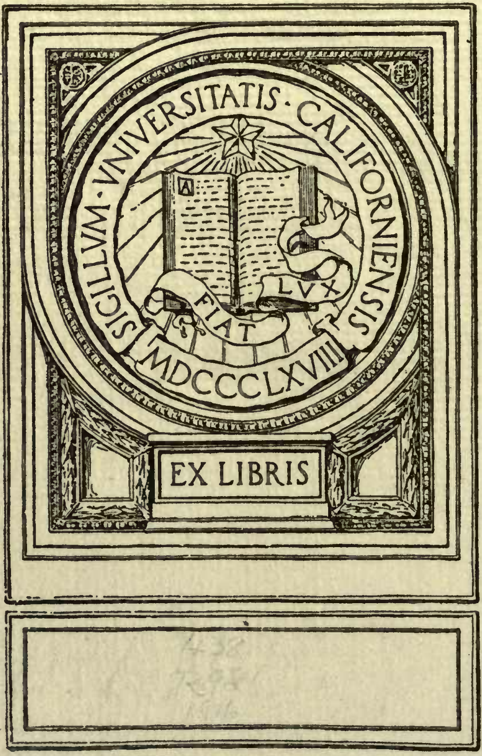
ELEMENTS OF MINERALOGY

By FRANK RUTLEY

REVISED BY H. H. READ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BY

FRANK RUTLEY

LATE LECTURER ON MINERALOGY IN THE ROYAL COLLEGE OF SCIENCE, LONDON

REVISED BY

H. H. READ

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INTRODUCTION BY

G. T. HOLLOWAY

CONSULTING METALLURGIST

NINETEENTH EDITION

LONDON
THOMAS MURBY & CO.
6, BOUVERIE STREET, E.C.
1916

REVISER'S PREFACE

In the preparation of the revised edition of this book, it has been considered advantageous to make somewhat fundamental alterations in several places. The advance of Mineralogy in recent years, the changed points of view of economic mineralogists, and the needs of the present-day student, have all been deemed to justify such changes; indeed, one indication of the need for some such revision was shown in the ever-increasing collection of appendices that were to be found in the former editions. Nevertheless, it has been the reviser's endeavour to conserve as much as possible of the original, and all alterations have been carefully considered.

Part I. treats of the Properties of Minerals. The original chapter on Crystallography has been entirely rewritten, and a chapter on Optical Properties has been added, which, it is hoped, will be found useful to the student.

Part II. consists of the description of Mineral Species. Here the original arrangement has been followed, except in regard to the silicates. New introductions to the elements have been given; specially important among these are introductions to the principal metals, which, together with certain statistics, have been supplied by Mr. W. G. Wagner. In the detailed description of the minerals the matter has been better displayed, chemical formulæ embodied, and greater stress has been laid on occurrences and uses. Types of occurrences rather than lists of localities have been given. A Glossary of Economic Geology Terms and a Table of the Geological Systems have been added.

Throughout it has been the aim of the reviser to bring the book into line with modern tendencies in economic mineralogy, and to make it an introduction to the scientific prospecting and determination of mineral deposits. Economic mineralogy is a youthful science, but its scope, literature, and importance are ever increasing. If this book but helps to guide the student and the practical man into a proper appreciation of the value of scientific method in prospecting, valuation, and determination of minerals, the work of the reviser will not have been in vain.

* * * * *

The thanks of the reviser are due to Mr. G. T. Holloway for his introduction, to Mr. W. G. Wagner for supplying introductions to certain of the metals, to Mr. F. Rowley and to Mr. G. S. Sweeting for great help in the preparation of the manuscript.

When the reviser was ordered abroad, Mr. H. G. Smith very kindly undertook the proof-reading, indexing, and other monotonous tasks, and for this and for many helpful suggestions the greatest thanks are due.

H. H. READ.

ST. ANDREW'S BARRACKS,
MALTA,
1915.

