

(corundum); SnO_2 , tin dioxide (cassiterite); SiO_2 , silicon dioxide (quartz); As_2O_3 , arsenic trioxide (arsenolite).

Another simple class of compounds are the *sulphides* (with the selenides, tellurides, arsenides, antimonides, etc.), compounds in which sulphur (selenium, tellurium, arsenic, antimony, etc.) plays the same part as oxygen in the oxides. Here belong Cu_2S , cuprous sulphide (chalcocite); ZnS , zinc sulphide (sphalerite); PbTe , lead telluride (altaite); FeS_2 , iron disulphide (pyrite); Sb_2S_3 , antimony trisulphide (stibnite).

446. Acids.—The more complex chemical compounds, an understanding of which is needed in a study of minerals, are classed as acids, bases, and salts; the distinctions between them are important.

An *acid* is a compound of hydrogen, or hydroxyl, with a non-metallic element (as chlorine, sulphur, nitrogen, phosphorus, etc.), or a radical containing these elements. In them the hydrogen atoms may be replaced by metallic atoms; the result being then the formation of a salt (see Art. 448). Acids in general turn blue litmus paper red and have a sharp, sour taste. The following are familiar examples:

HCl, hydrochloric acid,	H - Cl.
HNO_3 , nitric acid,	$(\text{HO}) = \text{NO}_2$.
H_2CO_3 , carbonic acid,	$(\text{HO})_2 = \text{CO}$.
H_2SO_4 , sulphuric acid,	$(\text{HO})_2 = \text{SO}_2$.
H_2SiO_3 , metasilicic acid,	$(\text{HO})_2 = \text{SiO}$.
H_3PO_4 , phosphoric acid,	$(\text{HO})_3 \equiv \text{PO}$.
H_4SiO_4 , orthosilicic acid,	$(\text{HO})_4 \equiv \text{Si}$.

The full explanation of the constitution of the different acids requires a more detailed discussion than is possible here. The second series of formulas given above must serve as suggestions in this direction.

It is to be noted that with a given acid element several acids are possible. Thus normal, or orthosilicic, acid is H_4SiO_4 , in which the bonds of the element silicon are all satisfied by the hydroxyl (HO). But the removal of one molecule of water, H_2O , from this gives the formula H_2SiO_3 , or metasilicic acid.

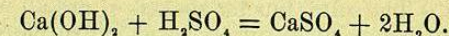
Acids which, like HNO_3 , contain one atom of hydrogen that may be replaced by a metallic atom (e.g., in KNO_3) are called *monobasic*. If, as in H_2CO_3 and H_2SO_4 , there are two atoms (e.g., in CaCO_3 , BaSO_4) the acids are *dibasic*. Similarly H_3PO_4 is *tribasic*, etc.

Most acids are liquids (or gases), and hence acids are represented very sparingly among minerals; $\text{B}(\text{OH})_3$, boric acid (sassolite), is an illustration.

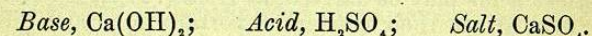
447. Bases.—The *bases*, or hydroxides as they are also called, are compounds which may be regarded as formed of a metallic element (or radical) and the univalent radical hydroxyl, $-(\text{OH})$; or in other words, of an oxide with water. Thus potash, K_2O , and water, H_2O , form $2\text{K}(\text{OH})$, or potassium hydroxide; also $\text{CaO} + \text{H}_2\text{O}$ similarly give $\text{Ca}(\text{OH})_2$, or calcium hydroxide. In general, when soluble in water, bases give an alkaline reaction with turmeric paper or red litmus paper, and they also neutralize an acid, as explained in the next article. Further, the bases yield water on ignition, that is, at a temperature sufficiently high to break up the compound.

Among minerals the bases are represented by the hydroxides, or hydrated oxides, as $\text{Mg}(\text{OH})_2$, magnesium hydrate (brucite); $\text{Al}(\text{OH})_3$, aluminium hydrate (gibbsite); also, $(\text{AlO})(\text{OH})$, diaspore, etc.

