

tory of the Collège de France. I could also have explained the successful syntheses, not less remarkable, of minerals and meteorites made by these experimentalists or by their pupils, among whom M. Bourgeois occupies a special position. But I must limit myself; and, indeed, what I have said is sufficient to show how their methods have advanced our knowledge in a domain to which access had previously appeared shut against investigation.

Wherever the experimental method has hitherto carried its torch, it has brilliantly illuminated the most striking phenomena in the science of the earth. It suffices to mention the name of Daubrée, the direct descendant of the illustrious geologists of the Scottish school, to indicate the extent of the field of the mineral sciences already explored by the method of experiment. It has been successfully applied to the interpretation of metalliferous deposits and of metamorphic rocks, and to the study of the fractures and deformation of the earth's crust, of the schistosity of rocks, and of certain features in mountain structure.

Geology, after having passed through the successive phases of observation and analysis, has therefore entered upon that of experiment and synthesis, in which it strives to imitate the creative power of Nature, thus crowning the scientific edifice by processes which allow us to catch a glimpse of the operation of causes the knowledge of which is the final aim of physical and natural science. It was this crowning of the work which Leibnitz foresaw when he wrote, two centuries ago:—"He will perform, in our opinion, an important work, who shall carefully compare the products extracted from the depths of the earth with those of the laboratory; for then will be brought vividly before our eyes the striking resemblance which subsists between the productions of Nature and those of Art. Although the Creator, inexhaustible in resource, has at command divers means of effecting His will, it nevertheless pleases Him to maintain a constancy in the midst of the variety of His works; and it is already a great step towards a knowledge of things to have discovered even one means of producing them; for Nature is only Art on a large scale."

SOME RECENT ADVANCES IN THE THEORY OF CRYSTAL-STRUCTURE.

THE growth of modern theories concerning the structure of crystals is perhaps not so closely followed by English chemists as might be expected from the inherent interest of the subject, in spite of the attention which is now devoted to all questions of atomic and molecular arrangement in space.

It is in the morphology of crystals that the geometrical arrangement of the atoms or molecules (in the solid) finds, if anywhere, a geometrical expression, and yet little or no account is taken of this subject in textbooks of chemistry or physics, so that it is difficult for the student to discover what views are held by modern authors. Moreover, crystallographic observations and theories are generally published in journals specially devoted to mineralogy which are not easily accessible to all who are interested in such questions.

It seems, therefore, advisable to draw attention to the progress which has recently been made in the theory of crystal-structure, and more especially to papers by Prof. Sohncke, of Munich, published in Groth's *Zeitschrift für Krystallographie und Mineralogie*, a journal which is a complete storehouse of information relating to the study of crystals.

Sohncke's theory, which was published in 1879,¹ has now emerged from the purifying fire of recent criticism in

an emended form in which perhaps it will more readily excite the interest of chemists.

In order to make it clear in what respects the theory of Sohncke in its latest form differs from those which have been previously advanced it will be necessary to give a brief sketch of the theory of Bravais, of which Sohncke's system is an extension.

The Abbé Haüy,¹ having found that all crystals of the same substance may be reduced by cleavage to the same solid figure, whatever their external form, argued that the cleavage solid has the form of the ultimate particles into which any crystal may in imagination be separated by repeated subdivision, and that this is therefore the form of the structural unit: it is not, of course, necessary or even probable that the latter should be identical with the chemical molecule. Hence a crystal is to be regarded as constructed of polyhedral particles, having the form of the cleavage fragment, placed beside one another in parallel positions. A crystal of salt, for example, which naturally cleaves parallel to the faces of the cube, is constructed of cubic particles.

Upon the relative dimensions of the structural unit depends the form assumed by the crystals of a given substance.

It will be found that this theory not only accounts for the existence of cleavage, but further defines the faces which may occur upon crystals of a substance having a given cleavage figure; for, if once it is assumed that a crystal-face is formed by a series of the particles whose centres lie in a plane, it follows that all such planes obey the well-known law which governs the relative positions of crystal-faces.

A natural advance was made from the theory of Haüy, without detracting from its generality, by supposing each polyhedral particle in Haüy's system to be condensed into a point at its centre of mass, so that the positions of the molecules, and therefore of the crystalline planes, remain the same as before; but the space occupied by a crystal is now filled, not by a continuous structure resembling brickwork, but by a system of separate points.