PREFACE

TO THE THIRTEENTH EDITION

THE alterations made in this edition consist chiefly in the insertion of a brief outline of the recently adopted treatment of crystal-symmetry, the addition of more than a dozen figures of crystals, the complete revision of the chemical formulæ, and the printing of such corrections and additions as seemed needful. The table of the thirty-two groups of symmetry is mainly adapted from that given by Professors Penfield and Brush in their "Determinative Mineralogy and Blowpipe Analysis," a work which the student may consult with great advantage.

F. R.

LONDON, 1902.

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INTRODUCTION

By GEORGE T. HOLLOWAY

The general recognition of Rutley's "Mineralogy" in its old form as a handy book of reference is shown by the fact that it passed through thirteen editions during its author's life, and that the eighteenth edition had been issued before the present revision was undertaken.

While the general arrangement and compactness of the work have been retained as far as possible, the additions made by the editor and the modifications which have been introduced by him and his collaborators are intended as a step towards a fuller realisation of the wide scope, interest, and utility of applied or economic mineralogy. As a development of this feature, it is to be hoped that Rutley may later on find a worthy companion in a work dealing fully with the business aspect of mineralogy, if an author who can devote the time and energy necessary for so difficult and responsible a task can be found.

Although mineralogy is generally and rightly regarded as a science, the study of minerals with a view to the determination of their commercial value is an art.

As a purely scientific man, the mineralogist regards a mineral as a homogeneous substance of definite composition, and usually of more or less definite form, and, while recognising the existence of wide variations in both respects, considers change in composition to be due to replacements which are explainable on definite and scientific lines. To him, ores and rocks are mixtures of definite minerals, each to be considered as a separate entity, and, when examining minerals, he is more concerned with the composition, form, and grouping of the purest specimens obtainable than with their commercial value.

By the ordinary geologist, the minerals constituting the rock masses and mineral deposits with which he is concerned are regarded from a broader point of view. The minerals, as such, are considered by him to be definite compounds, as defined by the mineralogist, but are dealt with by him mainly as units, only of primary importance as forming parts of the mixtures which constitute the various portions of the earth's crust. He regards geology as a science, and is not directly concerned with the commercial value of the rocks and ore bodies or of their products.

The business aspect of mineralogy or geology is, however, now receiving increased attention, and the terms economic mineralogist and economic geologist are applied to those who, while fully alive to the scientific part of their work, devote themselves more particularly to the art. It is to both, and especially to the former, that the mining man and prospector must look for guidance in carrying out a portion of their work which was formerly regarded as part of their routine duty, but which they have commonly neither time nor training to efficiently carry out.

Economic geology is commonly considered to include economic mineralogy, but it is more logical to regard the latter as an independent subject large enough to stand alone, and so important to all who search for or mine or handle ores and minerals, that it should form an essential part of their early training and of their life's work. Good properties are often "turned down," or worthless ones reported upon favourably by the prospector, ore-dressing operations are wrongly conducted, and products inefficiently disposed of, through a want of knowledge both of the main principles and of the details; on this knowledge depends the successful exploitation of minerals, and it forms the basis of economic mineralogy and of its branch, the valuation of minerals and ores.

Although the work of the economic mineralogist and geologist form important adjuncts to mining and metallurgy, mineralogy as an art—*i.e.*, "economic mineralogy"—has until recently been almost ignored at colleges and teaching institutions throughout the world, and has been but little studied by the metallurgist and particularly by the mining man. The economic mineralogist's work has commonly been regarded as included in that of the economic geologist, but it would be wiser to consider that he has a field which is entirely his own, but which overlaps that of the geologist at an ever-increasing rate.