448. Salts.—A third class of compounds are the *salts*; these may be regarded as formed chemically by the reaction of a base upon an acid, or, in other words, by the neutralization of the acid. Thus calcium hydrate and sulphuric acid give calcium sulphate and water:



Here calcium sulphate is the salt, and in this case the acid, sulphuric acid, is said to be neutralized by the base, calcium hydroxide. It is instructive to compare the formulas of a base, an acid, and the corresponding salt, as follows:



Here it is seen that a salt may be simply described as formed from an acid by the replacement of the hydrogen atom, or atoms, by a metallic element or radical.

449. Typical Salts.—The commonest types of salts represented among minerals are the following:

Chlorides: salts of hydrochloric acid, HCl; as AgCl, silver chloride (cerargyrite).

Nitrates: salts of nitric acid, HNO_3 ; as KNO_3 , potassium nitrate (niter).

Carbonates: salts of carbonic acid, H_2CO_3 ; as CaCO_3 , calcium carbonate (calcite and aragonite).

Sulphates: salts of sulphuric acid, H_2SO_4 ; as CaSO_4 , calcium sulphate (anhydrite).

Phosphates: salts of phosphoric acid, H_3PO_4 ; as $\text{Ca}_3(\text{PO}_4)_2$, calcium phosphate.

Silicates: several classes of salts are here included. The most common are the salts of metasilicic acid, H_2SiO_3 ; as MnSiO_3 , manganese metasilicate (rhodonite). Also salts of orthosilicic acid, H_4SiO_4 ; as Mn_2SiO_4 , manganese orthosilicate (tephroite).

Numerous other classes of salts are also included among mineral species; their composition, as well as that of complex salts of the above types, is explained in the descriptive part of this work.

450. Normal, Acid, and Basic Salts.—A *neutral* or *normal salt* is one in which the basic element completely neutralizes the acid, or, in other words, one of the type already given as examples, in which *all* the hydrogen atoms of the acid have been replaced by metallic atoms or radicals. Thus, K_2SO_4 is normal potassium sulphate, but HKSO_4 , on the other hand, is acid potassium sulphate, since in the acid H_2SO_4 only one of the bonds is taken by the basic element potassium. Salts of this kind are called *acid salts*. The formula in such cases may be written * as if the compound consisted of a normal salt and an acid; thus, for the example given, $\text{K}_2\text{SO}_4 \cdot \text{H}_2\text{SO}_4$.

A *basic salt* is one in which the acid part of the compound is not sufficient to satisfy all the bonds of the base. Thus malachite is a basic salt—basic carbonate of copper—its composition being expressed by the formula $\text{Cu}_2(\text{OH})_2\text{CO}_3$.

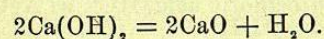
This may be written $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$, or $(\text{Cu}_2) \begin{matrix} = \text{CO}_3 \\ = (\text{OH})_2 \end{matrix}$. The majority of

* This early form of writing the composition explains the name often given to the compound, namely, in this case, "bisulphate of potash."

minerals consist not of simple salts, as those noted above, but of more or less complex double salts in which several metallic elements are present. Thus common grossular garnet is an orthosilicate containing both calcium and aluminium as bases; its formula is $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$.

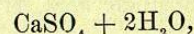
451. Sulpho-salts.—The salts thus far spoken of are all oxygen salts. There are also others, of analogous constitution, in which sulphur takes the place of the oxygen; they are hence called *sulpho-salts*. Thus normal sulpharsenious acid has the formula H_3AsS_3 , and the corresponding silver salt is Ag_3AsS_3 , the mineral proustite. Similarly the silver salt of the analogous antimony acid is Ag_3SbS_3 , the mineral pyrargyrite. From the normal acids named, a series of other hypothetical acids may be derived, as HAsS_2 , $\text{H}_2\text{As}_2\text{S}_5$, etc.; these acids are not known to exist, but their salts are important minerals. Thus zinkenite, PbSb_2S_5 , is a salt of the acid H_2SbS_4 , and jamesonite, $\text{Pb}_2\text{Sb}_2\text{S}_7$, of the acid $\text{H}_4\text{Sb}_2\text{S}_7$, etc.

