apparently overgrown with a creeping moss or jungermannia; and Mr Belt discovered a larval form in Nicaragua whose body was prolonged into thin green filaments, precisely like the moss in which it lurked. In other instances the insect probably uses its disguise rather to deceive its prey than to escape its enemies. Sir Joseph Hooker believes that an Indian *Mantis* deludes the little creatures which form its food by its singular likeness to a leaf; while Sir Charles Dilke found one which had its head and fangs moulded into the deceptive appearance of an orchid, so that small flies were actually attracted in search of honey into its very jaws. Outside the class of insects, similar phenomena sometimes occur. Thus, according to Mr Bates, many showy little tropical spiders double themselves up at the base of leaf stalks so as to resemble flower buds, and thus delude the flies on which they prey. Even among the vertebrates Mr Belt mentions a green Nicaraguan lizard looking like the herbage by which it is surrounded, and decked with leaf-like expansions, which hide its predaceous nature from passing beetles or butterflies.

These last instances are divided from true mimicry by a very narrow line. But they differ in the fact that some vague object only in the general environment is simulated, not a particular protected species, as in genuine mimetic resemblance. If we allow, however, that natural selection can produce the white colour of Arctic animals, and the sandy hue of the sole and the flounder, it is easy enough to extend the same principle to the leaf-insect and the stick-insect, or even to real mimicry, as in the case of the *Leptalis* and the *Heliconidæ*. Certain *Phasmidæ* may at first have varied in the direction of green coloration, and these would naturally escape the eyes of birds more readily than their fellows. After the lapse of many generations, all the *Phasmidæ* of that special group would have become green, and the birds which preyed upon them would have learned in many cases to penetrate the disguise; for, as Mr Belt has observed, each fresh deceptive resemblance in the prey is sure to be followed by increased keenness of discrimination in the enemies of the species. At this stage the ordinary green *Phasmidæ* would often be killed, while only those which happened to approximate rudely in the venation of their wings to leaves would now escape the sharper and more experienced eyes of the birds. Thus step by step the disguise would become more and more perfect, only the best-protected of each generation escaping on the average, while all the worse-protected would be discovered and devoured. Given the usual luxuriance of tropical life, it is not difficult to understand how favourable variations might continually occur, until at length we get such perfect deceptions as those of the leaf-insects, the stick-insects, and the moss-grown larvæ.

The phenomena of true mimicry may be explained by a parallel genesis. Suppose, to begin with, a group of large and brilliant butterflies like the South-American *Heliconidæ*, protected by a nauseous taste and odour, and therefore never eaten by birds. To such insects slow flight and conspicuous hues are a positive protection, because they enable birds readily to discriminate them, and therefore prevent attacks, just as the banded body of the wasp and the hum of the bee prevent us from catching and killing them upon a window pane. Suppose, again, that in the same district there lives a widely different species of edible butterfly presenting some very slight and remote resemblance to the protected species. At first, no doubt, the resemblance will be merely an accidental one of general hue; it may even be so slight as to deceive nobody except upon the most distant and casual glance. Now, suppose these edible butterflies to be devoured in large quantities by birds, then a few of them may happen to gain safety by associating with the flocks of inedible butterflies which the birds refuse. After a time, even if the habit of consorting with the protected species becomes fixed in the race, the birds will begin to recognize the edible insects amongst the flocks, especially such as vary most in the opposite direction from the protected species. On the other hand, they will overlook such as vary most in the same direction as the inedible kind; and thus the least mimetic individuals will be destroyed, while the most mimetic will be left to pair with one another and to produce young, most of whom will present the like peculiarities. From generation to generation the birds will go on picking out every bad copy, and sparing all the best ones, till at last the two species become absolutely indistinguishable upon the wing. But the mimicry will never of course affect any but the most external and noticeable parts of the organism; it will be to the last a mere matter of colour, shape of wing, visible appearance of legs or antennæ, and so forth. The underlying structural differences will remain as great as ever, though externally masked by the deceptive resemblance in form and hue.

In like manner we may explain the genesis of the mimetic resemblance borne by *Volucella* to the humble bee. Suppose an undisguised fly to enter the bees' nest, it would be at once attacked and killed. But if it presented some very slight resemblance to the bee it might manage to lay its eggs undisturbed, and its larvæ would then be able to feed quietly upon the larvæ of the bee. With each new generation the more flimsy disguises would be more and more readily detected, and only those flies which varied most in the direction of resembling the bees would survive or lay their eggs in peace. On the other hand, those which actually succeeded would possess great advantages over their neighbours, because their larvæ would thus obtain a safe and certain supply of food, and be guaranteed the protection of the bees' nest. In this way the flies would at last, by constant survival of the best-adapted, come exactly to imitate the bees amongst which they lived.

The theory of the origin of mimetic forms thus briefly sketched out is due to Mr Bates and Mr Wallace, and it explains all the facts more fully than any other. It shows us, first, why the mimicking organism always imitates a specially protected species; secondly, why the two always inhabit the same district; thirdly, why the mimicking species is always much rarer than the species mimicked; fourthly, why the phenomenon is confined to a few groups only; and fifthly, why several different mimicking species often imitate the same protected form. It also accounts for the absence of mimicry amongst large or dominant animals, and its comparative commonness amongst small and defenceless kinds. And by affiliating the whole of the phenomena upon the general principles of protective colouring it reduces a seemingly strange and marvellous fact to a particular case of a well-known law.