The collections shown in our museums are mainly composed of fine specimens, and are likely to lead the prospector to search for minerals of special appearance such as are not commonly to be found, except by luck, in the actual deposits, and may result in his passing over and ignoring or failing to recognise workable deposits. It must be remembered that the bulk of our enormous output of both base and precious metals is now derived from low grade and refractory and mixed ores. The deposits of rich or comparatively pure ore have been largely worked out, and ores which were worthless only a few years ago are now mined and dressed at a profit, through improvements in plant and processes and a growing experience as to market requirements. Mixed ores carrying two or more metals, such as refractory zinc-lead ores, usually containing small quantities of gold and silver, are the source of a large proportion of the total production of those four metals, and are becoming more and more important and essential as a source of them.

The most enthusiastic mineralogists are those who, while fully alive to the beauty of form or the purity of a specimen, regard minerals as being still more interesting from the economic point of view. The scientific knowledge of these economic mineralogists need not be less than that of the pure mineralogist, but those who study minerals from the broadest point of view, see sermons in stones and rocks, which are mere crude mixtures of minerals to the undiscerning eye. They find an interest in their study which the non-technical man can never enjoy. Economic mineralogy is, in fact, one of the few cases where the intrusion of the business element introduces a beauty and romance to a study which may otherwise tend to become little more than a matter of cataloguing and of arrangement.

The expert knowledge of minerals required of the ore valuer—*i.e.*, of the economic mineralogist as a business man—differs from that of any other class of man who deals with minerals and ores. While the purely scientific side of mineralogy is valuable to him, although perhaps crystallography is of less importance than any other branch, it is essential that he should be able to recognise at sight, or by simple tests, many minerals in admixture with others, whereas the man equipped with only the ordinary limited mineralogical training, would miss them by inspection, and would commonly fail to find them by the tests which he has been taught to apply to the selected specimens on which he has been accustomed to work.

The prospector should have been trained in, and have studied on his own behalf, the examination of crude minerals such as he seldom sees in museums, but which are the most likely to be found afield. Although he cannot, during his preliminary studies, see or examine the minerals as they occur in situ, he can commonly obtain and make trials upon the crude ore as it is delivered from the mine, and of the picked ore, dressed products, and waste. The broad geological aspect of the occurrence and association of minerals can only be gained in the field, and mining cannot be taught in our colleges. A training in economic mineralogy suitable for mining men, among whom, of course, is included the prospector, and with whom is commonly included, although probably wrongly, the ore dresser, can, however, be very efficiently given, and is one of the most essential, although most neglected, parts of a mining man's education. From this point of view, as well as from that of the metallurgist, the training should include, not merely the identification and determination of the nature of the individual minerals which are associated together, but their general physical characteristics and the prospect of being able to separate them either mechanically or by metallurgical means. Collections of rough minerals, ores, and products can easily be made by a student, and he can give himself, if he cannot obtain it otherwise, that grounding which is absolutely essential for his future welfare.

It is a curious fact, and one of the most injurious to the future of mining enterprise, that prospecting is usually entrusted to a young and inexperienced man, and that it appears to be regarded as the least important part of mining work, instead of being considered one of the most essential. The inexperienced man is more likely to miss or condemn a good property than to recommend a bad one, and a property thus overlooked may be lost for generations through the mere fact that it has once been examined and "turned down." The importance of an adequate knowledge of mineralogy is great throughout all the stages of mining and ore dressing, and it is unfortunate that, while undertaking the responsibility of dealing with minerals and ores apart from actual mining, and of recommending, erecting, and running plants for treating them, mining men commonly know less of either pure or economic mineralogy than of any other branch of their work.

The ore valuer must consider several questions in addition to the actual composition of the ore. How can one deal with the constituents, whether valuable or hurtful? What is their value? How far will the presence of some lead to penalisation, if they are not removed from their associates? It is important to remember that market conditions change, and that an ore, mineral, or product, which is useless to one buyer, may be much sought after by another, and that sources of revenue may exist even when disaster seems imminent.