452. Water of Crystallization.—As stated in Art. 447, the hydroxides, or bases and further basic salts in general, yield water when ignited. Thus calcium hydroxide $\text{Ca}(\text{OH})_2$ breaks up on heating into CaO and H_2O , as expressed in the chemical equation



So also the basic cupric carbonate, malachite (formula given in Art. 450), yields water on ignition; and the same is true of the complex basic orthosilicates, like zoisite, whose formula is $(\text{HO})\text{Ca}_2\text{Al}_2(\text{SiO}_4)_3$. It is not to be understood, however, in these or similar cases, that water as such is present in the substance.

On the other hand, there are a large number of mineral compounds which yield water readily when heated, and in which the water molecules are regarded as present as so-called *water of crystallization*. Thus, the formula of gypsum is written

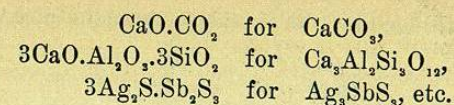


and the molecules of water ($2\text{H}_2\text{O}$) are considered as water of crystallization. So, too, in potash alum, $\text{KAl}(\text{SO}_4)_2 + 12\text{H}_2\text{O}$, the water is believed to play the same part.

453. Formulas of Minerals.—The strictly empirical formula expresses the kinds and numbers of atoms of the elements present in the given compound, without attempting to show the way in which it is believed that the atoms are combined. Thus, in the case of zoisite the empirical formula is $\text{HCa}_2\text{Al}_2\text{Si}_3\text{O}_{13}$. While not attempting to represent the structural formula (which will not be discussed here), it is convenient in certain cases to indicate the atoms which there is reason to believe play a peculiar relation to each other. Thus the same formula written $(\text{HO})\text{Ca}_2\text{Al}_2(\text{SiO}_4)_3$, shows that it is regarded as a basic orthosilicate, in other words, a basic salt of orthosilicic acid, H_2SiO_4 .

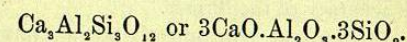
Again, the empirical formula of common apatite is $\text{Ca}_5\text{F}(\text{PO}_4)_3$; but if this is written $(\text{CaF})\text{Ca}_4(\text{PO}_4)_3$, it shows that it is regarded as a phosphate of the acid H_3PO_4 , that is, $\text{H}_3(\text{PO}_4)_3$, in which the nine hydrogen atoms are replaced by four Ca atoms together with the univalent radical (CaF). In another kind of apatite the radical (CaCl) enters in the same way. Similarly to this the formula of pyromorphite is $(\text{PbCl})\text{Pb}_3(\text{PO}_4)_3$, of vanadinite $(\text{PbCl})\text{Pb}_3(\text{VO}_4)_3$.

Further, it is often convenient to employ the method of writing the formulas in vogue under the old dualistic system. For example,



It is no longer believed, however, that the molecular groups CaO , Al_2O_3 , etc., actually exist in the molecule of the substance. But in part because these groups are what analysis of the substance affords directly, and in part because so easily retained in the memory, this method of writing is still often used.

454. Oxygen Ratio.—In the case of certain compounds, more especially the silicates, it is sometimes regarded as convenient to take note of the *oxygen ratio*, that is, the ratio in the number of oxygen atoms combined with the several elements, basic and acid. For example, the formula for grossular garnet given above is



Here the oxygen atoms combined with the basic elements (calcium and aluminium) and the acid element (silicon) are

$$3 : 3 : 6 \text{ or } 1 : 1 : 2,$$

or again, for the basic elements combined,

$$3 + 3 : 6 \text{ or } 1 : 1.$$

It must be noted that the oxygen ratio is in fact the ratio of the total valence of the elements of the different groups, the valence being measured by the combining power with hydrogen, while the oxygen ratio really notes the combining power with oxygen.