Whatever theory be adopted, however, the facts and most of their implications remain the same For, whether we suppose these imitative resemblances to be due to direct creative design or to survival of favourable variations, it is at least clear that the disguise subserves a function—that it is purposive and not accidental. Hence we may draw from the phenomena of mimicry certain important psychological implications. On the hypothesis of evolution, it is obvious that the mimicry can never go further than the senses of the creatures against whom the disguise is advantageous would naturally carry it; and even on the hypothesis of special design it is not likely that the imitation would be made more accurate than would be necessary for practical purposes of deception. There is much evidence in favour of this view. Mr B. T. Lowne, for example, who has carefully measured the curvature of the facets in the compound eyes of insects, upon which depends the minimum size of apprehensible objects, finds that the mimicry in the case of the flies parasitic upon bees' nests has proceeded just so far as the structure of the bee's eye would lead us to expect, and no further. In other words, so far as measurements of angular distance subtended can guide us, such a fly seems to be absolutely indistinguishable by a bee from one of his own species, within the limits of ordinary vision. The pictures cast upon the sensorium by the fly and by a brother bee are simply identical. In many other cases it can be shown that the mimicry seems specially intended to deceive the eyes of a particular class of animals; while there is no case of mimicry where the only enemies or prey consist of plants or eyeless animals. Naturally there can be no mimicry without a creature to deceive; the very conception implies an external nervous system to be acted upon, and to be acted upon deceptively. Thus mimicry in plants must have reference to the eyes of animals, in animals themselves to the eyes of one another. We may conclude, accordingly, that if a leaf-insect is green with faint violet-brown veins to the wings, exactly like a certain leaf, in order to deceive sundry tropical birds, then those birds are capable of perceiving the forms and colours imitated to that particular degree. So the presence of mimicry in any group may guide us to a rough idea of the perceptive powers of those creatures whom the mimicry serves to deceive. The exact imitation of sand and coloured pebbles in the flat-fish is a fairly safe indication that the predaceous fish by whose selection they have been developed (through the weeding out of ill-protected variations) can pretty accurately distinguish form and colour. The long green pipe fish which cling around green sea-weed have probably acquired their existing hues to deceive the eyes of small sharks; the *Phyllopteryx eques*, a hippocampus which looks precisely like a piece of tangled and waving fucus (see figure, vol. xi. p. 852), has doubtless in the same way taken on its delusive likeness to the algæ among which it lives. So the cricket which resembles its foe the sand-wasp must have gained its present shape and hue by deceiving its enemy, and therefore it suggests the probability of highly developed vision on the part of the wasps. There seems every reason to believe that in many instances insects, spiders, and even lizards have developed mimetic or other deceptive resemblances in order to delude the eyes of insects; while in other cases the disguise has been unconsciously adopted to deceive fish, amphibians, reptiles, birds, and mammals. Moreover, we have some grounds for believing that the sense of colour is exceptionally strong in birds and in one or two insect orders; and the mimicry of colour seems to have proceeded to the greatest length amongst animals which are most exposed to the attacks of these classes, or which would find it advantageous to deceive them. It may be added that these same classes have been most effective in producing the bright hues of flowers and fruits, on Mr Darwin's hypothesis, or are at least in any case most intimately correlated with such vegetable structures as fertilizers of blossoms and dispersers of seed. Mimicry is thus to some extent a rough gauge of the perceptive faculties of the species deceived by it.

The vocal mimicry which occurs among certain birds, such as the mocking-bird, starling, parrot, and bullfinch, must of course be placed in a wholly different category from these biological cases. It is a direct volitional result, and it is mimicry in a literal not in a figurative sense. The faculty seems to be due to the play-instinct alone, and not to subserve any directly useful function. (G. A.)

MIMNERMUS, a Greek elegiac poet, born at Smyrna, lived about 600 B.C. His life fell in the troubled time when the old Greek city of Smyrna was struggling to maintain itself against the rising power of the Lydian kings. One of the extant fragments of his poems refers to the struggle and contrasts the present effeminacy of his countrymen with the bravery of those who had once defeated the Lydian king Gyges. The poet mentions in another fragment that he belonged to the stock of the Colophonians who had seized the Æolic Smyrna. But his most important poems were a set of elegies addressed to a flute-player named Nanno; they were collected in two books called after her name. Hermesianax mentions his love for Nanno, and implies that it was unfortunate. Only a few fragments of these poems have been preserved; and their soft melancholy tone and delicate language give some idea of the poet's character. His ideal is the sweet soft luxurious Ionian life, and he would enjoy it free from sorrow and die as soon as he could no longer enjoy it. Yet there is apparent some of the old stronger strain of character which in early time raised the Ionian cities to greatness, pride in the glories of his race and scorn for those that are unworthy of their fathers' renown. His experience of life was evidently sad; he felt that his country was gradually yielding to the enemy it had once defeated, and he knew that his own hopes were disappointed. The sun himself has endless toils from rising to setting and again from setting to rising. The life of man is as transitory as the leaves of spring, he says, referring to a passage in the popular epic poetry of Ionia (*Iliad*, vi. 146). He wishes to die in his sixtieth year, a wish to which Solon replied bidding him reconsider and rather long to die when he was eighty years old. Mimnermus was the first to make the elegiac verse, which had previously had more of the epic character, the vehicle for love-poetry, and to impart to it the colour of his own mind. He found the elegy devoted to objective themes; he made it subjective. He set his own poems to the music of the flute, and the poet Hipponax says that he used the melancholy *νόμος Κραδίας*. He bears the epithet Λιγυαστάδης, by which Solon addresses him. It is doubtful whether this epithet is peculiar to himself or whether it marks him as belonging to a musical and poetic family or school; it is evidently akin to the epithet *λίγειαι Μοῦσαι*.

