and specific gravity, viz., about 1.89; and anthracite or charcoal, crystallized in the square prismatic system, and having a specific gravity of 1.77. These various forms are shown in *Figs.* 1, 2, 3, and 4, *Plate II.*

The manner in which I have been able to ascertain the crystalline form of coke, anthracite, and charcoal, is thus:—I bruise a portion in a mortar, along with soft chalk, which protects the fragments from injury, and then dissolve away the chalk with acid, and wash the powder left; then spreading some of it on a piece of the thin glass used for microscope object covers, and drying it, I examine it through the glass with a magnifying power of about 400 linear, and measure the angles by means of the doubly-refracting goniometer, invented by Dr. Leeson. By this means, and using proper precautions, the angles of a fragment of $\frac{1}{4000}$th of an inch in diameter, or even less, can be measured within a small fraction of a degree. Of course by this method one can only ascertain the magnitude of the angles which occur on one plane; but by measuring those of various fragments, one can, by calculation, build up from them the primary form from which they are derived.

It is not every sample of coke which shows the crystalline structure well. Those which are highly vesicular do not show it at all distinctly; but if we take a dense, highly-metallic-looking specimen, although the particles which have good angles well placed for measurement are rare, yet still sufficient can be found by a patient examination to show that it belongs to the regular system. The angles which are good and distinct are, I may say, invariably found to be of 90°, 60°, 30°, 45°, and 70½°, all of which are related, in a very simple manner, to the regular system; and I would


1
2
3
4
5
6
7
8

remark, that the angles found by careful measurement agree with those calculated, as near as could be expected from the nature of the case. The angles found in anthracite are $80\frac{1}{2}°$, $99\frac{1}{2}°$, $90°$, $40\frac{1}{4}°$, $49\frac{3}{4}°$, $62°$, $118°$, $31°$, $59°$, $45°$, $22\frac{1}{2}°$, $67\frac{1}{2}°$, $16\frac{1}{2}°$, $74\frac{1}{4}°$, $52\frac{3}{4}°$, and some others; the manner of derivation of which, and their mutual relationship, would require too much explanation. They are all, however, easily shown to be readily derivable from a square prism, which has its axes related as 5, 5, and 3, and which is not only cleavable with relation to those values of the axes, but also to the axes 5 and 5, and four times the axis 3; and that it is thus cleavable many fragments prove very clearly. I would also remark, that careful measurements agree, within a few minutes, with the angles calculated on these suppositions. Although charcoal is unfavourable for such an examination, yet I have found in it angles which agree with those of anthracite, as near as could be told.

Carbon is, therefore, crystallized in three different forms, viz., the regular and square prismatic systems, and in hexagonal prisms: and what is remarkable, (in fact, it is the only case of the kind known), it occurs in two perfectly distinct conditions, with different volumes, viz., diamond and coke, in one system of crystallization, the regular; making, therefore, four distinct species.

I will now explain what I believe to be the mutual relationships of these four species, and afterwards show in what manner their properties differ.

In order to determine the specific gravity of graphite, coke, anthracite, charcoal, and lamp-black, with sufficient accuracy, it is necessary to have them in a state of very fine powder; and in the case of charcoal it is absolutely essential to boil it first in acid, to dissolve away the glaze of ashes. I first heat the powder to dull redness, without access of air, and then thoroughly well boil it in water in a bulb of glass, and fill it full of boiled water, and cork it. By this means the water, being deprived of air, when cold, dissolves any that may be amongst the powder. It is then weighed in water, and after that dried in the bulb, from which the weight in air is told. It is then burned to ashes, and their amount, and also their weight in water, ascertained; and these, being deducted from the weight of the substance in air and water, we are able to calculate its specific gravity, free from the effects of the ashes. In this manner I find the specific gravity of the different varieties of carbon to be thus, which are mean results of several experiments, the details of which it is needless to particularize here:—Graphite 2.177, hard coke 1.891, lamp-black 1.774, anthracite 1.760, and charcoal 1.784. I have not examined the specific gravity of diamond, but the mean of many statements is 3.521.

Now I have ascertained the following remarkable fact with regard to these specific gravities. If we assume the ultimate atoms to be spheres in the regular system and the hexagonal prism, and spheroids in the square prismatic, and calculate mathematically the relative specific gravities that we ought to have, assuming them to be arranged in the manner indicated by the crystalline form and cleavage, we find that the whole of the four species of carbon are brought about by its existing in ultimate atoms, having the relative volumes of $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$.

In the first place, beginning with the square prismatic system, the mean specific gravity is 1.773, and this, multiplied by 2, gives 3.546 for the specific gravity of diamond; assuming the atoms to have their axes of the same relative magnitude as those of the two crystalline forms, and arranged similarly, that is to say, in the case of diamond, spheres, and in the other spheroids, with axes in the ratio of 3 and 5, as shown in *Figs.* 1, 5, 4, and 8. The mean of many statements of the specific gravity of diamond, which vary from 3.48 to 3.6, is 3.521, which differs from the calculated specific gravity by only $\frac{1}{140}$th. The volume of these two forms is, therefore, as $\frac{1}{2}$ to $\frac{1}{4}$.