455. Calculation of a Formula from an Analysis.—The result of an analysis gives the proportions, in a hundred parts of the mineral, of either the elements themselves, or of their oxides or other compounds obtained in the chemical analysis. In order to obtain the atomic proportions of the elements:

Divide the percentages of the elements by the respective ATOMIC WEIGHTS; or, for those of the oxides: Divide the percentage amounts of each by their MOLECULAR WEIGHTS; then find the simplest ratio in whole numbers for the numbers thus obtained.

Example.—An analysis of bournonite from Wolfsberg gave C. Bromé the results under (1) below. These percentages divided by the respective atomic weights, as indicated, give the numbers under (2). Finally the ratio of these numbers gives very nearly 1 : 3 : 1 : 1. Hence the formula derived is CuPbSbS_3 . The theoretical values called for by the formula are added under (4).

	(1)	(2)	(3)	(4)
Sb	24.34 ÷ 120	= 0.203	1	24.7
S	19.76 ÷ 32	= 0.617	3	19.8
Pb	42.88 ÷ 206.4	= 0.208	1	42.5
Cu	13.06 ÷ 63.2	= 0.207	1	13.0
	100.04			100.0

Second Example.—The mean of two analyses of a garnet from Alaska gave Kountze the results under (1) below. Here as usual the percentage amounts of the several molecular groups (SiO_2 , Al_2O_3 , etc.) are given instead of those of the elements. These amounts divided by the respective molecular weights give the numbers under (2). In this case the amounts of the protoxides are taken together and the ratio thus obtained is 3.09 : 1 : 2.92, which corresponds approximately to the formula $3\text{FeO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$, or $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$. The magnesium in this garnet would ordinarily be explained by the presence of the pyrope

molecule ($\text{Mg}_3\text{Al}_2[\text{SiO}_4]_3$) together with the simple almandite molecule whose composition is given above.

	(1)	(2)	(3)
SiO_2	$39.29 \div 60 = 0.655$		3.09
Al_2O_3	$21.70 \div 102 = 0.212$		1
Fe_2O_3	<i>tr.</i>		
FeO	$30.82 \div 71.9 = 0.429$	} 0.619	2.92
MnO	$1.51 \div 70.8 = 0.022$		
MgO	$5.26 \div 40 = 0.132$		
CaO	$1.99 \div 55.9 = 0.036$		
	<u>100.57</u>		

It is necessary, when very small quantities only of certain elements (as MnO , MgO , CaO above) are present to neglect them in the final formula, reckoning them in with the elements which they replace, that is, with those of the same quantivalence. The degree of correspondence between the analysis and the formula deduced, if the latter is correctly assumed, depends entirely upon the accuracy of the former.

456. Isomorphism.—Chemical compounds which have an analogous composition and a closely related crystalline form are said to be *isomorphous*. This phenomenon, called ISOMORPHISM, was first clearly brought out by Mitscherlich.

Many examples of groups of isomorphous compounds will be found among the minerals described in the following pages. Some examples are mentioned here in order to elucidate the subject.

In the brief discussion of the periodic classification of the chemical elements of Art. 439, attention has been called to the prominent groups among the elements which form analogous compounds. Thus calcium, barium, and strontium, and also lead, form the two series of analogous compounds,

Aragonite Group.	Also	Barite Group.
CaCO_3 , aragonite.		CaSO_4 , anhydrite.
BaCO_3 , witherite.		BaSO_4 , barite.
SrCO_3 , strontianite.		SrSO_4 , celestite.
PbCO_3 , cerussite.		PbSO_4 , anglesite.