It will be found that in such a system of points, if the straight line joining any pair be produced indefinitely in both directions, it will carry particles of the system at equal intervals along its entire length; in other words, all the structural molecules of a crystal must lie at equal distances from each other along straight lines. The interval between particles along one straight line will in general be different from those along another, but the molecular intervals along parallel straight lines will always be the same.

Bravais,² therefore, following in the steps of Delafosse and Frankenheim, treated the subject as a geometrical problem, and inquired what are the possible ways in which a system of points may be arranged in space so as to lie at equal distances along straight lines—in other words, so as to constitute what may be called a *solid network* (*assemblage, Raumgitter*).

The geometrical nature of a network may be best realized as follows. Take any pair ($O C_1$) of points in space, draw a straight line through them, and place points at equal distances along its entire length (C_2, C_3, \dots); such a line may be called a *thread* of points (*rangée*). Parallel to this line, and at any distance from it, place a second thread of points ($A_1 A_1'$), identical with the first in all respects; in the plane containing these two threads place a series of similar equidistant parallel threads ($A_2 a_2, \&c.$) in such positions that the points in successive threads lie at equal intervals upon straight lines whose direction ($O A_1$) is determined by the points upon the first two threads. Such a system of points lying in one plane may be called a *web* (*réseau*). Now, parallel to this plane, and at any distance from it, place a second web ($B_1 b_1$), identical with the first.

¹ "Traité de Cristallographie." (Paris, 1822.)

² "Études cristallographiques." (Paris, 1866.)

¹ "Entwicklung einer Theorie der Krystallstruktur." (Leipzig.)

Finally, parallel with these, place a series of similar equidistant webs in such positions that the points in successive planes lie at equal intervals upon straight lines whose direction ($O B_1$) is determined by the points in the first two webs.

In this way a *network* of points is constructed, in which the line joining any two points is a *thread*, and the plane through any three points is a *web*.

The space inclosed by six adjacent planes of the system having no other points of the network between them is a parallelepiped ($O A_1 B_1 C_1$), from which the whole system may be constructed by repetition, and which may be taken to represent the structural element (*molécule soustractive*) of Hailly.

The complete investigation of all possible solid networks led Bravais to the conclusion that these, if classified by the character of their symmetry, fall into seven groups, which correspond exactly to the seven systems into which crystals are grouped in accordance with their symmetry.

It follows, then, that two (not, however, independent) features of crystals are fully accounted for by a parallelepipedal arrangement of points in space—namely, the symmetry of the crystallographic systems and the law which governs the inclinations of the faces (law of rational indices).

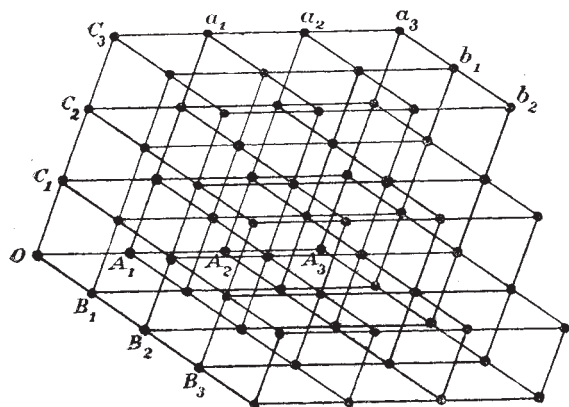


FIG. 1.

There are, however, subdivisions of the various systems consisting of the merohedral or partially symmetrical crystals belonging to them, which are not explained by the geometry of a network; these consequently were referred by Bravais, not merely to the arrangement of the molecules in space, but also to the internal symmetry of the molecule itself.

Hence the theory of Bravais, while able to a certain extent to explain the form of crystals, requires an auxiliary hypothesis if it is to explain those modifications which are partially symmetrical or merohedral.

Sohncke, treating the problem in a different manner, and reasoning from the fact that the properties of a crystal are the same at any one point within its mass as at any other but different along different directions, inquired in how many ways a system of points may be arranged in space so that the configuration of the system round any one point is precisely similar to that round any other. Such a configuration may be called a *Sohncke system* of points in space (*regelmässiges Punktsystem*).