Suppose the spherical atoms of diamond to be arranged as an octahedron, *Fig*. 1, in that case they would be placed with relation to one another on each equilateral triangular face, in the manner shown in *Fig*. 5; and such an arrangement agrees perfectly with the well known cleavage of this mineral. Also let us suppose the atoms of coke to be spheres, but arranged as a cube, *Fig*. 3, in which case they would be related to one another on each of its square faces, as shown in *Fig*. 7. On these suppositions it is easily shown mathematically that the relative volumes would be as $1 : \sqrt{2}$; and calculating on this supposition, and also that the volumes of the ultimate spheres in coke are to those in diamond as $\frac{1}{3} : \frac{1}{4}$, we should have for the specific gravity of coke, by calculation, 1.880. Four very careful experiments, which only differed by $\frac{1}{500}$th from one another, gave me a mean specific gravity of 1.891, which only differs from that calculated by $\frac{1}{180}$th.

Again, supposing the spheres of coke and graphite to be of the same magnitude, but in the latter arranged as an hexagonal prism, *Fig*. 2, in that case they would be related to one another on the terminal planes, in the manner shown by *Fig*. 6, and rectangularly in the direction perpendicularly to them, a structure indicated by the crystalline form and cleavage. If such be supposed, it is easily shown that their relative specific gravities should be to one another as $\sqrt{3} : 2$; and this gives for the specific gravity of graphite, by calculation, 2.172. The mean of six careful experiments gave me 2.177, which only differs from that calculated by $\frac{1}{400}$th.

I think, therefore, that these calculated results agree so very well with those found by experiment, that I am entitled to conclude, as I before said, that the four species of carbon are caused by its existing in atoms of the relative volumes of $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$, arranged in such a manner as the form and structure of the different crystals indicate; and what makes this fact very interesting is, that there is no case known at all similar, with respect to any other elementary body.

There is one fact of very great theoretical importance connected with these relative volumes, viz., their specific heat. In the case of charcoal and diamond I had predicted a considerable time before I knew that it was so, that their relative specific heats would be as 2 : 1; and such is really the case. Moreover, the specific heat of coke and graphite is the same, whereas it is to that of diamond as $\frac{1}{3} : \frac{1}{4}$, and to that of charcoal as $\frac{1}{3} : \frac{1}{2}$; whence it will be seen that the specific heat of the four species of carbon is in precisely the same ratio as the volume of their atoms; or in other words, the capacity for heat of the atoms of carbon, when of different volumes, varies in the same ratio with their magnitudes, which I believe to be an entirely new law as regards an elementary body. To render these facts more apparent I subjoin the following table, which is calculated from the found mean specific gravity and heat of the square prismatic form:

	Square Prism-atic form	Coke.	Graphite.	Diamond.
Specific gravity—				
Theory	$2 \times \sqrt{2}$ 1.773	3×1 1.880	$3 \times \sqrt{\frac{2}{3}}$ 2.172	$4 \times \sqrt{2}$ 3.546
Experiment	1.773	1.891	2.177	3.521
Comparison of theory and experiment ...	...	$\frac{1}{180}$ too little	$\frac{1}{400}$ too little	$\frac{1}{140}$ toomuch
Relative volume of atoms	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{4}$
Specific heat—				
Theory	$\frac{1}{2}$ .2714	$\frac{1}{3}$ .1809	$\frac{1}{3}$ .1809	$\frac{1}{4}$ .1357
Experiment	.2714	.2028	.2019	.1331
Comparison of theory and experiment ...	...	$\frac{1}{9}$ too little	$\frac{1}{9}$ too little	$\frac{1}{30}$ too much

NOTE.—In this table, in the upper line of figures, the number on the left hand side of the × indicates the inverse volume of the atoms; and that on the right the correction required for difference in crystalline form and arrangement of the atoms.

These specific heats are not from my experiments, but are the mean of those given in Gmelin's Hand-book of Chemistry; and though they differ considerably from theory, yet to any one acquainted with the nature of the experiments, and the usual great difference, as determined by various authors, it will not appear anything more than what might result from errors of observation.

If we take into consideration only the specific gravities, this law is not at all apparent; for, as I have shown, the specific gravity is not a simple function of the volume of the atoms, but a compound one of it and of the crystalline form and arrangement of the particles; whereas the specific heat is a simple function of the volume, and is in no way related to the crystalline form. So far as I am aware, this important distinction has been overlooked in discussing the relative specific gravities of various bodies.

Gmelin, in his Hand-book of Chemistry, in mentioning the relation of the specific heats of the various forms of carbon, says—"The capacity for heat of carbon in the form of diamond is one-fourth, in that of graphite one-third, and in that of charcoal one-half the ordinary amount. These exceptions cannot be explained away; we cannot triple, quadruple, nor even double the atomic weight of carbon without incurring great inconvenience." I, however, think that, from what I have shown to be the case in carbon, chemists will not insist on a constant, perfectly simple ratio between the specific heat and atomic weight of elementary bodies, since they may exist in different relative volumes, and thus much modify the relation of their specific heats.