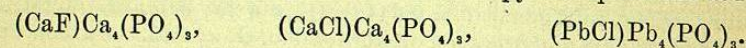
Further, the members of each series crystallize in closely similar forms. The carbonates are orthorhombic, with axial ratios not far from one another; thus the prismatic angle approximates to 60° and 120° , and corresponding to this they all exhibit pseudo-hexagonal forms due to twinning. The sulphates also form a similar orthorhombic series, and though anhydrite deviates somewhat widely, the others are close together in angle and in cleavage.

Again, calcium, magnesium, iron, zinc, and manganese form a series of carbonates with analogous composition, as shown in the list of the species of the *Calcite Group* given on p. 353. This table brings out clearly the close relation in form between the species named. Incidentally, as an example of the deviation in form sometimes observed, it is to be noticed that dolomite (and perhaps others) are not normally rhombohedral like calcite, but belong to the phenacite type (p. 80).

This table also illustrates another essential point in regard to an isomorphous series, viz., the presence of intermediate members, or *isomorphous mixtures* of the simple compounds. These are viewed by most authors as due to the presence of both molecules crystallized together, usually in a certain definite ratio. Thus in normal dolomite, (CaCO_3) and (MgCO_3) are both present in the ratio of 1 : 1, and its formula is $\text{CaMg}(\text{CO}_3)_2$, or $\text{CaCO}_3 \cdot \text{MgCO}_3$. In mesitite (MgCO_3) and (FeCO_3) are present in the ratio of 2 : 1; its formula is $\text{Mg}_2\text{Fe}(\text{CO}_3)_3$, or $2\text{MgCO}_3 \cdot \text{FeCO}_3$. If it is not desired to express the ratio of

the elements present, it is convenient to write the elements together in a parenthesis separated by a comma. Thus $(\text{Ca}, \text{Mg}, \text{Fe})\text{CO}_3$ would mean a carbonate in which calcium, magnesium, and iron are all present.

The *Apatite Group* forms another valuable illustration since in it are represented the analogous compounds, apatite and pyromorphite, both phosphates, but respectively phosphates of calcium and lead; also the analogous lead compounds pyromorphite, mimetite, and vanadinite respectively lead phosphate, lead arsenate, and lead vanadate. Further, in all these compounds the radical (RCl) or (RF) enters in the same way (see Art. 453). Thus the formulas for the two kinds of apatite and that for pyromorphite are as follows:



Some of the more important isomorphous groups are mentioned below. For a discussion of them, as well as of many others that might be mentioned here, reference must be made to the descriptive part of this work.

Isometric System.—The Spinel group, including spinel, MgAl_2O_4 ; also magnetite, chromite, franklinite, gahnite, etc. The Galena group, as galena, PbS ; argentite, Ag_2S , etc. The Garnet group, as grossularite, $\text{Ca}_3\text{Al}_2\text{Si}_2\text{O}_{12}$, etc.

Tetragonal System.—Rutile group, including rutile, TiO_2 ; cassiterite, SnO_2 . The Scheelite group, including scheelite, CaWO_4 ; stolzite, PbWO_4 ; wulfenite, PbMoO_4 .

Hexagonal System.—Apatite group, already mentioned, including apatite, pyromorphite, mimetite, and vanadinite. Corundum group, corundum, Al_2O_3 ; hematite, Fe_2O_3 .

Rhombohedral System.—Calcite group, already mentioned. Phenacite group, etc. *Orthorhombic System.*—Aragonite group, and Barite group, both mentioned above. Chrysolite group, $(\text{Mg}, \text{Fe})_2\text{SiO}_4$; Topaz group, etc.

Monoclinic System.—Copperas group, including melantherite, $\text{FeSO}_4 + 7 \text{ aq}$; Bieberite, $\text{CoSO}_4 + 7 \text{ aq}$, etc. Pyroxene and Amphibole groups, and the Mica group.

Monoclinic and Triclinic Systems.—Feldspar group.