From his analysis of this problem, it appears that there are sixty-five possible Sohncke systems of points, and that these may be grouped according to their symmetry into seven classes corresponding to the seven crystallographic systems; and further that there are within each class

minor subdivisions, characterized by a partial symmetry corresponding to the hemihedral and tetartohedral forms of crystallographers.

It may be expected, then, that the theory of Sohncke contains within itself the essential features of a Bravais network of structural molecules, and also the auxiliary hypothesis regarding the arrangement of parts within the molecule which is required to account for merohedrism.

Now, on closer examination the arrangement of Sohncke does prove to be a simple extension of that of Bravais.

Each of Sohncke's arrangements may in fact be regarded as derived from one of the parallelepipedal networks of Bravais if for every point of the latter be substituted a group of symmetrically arranged satellites. It is not necessary that any particle in a group of these satellites should actually coincide with the point of the Bravais network from which the group is derived; and the points of the Sohncke system do not themselves form a network; it is only when all the points in each group of satellites are condensed into one centre that a Sohncke system coincides with a Bravais network.

To any particle of one of the satellite groups corresponds in every other group a particle similarly situated with regard to the point from which the group has been derived. Every such point may be said to be homologous with the first.

It will then be found that each complete set of homologous points is itself a Bravais network in space, and that consequently any Sohncke system may be regarded as a certain number of congruent networks interpenetrating

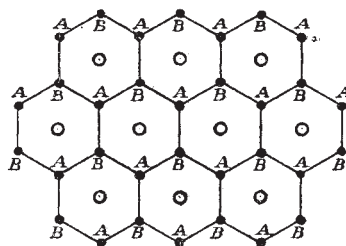


FIG. 2.

one another: the number of such networks is in general equal to the number of points which constitute each group of satellites.

The relation of a Sohncke system to the network from which it is derived may be illustrated by a bees'-cell distribution of points in one plane, *i.e.* by points which occupy the angles of a series of regular hexagons. Thus in the adjoining figure the dots form a Sohncke system in one plane, since the configuration of the system round any one point is similar to that round any other; but they do not form a Bravais web, since the points do not lie at equal distances along straight lines.

If, however, points, represented in the figure by the circles O, be placed at the centres of the hexagons, they will by themselves constitute a web, and the hexagonal system may be derived from this web by replacing each of its points by a group of two satellites, A and B. Or, from the second point of view, the arrangement may be regarded as a triangular web, A, completely interpenetrated by a similar web, B.

It is a remarkable feature of the Sohncke systems that some among them are characterized by a spiral disposition of the particles along the threads of a right- or left-handed screw: now this spiral character, which does not belong to any of the Bravais networks, supplies a geometrical basis for the right- or left-handed nature of some merohedral crystals which possess the property of right- or left-handed rotatory polarization.

The theory of Sohncke as sketched above appeared to

be expressed in the most general form possible, and to include all conceivable varieties of crystalline symmetry.

It has, however, recently been pointed out by Wulff¹ that the partial symmetry of certain crystals belonging to the rhombohedral system—that, namely, of the minerals phenacite and diopase—is not represented among the sixty-five arrangements of Sohncke.

Other systems of points in space have also been studied by Haag² and Wulff, which do not exactly possess the properties of a Sohncke system, and yet might reasonably be adopted as the basis of crystalline structure, since they lead to known crystalline forms.³ These, however, and all other systems of points which have been proposed to account for the geometrical and physical properties of crystals, may be included in the theory of Sohncke after this has received the simple extension which is now added by its author.

In Bravais's network all the particles or structural elements were supposed to be identical, and in Sohncke's theory also there is nothing in their geometrical character to distinguish one particle from another.

In Fig. 2, the hexagonal series of dots may, as was said above, be regarded as composed of a pair of triangular webs, A and B; now these, although identical in other respects, are not parallel, for the distribution of the system round any point of A is not the same as that round any point of B until it has been rotated through an angle of 60° .

It is possible, however, to conceive similar interpenetrating networks which differ not only in their orientation but even in the character of their particles. The centre of each hexagon, for example, may be occupied by a particle of different nature from A and B to form a new web, O. The three webs are precisely similar in one respect, since their meshes are equal equilateral triangles; moreover, if the position of the points alone be taken into account, the whole system would form a Bravais web, *i.e.* if the particles of O were identical with those of A and B. If, however, as is here supposed, the set O consists of particles different in character from A and B, the distribution round any point of O is totally distinct from that round any point of A or B. The points O are geometrically different from the points A B. The web A is interchangeable with B, but O is interchangeable with neither.