MIMOSA. The *Mimoseæ* (so named from their mimicry of animal movements) form one of the three suborders of *Leguminosæ*, and are characterized by their (usually small) regular flowers and valvate corolla. Their 28 genera and 1100 species are arranged by Baillon in four series, of which the acacias (see ACACIA) and the true mimosas are the most important. They are distributed throughout almost all tropical and subtropical regions, the acacias preponderating in Australia and the true mimosas in America. The former are of considerable importance as sources of timber, gum, and tannin, but the latter are of much less economic value, though a few, like the talh (*M. ferruginea*) of Arabia and Central Africa, are important trees. Most are herbs or undershrubs, but some South-American species are tall woody climbers. They are often prickly. The roots of some Brazilian species are poisonous, and that of *M. pudica*, L., has irritating properties. *M. sensitiva* has been used in America in the treatment of fistula, &c., probably as an astringent. The mimosas, however, owe their interest and their extensive cultivation, partly to the beauty of their usually bipinnate foliage, but still more to the remarkable development in some species of the sleep movements manifested to some extent by most of the pinnate *Leguminosæ*, as well as many other (especially seedling) plants. In the so-called "sensitive plants" these movements not only take place under the influence of light and darkness, but can be easily excited by mechanical and other stimuli. When stimulated, say at the axis of one of the secondary petioles, the leaflets move upwards on each side until they meet, the movement being propagated centripetally. It may then be communicated to the leaflets of the other secondary petioles, which close (the petioles, too, converging), and thence to the main petiole, which sinks rapidly downwards towards the stem, the bending taking place at the pulvinus, or swollen base of the leafstalk. See BOTANY, vol. iv. p. 113, fig. 117. When shaken in any way, the leaves close and droop simultaneously, but if the agitation be continued, they reopen as if they had become accustomed to the shocks. The common sensitive plant of hot-houses is *M. pudica*, L., a native of tropical America but now naturalized in corresponding latitudes of Asia and Africa; but the hardly distinguishable *M. sensitiva* and others are also cultivated. The common wild sensitive plants of the United States are two species of the closely allied genus *Schrankia*.

MINDANAO, MINDORO. See PHILIPPINE ISLANDS.

MINDEN, the chief town of a district of the same name in Prussia, province of Westphalia, is situated about 22 miles to the west-south-west of Hanover, on the left bank of the Weser, which is spanned there by two bridges. The older parts of the town retain an old-fashioned appearance, with narrow and crooked streets; the modern suburbs occupy the site of the former fortifications. The most interesting building is the Roman Catholic cathedral, the tower of which, dating from the 11th century, illustrates the first step in the growth of the Gothic spire in Germany. The nave was erected at the end of the 13th century, and the choir in 1377–79. Among the other chief edifices are the old church of St Martin; the town-house, with a Gothic façade; the extensive court-house; and the Government offices, constructed, like many of the other buildings, of a peculiar veined brown sandstone found in the district. Minden contains a gymnasium and several hospitals, besides other charitable institutions. Its industries include linen and cotton weaving, dyeing, calico printing, and the manufacture of tobacco, leather, lamps, chicory, and chemicals. There is also some activity in the building of small craft. In 1881 107 vessels of an aggregate burden of 12,569 tons entered and cleared the river-harbour of Minden. The population in 1880 was 17,869.

Minden (Mindun, Mindo), apparently a trading place of some importance in the time of Charlemagne, was made the seat of a bishop by that monarch, and subsequently became a flourishing member of the Hanseatic League. In the 13th century it was surrounded with a wall. Punished by military occupation and a fine for its reception of the Reformation in 1547, Minden underwent similar trials in the Thirty Years' War and the wars of the French occupation. In 1648 the bishopric was converted into a secular principality under the elector of Brandenburg. From 1807 to 1814 Minden was included in the kingdom of Westphalia, and in the latter year it passed to Prussia. In 1816 the fortifications, which had been razed by Frederick the Great after the Seven Years' War, were restored and strengthened, and as a fortress of the second rank it remained the chief military place of Westphalia down to 1873, when the works were finally demolished. At Todtenhausen, 3 miles to the north of Minden, the allied English and German troops under the duke of Brunswick gained a decisive victory over the French in 1759. About 3 miles to the south of Minden is the so-called "Porta Westfalica," a narrow and picturesque defile by which the Weser quits the mountains and reaches the plain.