457. Isomorphous Mixtures.—It is important to note that the intermediate compounds in the case of an isomorphous series, such as those spoken of in the preceding article, often show a distinct gradation in crystalline form, and more particularly in physical characters (*e.g.*, specific gravity, optical properties, etc.) This is illustrated by the species of the calcite group already referred to; also still more strikingly by the group of the triclinic feldspars as fully discussed under the description of that group. See further Art. 406.

The feldspars also illustrate two other important points in the subject, which must be briefly alluded to here. The triclinic feldspars have been shown by Tschermak to be isomorphous mixtures of the end compounds in varying proportions:



Here it is seen that these compounds have not an analogous composition in the narrow sense previously illustrated, and yet they are isomorphous and form an isomorphous series. Other examples of this are found among the pyroxenes, the scapolites, etc.

Further, the Feldspar group in the broader sense includes several other species, conspicuously the monoclinic orthoclase, KAlSi_3O_8 , which, though belonging to a different system, still approximates closely in form to the triclinic species.

458. Dimorphism. Isodimorphism.—A chemical compound, which crystallizes in two forms genetically distinct, is said to be *dimorphous*; if in three, *trimorphous*, or in general *pleomorphous*. This phenomenon is called DIMORPHISM or PLEOMORPHISM.

An example is given by the compound calcium carbonate (CaCO_3), which is dimorphous: appearing as calcite and as aragonite. As *calcite* it crystallizes

in the rhombohedral system, and, unlike as its many crystalline forms are, they may be all referred to the same fundamental rhombohedron, and, what is more, they have all the same cleavage and the same specific gravity (2.7), and, of course, the same optical characters. As *aragonite*, calcium carbonate appears in orthorhombic crystals, whose optical characters are entirely different from those of calcite; moreover, the specific gravity of aragonite (2.9) is higher than that of calcite (2.7).

Many other examples might be given: Silica (SiO_2) is dimorphous; appearing as *quartz*, rhombohedral, $G. = 2.66$; as *tridymite*, hexagonal, $G. = 2.3$, and perhaps in other forms. Titanium dioxide (TiO_2) is trimorphous, the species being called *rutile*, tetragonal ($\epsilon = 0.6442$), $G. = 4.25$; *octahedrite*, tetragonal ($\epsilon = 1.778$), $G. = 3.9$; and *brookite*, orthorhombic, $G. = 4.15$. Carbon appears in two forms, in diamond and graphite. Other familiar examples are pyrite and marcasite (FeS_2), sphalerite and wurtzite (ZnS), etc.

When two or more analogous compounds are at the same time isomorphous and dimorphous, they are said to be *isodimorphous*, and the phenomenon is called ISODIMORPHISM. An example of this is given in the Pyrite and Marcasite groups described later. Thus we have in the isometric Pyrite Group, pyrite, FeS_2 , smaltite, CoAs_2 ; in the orthorhombic Marcasite Group, marcasite, FeS_2 , safflorite, CoAs_2 , etc.

459. Chemical and Microchemical Analysis.—The analysis of minerals is a subject treated of in chemical works, and need not be touched upon here except so far as to note the convenient use of certain qualitative methods, as described in the later part of this chapter.

Of more importance are the *microchemical* methods applicable to sections under the microscope and often yielding decisive results with little labor. This subject has been particularly developed by Bořický, Haushofer, Behrens, Streng, and others. Reference is made to the discussion by Rosenbusch (Mikr. Phys., 1892, p. 259 *et seq.*, also the list of authors on p. 212.)

460. Mineral Synthesis.—The occurrence of certain mineral compounds (*e.g.*, the chrysolites) among the products of metallurgical furnaces has long been noted. But it has only been in recent years that the formation of artificial minerals has been made the subject of minute systematic experimental study. In this direction the French chemists have been particularly successful, and now it may be stated that the majority of common minerals—quartz, the feldspars, amphibole, mica, etc.—have been obtained in crystallized form. Even the diamond has been formed in minute crystals by Moissan. These studies are obviously of great importance particularly as throwing light upon the method of formation of minerals in nature (*e.g.*, the diamond). The chief results of the work thus far done are given in the volumes mentioned in the Introduction, p. 4.