Now, it is precisely an extension of this kind which must be given to Sohncke's earlier theory if it is to embrace all the crystalline arrangements which have been alluded to above. The interpenetrating networks are no longer to be regarded as consisting necessarily of identical particles; the structural units of a crystal may be of more than one kind.

The above figure represents a Sohncke system, A B, of particles of one sort interpenetrated by a Bravais web, O, of another sort; but there is no reason why two or more different Sohncke systems, no one of which is identical with a Bravais network, may not interpenetrate to form a crystal structure.

In its most general form, then, the theory may now be expressed—

A crystal consists of a finite number of interpenetrating Sohncke systems which are derived from the same Bravais network. The constituent Sohncke systems are in general not interchangeable, and the structural elements of one are not necessarily the same as those of another.

Or, since each Sohncke system consists itself of a set of interpenetrating networks, the theory may be thus expressed—

A crystal consists of a finite number of parallel interpenetrating congruent networks: the particles of any one network are parallel and interchangeable; these networks group themselves into a number of Sohncke systems in

each of which the particles are interchangeable but not necessarily parallel.

The number of kinds of particles which constitute the crystal may therefore be equal to the number of Sohncke systems involved in its construction.

The structural units are no longer, as they were in the theory of Bravais, necessarily identical, but may represent atomic groups of different nature.

The system in Fig. 2 consists of two sets of particles, A B and O; and, if a large enough number of these be taken, any portion of the system (*i.e.* any crystal constructed in this manner) consists of the particles united in the proportion of two of the first group to one of the second. Such an arrangement, then, may represent the structure of a compound, $O A_2$.

"When, for example, a salt in crystallizing takes up so-called water of crystallization which is only retained so long as the crystalline state endures, the chemical molecule salt + water cannot be said to exist except in the imagination, for the presence of such a molecule cannot be proved. To obtain an easily intelligible example, without, however, pronouncing any opinion as to whether it may be realized, imagine the centred hexagons in the figure to be constructed in such a way that each corner consists of the triple molecule $3H_2O$, and each centre consists of the molecule R. The chemical formula would then be $R + 6H_2O$, and yet a molecule of this constitution would not really exist; on the contrary, the structural elements in the crystallized salt would be of two sorts—namely, R and $3H_2O$."¹

Hence it is geometrically possible that the structural elements of a crystal may be different atomic groups which are held in a position of stable equilibrium by virtue of being interpenetrating networks.

Whether such systems are chemically and physically possible must be left for future criticism to decide.

Finally, we may call attention to a remarkable declaration of faith which has recently been made in Germany by one who is a recognized leader in crystallographic and mineralogical science.

Prof. Groth² has suggested that there may be something more than a chance similarity between the theory of Sohncke and the views of the eminent French crystallographer Mallard, whose classical research upon the optical anomalies of crystals has been the means of dividing the students of this subject into two adverse camps. The explanation of Mallard has up to the present time found little favour among those German mineralogists who have made similar investigations. Prof. Groth has now, however, declared himself in favour of Mallard, being apparently induced to do so by the support which is given to his views by the theory of Sohncke.

Mallard has ascribed the optical anomalies of various substances to a complete or partial intergrowth of two or more crystals which combine in such a manner as to simulate a symmetry of higher order than that which naturally belongs to them. Now, since Mallard regards each crystal as composed of a Bravais network, it is evident that his views are not far removed from those of Sohncke, whose system is based upon the possible intergrowth of two or more networks.

H. A. MIERS.

THE EARTHQUAKE AT BAN-DAI-SAN, JAPAN.

AS it may interest our readers to know the present state of matters at the scene of the great earthquake which occurred lately at Ban-dai-san, Japan, we think it well to publish the following narrative just received by Dr. George Harley, F.R.S., in a private letter from his son, who has recently visited the locality of the sad disaster.

¹ *Zeitschr. f. Kryst.* xiii. (1887) p. 503.

² "Die regulären Kristallkörper." (Rottwell, 1887.)

³ Cf. W. Barlow, *NATURE*, xxix. (1884) pp. 186, 205.

¹ Sohncke, *Zeitsch. f. Kryst.* xiv. p. 443.

² "Ueber die Molekularbeschaffenheit der Krystalle." (Festrede, München, 1888.)