Minden is not to be confounded with the Hanoverian Münden, also sometimes written Minden (population 6355), at the confluence (*Mündung*) of the Werra and Fulda.

MINE. See MINING.

# MINERALOGY

NATURAL objects which are homogeneous in their mass, and in which no parts formed for special purposes can be distinguished, are termed "minerals"; and the branch of natural science which treats of these is termed mineralogy. Minerals differ from the structures treated of in botany and zoology in the three following particulars. (1) They differ in the mode of their formation; this has been accomplished, not by assimilation of matter, producing growth from within, but by augmentation of bulk through accretion of particles from without. (2) Minerals are not heterogeneous. While the objects treated of in the other departments of natural history consist of beings possessed of life, and having parts which, being mutually dependent, cannot be separated from one another without a more or less complete destruction of the individual, the objects treated of under the department of mineralogy have so uniformly consistent an individuality that they are not destroyed by any separation of parts,—each portion or fragment possessing the same properties and the same composition as the whole. And (3), while those beings which are possessed of life have their component elements grouped into complexes, for the most part capable of more or less freedom of motion and susceptible of change, minerals have a constitution resulting from chemical attractions alone and an arrangement of their parts, under physical influences, which has resulted in rigidity and an absence of all tendency to change.

## FORM OF MINERALS—CRYSTALLOGRAPHY.

Definition of a mineral. The most precise definition of a mineral would be—an inorganic body possessed of a definite chemical composition, and usually of a regular geometric form. Of these, the second is in one respect the direct outcome of the first; while many of the most important physical properties possessed by minerals are outcomes of the second.

Both the geometric form and the composition of minerals are produced and modified under the influence of general laws.

Mineral bodies occur in the three physical conditions of solid, liquid, and gas. Those now found in the last two states are few in number, and are of altogether inferior interest to those which occur as solids; but there is reason to believe that the minerals we know as solids once existed in the liquid or gaseous state, and that their present structure was determined in the process of solidification. All bodies thus formed may be divided into two great classes:—

1. Amorphous bodies, or such as do not possess a definite and characteristic geometrical form. These (when transparent) refract light singly in every direction (except when under stress); they are equally easy or equally difficult to break in all directions; when broken they exhibit a conchoidal or an earthy fracture; they are equally hard throughout all their parts; they are equally elastic in all directions; they conduct heat with equal rapidity and in equal amount in all directions.

2. Crystalline bodies, or such as occur in definite geometrical forms bounded by flat surfaces. These present greater facilities of separation of their particles, or "cleavage," in certain directions lying in determinate planes than they do in others; most of them are neither equally hard nor equally elastic in all directions, conduct heat more rapidly in certain directions than they do in others, and, when transparent, refract light doubly except in certain directions.

Mineral bodies are found in both of the above classes; and the same mineral body may occur in both the amorphous and the crystalline condition. This is seen in the piece of gold shown in fig. 1, where the upper portion has a sharply angular and a well-defined shape, while the lower presents curvilinear and rugged outlines, similar to one another in no part. Under favouring circumstances, it is possible that every substance whose composition is capable of being represented by a definite chemical formula—*i.e.*, which has an unvarying composition—may be capable of assuming a definite crystalline form.

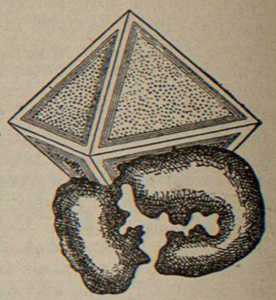

Fig. 1.

*Size and Form of Crystals.*—They are of every size from over a yard in diameter to mere specks requiring a high power of the microscope to reveal their existence. Beryls have been obtained in America more than 4 feet in length by 2½ in thickness, weighing 2½ tons. Equally large crystals of apatite have been found in Canada. There is a rock crystal at Milan 3¼ feet long by 5½ in circumference, weighing 870 lb. The highest perfection of form, and hence of other properties, is only found, however, in crystals of moderate or of small size.

*Variety of Form, and Constancy of Form.*—The same mineral may be found in different localities, or sometimes in the same locality, exhibiting an almost endless variety of forms. Variety of form. Calc-spar occurs at a Scottish locality in acicular pyramidal crystals of which the length may be ten or more times as great as the width (fig. 2); in flat plates as thin as paper, in which the length is not the hundredth part of the width; also in prisms, pyramids, and rhombohedra, which at first sight (as in figs. 3, 4) seem destitute of any relationship to each other. This substance has elsewhere been noted in several hundred forms. The minerals fluorite, pyrite, and baryte have each been observed in over a hundred diverse forms. Nevertheless, however great the number, all the forms, in the case of each mineral, may be reduced or referred to a single type, by the simple process of examining its internal structure or the mode of arrangement of its molecules. This is accomplished in two ways—(1) by finding the weak joints in that arrangement, through splitting the crystal, and (2) by measuring the angular inclination of the outside surfaces which bound the form and, from these measurements, by simple mathematical laws, arriving at what has been termed its "primitive" or simplest form.

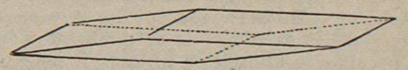

Fig. 3.