The properties of these four species of carbon, as is well known, vary very remarkably, and it may, perhaps, be well to mention some of the leading differences between them.

In the first place, the distinction between diamond and charcoal is very great, and has long been a subject which has excited much attention and surprise; and has hitherto, in my opinion, been referred to a very wrong cause, viz., mere molecular arrangement. Diamond is twice as dense, it is colourless and transparent; whereas the other is black and opaque. Its hardness is incomparably greater, and it is a non-conductor of electricity; whilst the other conducts tolerably well. It becomes positively electric by friction; whereas anthracite becomes negatively so.

The chief difference between diamond and coke is, that diamond is colourless and transparent, but coke is opaque and has a metallic lustre. It is a non-conductor of electricity, but coke conducts extremely well. It is also much harder than coke; for though coke cuts glass, and even scratches topaz, it will not scratch corundum. Diamond, as is well known, is converted by intense heat into the coke form of carbon.

Coke and graphite have both the same metallic lustre, and differ chiefly in hardness; graphite, when pure, being vastly softer. When coke is used for the electric light, that piece which is attached to the anode is softened, and partly converted into graphite, and its specific gravity is thereby increased; whereas that attached to the cathode is unaltered.

With regard to the square prismatic form of carbon, I would state that anthracite, charcoal, and lamp-black belong to it; and the chief difference between them and coke is, the want of the metallic lustre which the latter possesses. It is also very much harder; for anthracite will not scratch calcareous spar, whereas coke is inferior in hardness only to diamond and corundum. Coke is also a very much better conductor of electricity than they are. When exposed to a white heat, anthracite will cut glass like coke; and both it, charcoal, and lamp-black, when thus heated, conduct electricity vastly better than when only heated to dull redness. The specific heat of charcoal is also diminished. I therefore think that the ultimate atoms are converted into the coke form, though they retain their former crystalline structure, and are therefore pseudomorphous. It is, however, remarkable that the specific gravity of anthracite is not increased by this treatment, when it is determined from fine powder.

One point of geological interest in this inquiry is, the fact that anthracite is found in the same condition as wood takes when exposed to a red heat, and not that produced by the action of heat on coal; for in the latter case we, I believe, invariably obtain the coke form. Why this should be so I will not venture to say, farther than that perhaps it may be owing to the manner of heating, joined to the great pressure *which must usually have been in operation in the case of coal* converted into anthracite. Moreover, it should appear that anthracite cannot have been exposed to a white heat, or else it would, in all probability, have been converted into pseudomorphous coke.

As to the manner in which anthracite has been converted into graphite, the fact of the piece of coke which is attached to the anode being converted into it, and not that to the cathode, would point not so much to the mere effect of heat, as to the combined action of a positively electric condition.

I should therefore conclude, from various circumstances, that diamond has been formed at a low temperature; the square prismatic or charcoal form at about a red heat; the coke form at a still higher temperature; and graphite at an intense heat, combined with the action of highly-developed positive electricity; and it is worthy of remark that the relation of their specific gravities, as calculated and as found by experiment, coincides with this view of the subject. I have compared them by calculation, (see table), supposing the charcoal form to be normal, and it will be observed that the specific gravity of diamond is lower, and those of coke and graphite higher, than indicated by theory; which agrees perfectly with the supposition of its having been formed at a lower, and they at a higher, temperature.

ON A NEW GAS STOVE. BY W. SYKES WARD, ESQ., LEEDS.

Mr. Ward stated that in his invention the stove is constructed in a vertical position, so as to expose a considerable surface for the absorption of heat from gas burners, and for the radiation of the heat; and that, from the flatness of construction, the apparatus occupies little space, not projecting into the room more than two or three inches, being thus productive of little inconvenience when out of use.

A plate of thin sheet iron is fitted into an ordinary fireplace, in the manner of a fire board, about two inches within the projection of the mantel-piece; about three inches in front of the back plate, a similar plate of sheet iron is secured by bolts; a third somewhat smaller plate of iron is placed about one inch from the second plate, and enclosed at the top, bottom, and sides, so as to form a chamber of about two to three feet square, and one inch in depth. Towards the bottom of the last plate a long aperture is cut, closed by a sliding plate, acting as a door for lighting the gas jets, and admitting a small quantity of air. A little below the aperture a pipe is introduced, in which are fixed three or more gas jets, either the ordinary small bat-wing burners, or burners with two or three holes, so that the flames may extend laterally, not coming into immediate contact with the iron. From the top of the enclosed chamber, a pipe, an inch and a-half in diameter, proceeds through the second and first plates into the chimney of the room.

The Author found that this apparatus was sufficient to raise the temperature of a moderate-sized apartment from five to ten degrees Fahrenheit, with a consumption of about three feet of gas per hour, costing about twopence for ten