461. Alteration of Minerals. Pseudomorphs.—The chemical alteration of mineral species under the action of natural agencies is a subject of great importance and interest, particularly when it results in the change of the original composition into some other equally definite compound. A crystallized mineral which has thus suffered change so that its form no longer belongs to its chemical composition has already been defined (Art. 252, p. 144) as a *pseudomorph*. It remains to describe more fully the different kinds of pseudomorphs. Pseudomorphs are classed under several heads:

1. Pseudomorphs by *substitution*.
2. Pseudomorphs by simple *deposition*, and either by (a) *incrustation* or (b) *infiltration*.

3. Pseudomorphs by *alteration*; and these may be altered
 - (a) without a change of composition, by *paramorphism*;
 - (b) by the loss of an ingredient;
 - (c) by the assumption of a foreign substance;
 - (d) by a partial exchange of constituents.

1. The first class of pseudomorphs, by *substitution*, embraces those cases where there has been a gradual removal of the original material and a corresponding and simultaneous replacement of it by another, without, however, any chemical reaction between the two. A common example of this is a piece of fossilized wood, where the original fiber has been replaced entirely by silica. The first step in the process was the filling of the pores and cavities by the silica in solution, and then as the woody fiber by gradual decomposition disappeared the silica further took its place. Other examples are quartz after fluorite, calcite, and many other species; cassiterite after orthoclase; native copper after aragonite, etc.

2. Pseudomorphs by *incrustation* form a less important class. Such are the crusts of quartz formed over fluorite. In most cases the removal of the original mineral has gone on simultaneously with the deposition of the second, so that the resulting pseudomorph is properly one of substitution. In pseudomorphs by *infiltration* a cavity made by the removal of a crystal has been filled by another mineral.

3. The third class of pseudomorphs, by *alteration*, includes a considerable proportion of the observed cases, of which the number is very large. Conclusive evidence of the change which has gone on is often furnished by a nucleus of the original mineral in the center of the altered crystal—*e.g.*, a kernel of cuprite in a pseudomorphous octahedron of malachite; also of chrysolite in a pseudomorphous crystal of serpentine, etc.

(a) An example of *paramorphism*—that is, of a change in molecular constitution without change of chemical substance—is furnished by the change of aragonite to calcite (both CaCO_3) at a certain temperature; also the *paramorphs* of rutile after brookite (both TiO_2) from Magnet Cove, Arkansas.

(b) An example of the pseudomorphs in which alteration is accompanied by a loss of ingredients is furnished by crystals of native copper in the form of cuprite.

(c) In the change of cuprite to malachite—*e.g.*, the familiar crystals from Chessy, France—an instance is afforded of the assumption of an ingredient—viz., carbon dioxide (and water). Pseudomorphs of gypsum after anhydrite occur where there has been an assumption of water alone.

(d) A partial exchange of constituents—in other words, a loss of one and gain of another—takes place in the change of feldspar to kaolin, in which the potash silicate disappears and water is taken up; pseudomorphs of limonite after pyrite or siderite, of chlorite after garnet, pyromorphite after galena, are other examples.

The chemical processes involved in such changes open a wide and important field for investigation. Their study has served to throw much light on the chemical constitution of mineral species and the conditions under which they have been formed. For the literature of the subject see the Introduction, p. 3 (Blum, Bischof, Roth, etc.). As typical studies of special cases the following articles are referred to:

Genth. Corundum, etc. Am. Phil. Soc. Philad., 13, 361, 1873.

J. D. Dana. Serpentine pseudomorphs, Tilly Foster mine. Am. J. Sc., 3, 371, 1874.

Brush and Dana. Spodumene, etc., Branchville, Ct. Am. J. Sc., 20, 257, 1880.

Schrauf. Serpentine of Bohemia. Zs. Kryst., 6, 321, 1882.