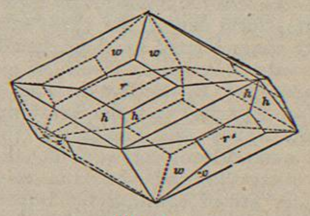

Fig. 4.

Fig. 2.

As regards the mere recognition of a substance, such measurement in itself suffices,—the angular inclination, if the same surfaces be measured, being unvarying in each species. It can, moreover, be shown that the possible range of external variety of form is governed by fixed mathematical laws, which determine precisely what crystalline forms are or may be produced for each species. Comparatively few of these actually occur in nature; but crystallographic laws can point out the range of those which can possibly occur, can delineate them even before they are found, and can in all cases show the relationship which subsists between them and the simple or fundamental form from which or out of which they all originate. It must be observed that in crystalline bodies the internal structure—that is, the arrangement of the molecules—is as regular in an outwardly shapeless mass as in the modelled crystal which presents itself as a perfect whole.

*Definitions of Crystals, and their Members or Parts.*—A crystal is a symmetrical solid, either opaque or transparent, contained within surfaces which theoretically are flat, and of a perfect polish, but which are actually frequently curved, striated, or pitted. These surfaces are called "planes," or "faces." The external planes of a crystal are called its "natural planes"; the flat surfaces obtained by splitting a crystal are called its "cleavage planes." The intersections of the bounding planes are called "edges," and planes are said to be similar when their corresponding edges are proportional and their corresponding angles equal. Crystals bounded by equal and similar faces are termed "simple forms." The cube, bounded by six equal squares, the octahedron, bounded by eight equilateral triangles, and the rhombohedron, bounded by six equal rhombs, are thus simple forms. Crystals of which the faces are not all equal and similar are termed compound forms, or "combinations," being regarded as produced by the union or combination of two or more simple forms. Edges are termed rectangular, obtuse, or acute, according as the angle at which the faces which form the edge meet is equal to, or greater or less than, a right angle. Edges are similar when the planes by the intersection of which they are formed are respectively equal and equally inclined to one another; otherwise they are unlike or dissimilar.

When a figure is bounded by only one set of planes, it is said to be "developed." When an edge is cut off by a new plane, it is said to be "replaced"; when cut off by a plane which forms an equal angle with each of the original faces which formed the edge, it is said to be "truncated." When an edge is cut off by two new faces equally inclined to the two original faces respectively, it is said to be "bevelled." When a solid angle is cut off by a new face which forms equal angles with all the faces which went to form the solid angle, it is said to be truncated.

In classifying crystals and studying their properties, it is found convenient to introduce certain imaginary lines called "axes." Axes are imaginary lines connecting points in the crystal which are diametrically opposite,—such as the centres of opposite faces, the apices of opposite solid angles, the centres of opposite edges. Different sets of axes may thus be drawn through the same crystal; but there is always one set, usually of three, but in one special class of crystals of four, axes, by reference to which the geometrical and physical properties of a crystal can be most simply explained. These axes intersect one another, either at right angles, producing "orthometric" forms, or at oblique angles, producing "clinometric" forms. The axes may be all equal, or only two equal, or all unequal.

There is a definite conventional position in which for purposes of description a crystal is always supposed to be held. With reference to this position one of the axes,—that which is erect or most erect,—is termed the "vertical," and the others the "lateral." The planes in which any two of the axes lie are called the "axial" or "diametral planes,"—sometimes "sections." By these the space around the centre is divided into "sectants." If there are, as is generally the case, only two lateral axes, the space is divided into eight sectants, or octants; but, if there are three lateral axes, it is divided into twelve sectants.

*Primitive Forms of Crystals.*—If we attempt to arrive, through a study of the internal structure of crystals, as evidenced by directions of weakness of cohesion, at the total number of primitive or parent forms which can exist we find that there are thirteen such forms and no more.

Nine of these may be regarded as prisms standing upon a base, three as octahedra standing upon a solid angle; and there is one twelve-sided figure, or dodecahedron.

*Prisms.*—Of the prisms eight have a four-sided base. Prisms.

If the base is square and the prism stands erect—that is, if its sides or lateral planes, as they are called, are perpendicular to the base—the form is termed a "right square prism" (fig. 6). In this the four lateral planes are rectangular and equal; they may be either oblong or square; in the latter case the form is the "cube" (fig. 5). When the base is a rectangle instead of a square, the form is a "right rectangular prism" (fig. 7). In each of the above three forms the edges are twelve in number. In the cube all the edges are equal. In the square prism the lateral edges are all equal, but are different from the four equal edges of the base. In the rectangular prism, two at each base differ in length from the other two, while both differ from the lateral; hence there are here three sets of edges, four in each. In each of the three forms, however, the solid angles are eight in number. all equal, and each enclosed by three right angles.

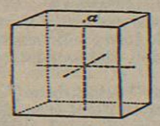

Fig. 5.

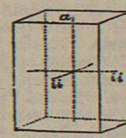

Fig. 6.

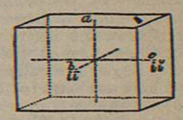

Fig. 7.