A knowledge of economic mineralogy is of supreme importance to the mining man as producer and seller, and to the metallurgist as buyer and user; but the two occupy entirely different positions as regards the business aspects of the subject. The latter, or the buyer for whom he acts, can refuse to purchase what he does not want, and can impose his own limits as to percentage values which must be reached, and impurities which must be removed, or whose amount must not exceed a definite proportion. He inserts penalisation and other clauses which protect him from loss and, except for the growing competition between the more competent, and particularly between those who are on the look-out for by-products, he is independent of bad work in the mines or on the dressing floors. He pays only for what he wants, and is often able to obtain his material for much less than he would pay if the producers possessed more than the elementary knowledge of mineralogy, and the crude ideas as to market conditions and requirements with which they are generally equipped.

The mining man or ore dresser, however, depends for his profit on what he sells, and it is to his interest to know everything possible about his ores or minerals in order to minimise losses, and to secure the best prices for his products. The losses depend partly on his mechanical efficiency and on that of his staff, but are largely dependent also on a careful study of what he is treating and producing, and on his own special knowledge or on what he can learn from others as to the requirements of the markets. What is only just saleable to one firm, may be particularly suitable to the requirements of another, and a higher price, or at any rate a greater facility of sale, may be secured by selecting, dressing, or blending ores or products, or by bearing in mind how the purchaser is likely to be able to himself deal with the question of blending and, if it is possible, to know what other materials suitable for such purpose are available at the place where the products are treated. Such matters as the cost of transport, and the best method of conveying the ore from place to place, are among the many items of information which should be known by the mining man, and must be borne in mind by the valuer; and this fact emphasises the necessity, not only for a knowledge of minerals and ores, and the method of treatment as a commercial proposition, but for a broad view and considerable knowledge of business conditions entirely independent of those which might ordinarily be considered as included among his duties.

The intimate relation and co-operation which should exist between the mining man and the metallurgist is, of course, more or less admitted, although commonly ignored, by both, but the advisability of association between the metallurgist and the chemical technologist is less understood, and even when realised, is scarcely regarded as having the extreme importance which it really possesses. Many instances might be cited where a mineral which was formerly used only by the chemical manufacturer is now mainly employed by the metallurgist. This is, for instance, especially the case with manganese ores, and with those of tungsten and chromium, and to a great extent with the ores of nickel and cobalt. Many minerals or ores which are specially penalised, or perhaps refused for one purpose, are thoroughly suitable and sometimes preferable for another.

The purchase and treatment by the chemist of by-products from ore dressing and metallurgical operations has often been the salvation of a mine, and has sometimes formed the foundation of a new or prevented the death of an old branch of chemical industry; and one of the most important functions of the economic mineralogist is to indicate to those who rule the destinies of an ore the opportunities and pitfalls which exist. His influence is felt directly or indirectly throughout the history of the development of any mining property from its birth to its death.

It will no doubt be contended that for the ore valuer or prospector to consider such details is to encroach upon the work of others, but it is better that they should be dealt with at once. Cases often occur where a property can be thus proved to be hopeless under the existing conditions, even though its "assay value" may be excellent.

The mere difficulty which may be experienced in separating minerals by panning and other routine tests is, however, not necessarily a proof that they cannot be dealt with. During recent years special processes of dealing with refractory ores, such as oil-flotation and electromagnetic and electrostatic methods of treatment, have been introduced, and, in some cases, mines which were formerly unworkable have been converted into highly profitable enterprises. For some of these processes, a preliminary treatment, such as a flash-roast, or other simple means of superficially altering the surface of a mineral, so that it becomes amenable to a special process of treatment, may require to be adopted, and the ore valuer must make trials, or at least remember the possibility that such treatment may be feasible, before deciding as to whether a property should be developed or a process should be modified to adapt it to the ore under consideration.

To carry the duties of the ore valuer—*i.e.*, of the economic mineralogist acting as a business man—to a logical conclusion would be to expect him to have knowledge and experience which no single individual could possibly possess; but it is logical for *everyone* who deals with ores and minerals to aim at knowing as much as possible of the principles and practice of economic mineralogy. It is one of the few cases where a little knowledge is not dangerous, and where a mere appreciation of the difficulties which *may* exist is likely to save mistakes which might lead to disaster.