When the base is a rhombus, and the prism stands erect, the form is a "right rhombic prism" (fig. 8). Two of the angles in the base being here acute and two obtuse, two of the solid angles corresponding each with each must differ from the others. So also must two of the lateral angles be acute and two obtuse. The four lateral faces are equal.

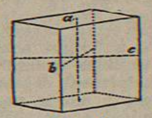

Fig. 8.

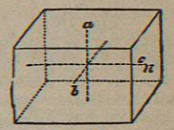

Fig. 9.

When the base is a rhomboid, and the prism stands erect, it is only the opposite lateral faces that can be equal. The form is called a "right rhomboidal prism" (fig. 9).

When the base is a rhombus, but the prism stands obliquely on its base, the form is called an "oblique rhombic prism" (fig. 10). Here the basal edges of the lateral planes are all equal in length, but on account of the inclination of the prism the angles which these edges form with the lateral edges of the lateral planes are two acute and two obtuse.

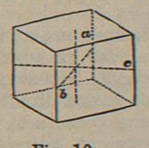

Fig. 10.

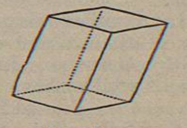

Fig. 11.

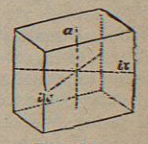

Fig. 12.

If all the edges of an oblique rhombic prism are equal in length to the breadth of the base, and if the lateral planes are rhombi equal in all respects to the basal, the form is called a "rhombohedron" (fig. 11). This is included within six equal planes, like the cube, but these planes have oblique angles. The rhombohedron thus bears the same relation to the oblique rhombic prism which the cube does to the right square prism. Of the eight solid angles of a rhombohedron only two are contained by three equal plane angles, and these two "apices," as they may be called, are opposite one another. According as the apices are acute or obtuse, we have an acute or obtuse rhombohedron.

When the base of an oblique prism is a rhomboid, the prism becomes an "oblique rhomboidal prism" (fig. 12). In this form, only diagonally opposite edges are similar, as regards equality of length and the value of the included angle. Only opposite solid angles are equal, as are also the opposite and parallel faces.

A right prism may have an equilateral six-sided base; it is then called an "hexagonal prism." This form may be developed in two positions relatively to each other,—one in which the transverse axes pass from the centres of opposite faces (fig. 13), the other in which they pass from the centres of opposite edges of the planes (fig. 14). The faces of the one set mutually truncate the edges of the other. If a rhombohedron be positioned so as to rest upon one of its apices, the faces of one hexagonal prism would truncate the lateral *edges* of the rhombohedron, while the faces of the other hexagonal prism would truncate its lateral *solid angles*. Hexagonal prisms may be longer or shorter than the width of their bases. The interfacial lateral angles are 120°. The angle between the lateral and terminal faces is 90°.

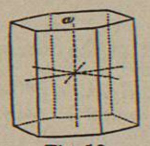

Fig. 13.

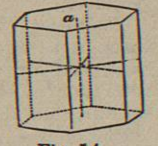

Fig. 14.

*Octahedra.*—The planes of these eight-faced solids are triangular, and they may be regarded as made up of two four-sided pyramids applied to each other, base to base. They are always positioned so that they stand upon a solid angle with the "basal plane"—that is, the plane which is the common base of the two pyramids—horizontal. In the primitive forms now under consideration the vertices of the two pyramids will in this position be vertically above and below the centre of the base. The upper and lower solid angles are then termed the "vertical solid angles," and the four lateral solid angles are called the basal solid angles.

There are three octahedrons. In the "regular" octahedron (fig. 15) the base is a square, and the eight faces are equilateral triangles of equal size. There are twelve edges, which are all equal. The faces incline to each other at an angle of 109° 28′ 16″, and have the plane angles all 60°. There are six equal solid angles. When the base of the octahedron is square, but the other edges, although equal to one another, are either longer or shorter than the edges of the base, the form is a "right square octahedron" (fig. 16). In this the faces are isosceles triangles, the equal angles being at the basal edge of the planes. These basal edges are equal and similar, but differ in length and in angles from the eight equal pyramidal edges. When the base of an octahedron is a rhombus, it is called a "right rhombic octahedron" (fig. 17).

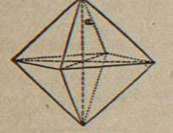

Fig. 15.

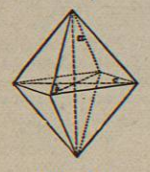

Fig. 16.

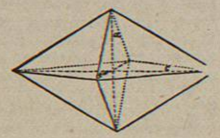

Fig. 17.

*Dodecahedron.*—This (fig. 18) has each of its twelve faces a rhombus. It is, like the cube and the octahedron, a solid which is symmetrical. The interfacial angles are all 120°, the plane angles are 109° 28′ 16″ and 70° 31′ 44″. The edges are twenty-four, and similar. There are fourteen solid angles, of which six are formed each by the meeting of four acute plane angles, and eight by the meeting of three obtuse plane angles.

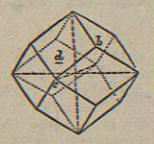

Fig. 18.

It has been said that the above simple forms were arrived at through a study of the internal structure of crystals, chiefly as disclosed by cleavage. Inasmuch, however, as there are some minerals which cleave in only one direction, and many which cannot be cleaved in any direction, this method of investigation fails. Its employment, moreover, frequently led to conflicting or embarrassing results. A conflicting result is when a substance has more than one set of cleavages,—that is, splits up in directions which would result in the production of more than one of the above primary or simple forms. Thus the mineral fluorite occurs with much the greatest frequency in the form of the cube, and it might very consistently be held that its frequent occurrence in this form was a clear natural indication that the cube was the primary or simplest form of fluorite; but it splits up into an octahedron. Galena crystallizes frequently in the form of the octahedron; yet to cleavage galena yields a cubic primary form. It might be conceived that there had been, in each case, some special tendency to assume the cubic form and the octahedral form; but one and the same piece of rock may bear on its surface cubic crystals of fluor and octahedral crystals of galena,—each of the minerals having here assumed the primitive cleavage form of the other in preference to its own. The mineral blende crystallizes not unfrequently in octahedra, which yield the dodecahedron on cleavage. Fluor crystallizes in dodecahedra, yet yields the octahedron to cleavage. Argyrite crystallizes in cubes and in octahedra, but yields the dodecahedron on cleavage. Pyrite crystallizes in cubes, octahedra, and dodecahedra, and yields both the cube and the octahedron on cleavage.

These are most embarrassing results, but they early indicate so intimate a relationship to subsist between three of the above simple forms that it is obvious that one alone would serve as a type form for representing the others. The selection of that one should be based upon grounds of most eminent simplicity, and this again is to be arrived at by a consideration of the smallness of number of parts, *i.e.*, of faces, edges, and solid angles. In such a consideration we find that the dodecahedron, with its higher number of each of these, at once gives place. The cube has six faces, the octahedron eight; simplicity here is in favour of the cube. The cube has twelve edges, the octahedron has twelve; in this respect they are equal. The cube has eight solid angles, the octahedron six; here the greater simplicity is on the side of the octahedron. So that this method of adjudicating by simplicity fails, and we are thrown back upon the relationships which may be unfolded through a consideration of the other elements of crystals,—their axes.

### *Systems of Crystals and Laws of Crystallization.*

Relation of faces to axes.

This consideration led, first, to the remarkable discovery that several of the above primary forms are mere modifications of each other, and ultimately showed that all crystals found in nature may be referred to six systems, based on certain relations of their axes, and that every face which could occur upon a crystal bears a definite and simple relation, in position and in angular inclination, to these axes.

Axes directions of dominant accretion.

As regards mere geometric measurement, there are several directions in which axes may with nearly equal advantage be projected. For example, in the cube (fig. 19) they may be drawn from the centres of opposite faces, as lettered O; or from opposite solid angles, as lettered C; or from the centres of opposite edges, as lettered D. There is abundance of evidence that each of these directions must be regarded as lines of dominant accretion of molecules.

But the accretion may be not only dominant but overwhelmingly so in one only of these directions in certain cases, or existent along one set of axes alone in certain others. In a specimen of native silver from Alva in Scotland (fig. 20), along O this is so much the case that the concreting molecules have done little more than delineate the form of an octahedron, and this they have only been able to do by aggregating themselves in lines of minute crystals of the very shape of which they were projecting the skeleton form. Moreover, a polar aggregation at the terminal ends of these octahedral axes is here shown by the amount of concreting and crystallizing material being larger at the terminations of these axes than elsewhere. In the hollow-faced cube again (fig. 21), an aggregation of molecules in the direction of the lines D and C has filled the edges and solid angles, while none have been deposited along O.

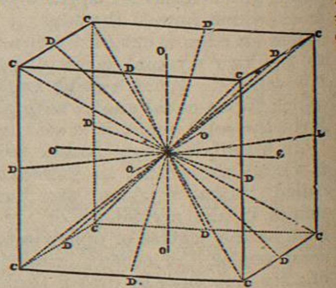

FIG. 19.—Position of three sets of axes.

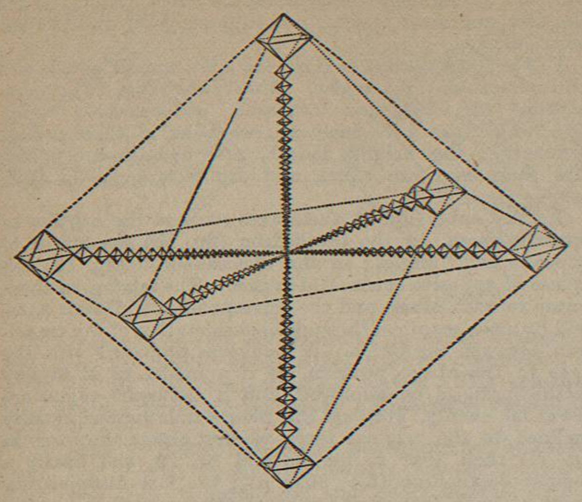

Fig. 20.

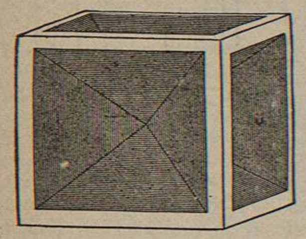

Fig. 21.

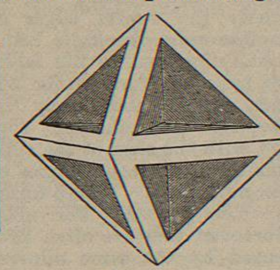

Fig. 22.

This occurs in crystals of salt. In the hollow-faced octahedron, again (fig. 22), there has been no deposition of matter along the line C. Cuprite often shows this form; and it as frequently occurs in hollow-faced dodecahedra, wherein the vacuity is in the direction of D.

In the specimen of pyrite from Elba (fig. 23), a deposition along D and C would ultimately have erected the scaffolding of a hollow cube, in twelve lines of minute combinations of the cube and octahedron. Such directional arrangements may, moreover, not only be intermittent but often alternate. The pyrite from Traversella (fig. 24) is an illustration of the first. A large pentagonal dodecahedron having been completed, a new accession of material has been attached, not uniformly spread over the pre-existent crystal, to enlarge it, but locally arranged, in equal amount, at the poles of O. But here the special method of the arrangement has determined the formation of a number of small crystals of the same form as that originally projected.

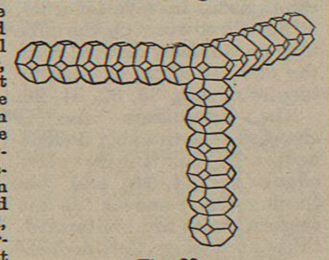

Fig. 23

An alternation, as it were, in plan is shown in such a crystal of calcite as that in fig. 25. Here a scalenohedron is seen in the centre of the figure; then a rhombohedron has been perched upon its summit, and lastly both have been sheathed in a six-sided prism with trihedral summits. Different as these three forms are, it is found that they all here stand in a definite position one to the other; that definite position is the relation which they bear to one of the sets of axes, and this set may be assigned, not only to all the three crystals here combined, but also to all the crystals belonging to the same mineral, wherever occurring. This general applicability constitutes one of the respects in which one special set of axes is, in each of the systems, preferred to the others.

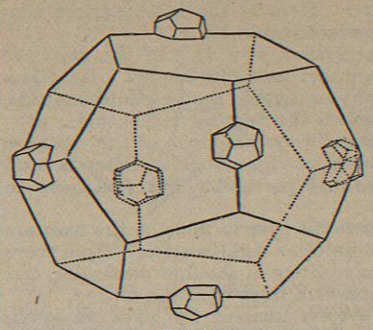

Fig. 24.

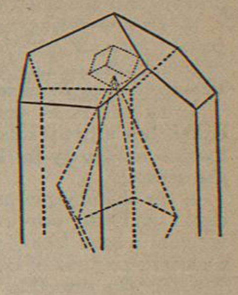

Fig. 25.

Coherence of particles not equal in all directions.

Another respect is the intensity with which the molecules cohere in the different parts of the crystal, as referred to these axes, and the resultant different hardness of certain parts of crystals. It will be afterwards found that this obtains in a very limited manner in the crystals which belong to the first of the following systems, on account of its regularity and sameness as a whole. It may be laid down as a general rule that the edges of crystals are harder than the centres of their faces, and the solid angles harder than the edges. This is markedly the case in the diamond. But, apart from this, there is no distinctive hardness in any one part, side, or end of the crystals of the first system. It is otherwise with the crystals which fall to be considered in all the other systems. So different is the hardness of the various portions of these, so diverse the appearance of their parts in lustre, colour, polish, &c., so varying the amount of the recoil of these when struck, so unequal their power of conducting heat, so dissimilar their power of resisting the agencies of decay, and so irreconcilable their action upon transmitted light, that we cannot but conclude that the molecules which build them up are packed with greater force, if not in greater number, in certain directions in preference to others. There thus remains no question that these nature-indicated sets of axes are those along which there has been a specially selective or "polar" arrangement.

Systems of crystals.

The six systems are founded upon the relationships of the axes in number, in length, and in angular inclination. All crystals may be divided into "orthometric" or erect forms and "clinometric" or inclined forms; and in similar manner may the systems be, through a consideration of the relative lengths of their axes, divided into three classes. In the first, or most regular, of these the axes are all equal, that is, they are of one length; in the second there is one axis which differs in length from the others, and therefore they are of two lengths; while in the third the axes are all unequal, and therefore they are of three lengths. Of the six systems one belongs to the first class, two to the second, and three to the third. Hence they are thus classed :—

| *Monometric.* | *Dimetric.* | *Trimetric.* |
|---|---|---|
| Cubic. | Tetragonal. | Right Prismatic. |
| | Hexagonal. | Oblique Prismatic. |
| | | Anorthic. |

Though the grouping of the systems into three classes in virtue of axial dimensions is markedly borne out by optical and other properties, yet it is altogether insufficient for determining the relationships of the myriad forms in which bodies crystallize. Such knowledge is only attained by combining the consideration of axial length with axial inclination; and it is through a due regard of both of these that the six systems are instituted.

The above table may be read in two different ways,—either across or consecutively up and down the page. The six systems may be treated of in either of these ways;