The common association together of certain minerals or metals is so well known that it seems scarcely necessary to refer to them here; but, as this handbook is intended for the experienced mining man and prospector, as well as for the student, it may be permissible to refer to one or two typical associations, some of which are objectionable, and others highly desirable. It is interesting, for instance, to note that, in serpentine rocks, one commonly finds asbestos, chrome iron ore, nickel ore and cobalt ore, which may be actually associated together, or may occur in distinct deposits, as they do in New Caledonia.

It is extremely important to know whether the associated minerals, in case their presence together is objectionable, can be separated sufficiently from each other by commercial means, to meet market requirements. This should be specially borne in mind by the prospector in the case of zinc blende and galena, which are commonly associated together. In some cases, the zinc blende and the galena are sufficiently independent to be obviously easy of separation in a coarse condition by jigging or other wet-dressing processes. In others it is evident that, although a portion of each mineral may be separated in a condition of considerable purity, there will be other portions, either large or small, which will require fine grinding, and whose dressing will result in heavy losses or in the production of a large proportion of intermediate product, which may have to be discarded, or can only be sold at an extremely low rate. In some cases the valuable mineral constituents are so finely divided, or so intimately mixed or intercrystallised, that they cannot be separated from each other, or are associated with other minerals from which separation is so difficult or expensive that even a large deposit must be considered of doubtful value, or perhaps untreatable by present methods. The physical state of both the valuable and hurtful minerals is, in fact, a point of vital importance in considering the value of most mineral deposits, and in deciding as to the possibility of working them under the conditions which exist in the locality.

The association of gold and silver, and even of platinum and palladium with copper, copper-nickel, and many other ores, often in such small amounts as to appear to be worthless to judge from an assay of the original ore, is often sufficiently important, on account of the concentration which occurs in the dressing or smelting of such ores, to render valuable a deposit which, on the result of a mere analysis, might appear to be worthless. Not only are these valuable metals concentrated, but certain other constituents, such as bismuth, selenium, etc., are also concentrated with them in the electrolytic refining of crude copper. The "mud" left as the anodes dissolve contains gold, silver, often platinum and palladium, and usually bismuth and selenium, which would be lost if the electrolytic purification were not carried out.

The association of certain minerals in alluvial deposits is of particular interest and of growing importance, on account of the enormous quantities of material which are now dressed by dredging and other hydraulic methods for the recovery of gold, platinum, tin, monazite, and other valuable minerals. Some of these were formerly little more than curiosities. They become concentrated in the final product from the dredge, and must be removed either in order to get rid of them or to recover them while the metal or mineral, which is the actual aim of the worker, is being separated. Zircons are now thus obtained by the hundreds of tons, titaniferous iron ore, rich in titanium, by the thousands of tons, together with topaz, garnets, etc. Their output exceeds the present demands of the market, although such demands are rapidly increasing. In many cases, these minerals, which may be called by-products, far exceed in quantity the mineral for which the search is being made, and are often completely unsaleable. The buyers are often but little interested in them, or are doubtful as to continuity of supply, and are also frequently not aware of the fact that the supply could be maintained, if the producers knew that any demand existed, or was likely to exist.

The effect of change in market conditions is well shown by the case of bauxite, at present the only commercial source of the metal aluminium. The demand for this material is largely increasing, but the class of ore sold for making metallic aluminium is very different from that used twenty or thirty years ago. The process now employed for producing alumina for such manufacture has resulted in certain qualities of bauxite, which were formerly unsaleable, being largely used, and others which were formerly considered of good quality for making the metal, being now employed for entirely different purposes. Silica and titanium are highly objectionable to the manufacturers of aluminium, but iron makes very little difference. On the other hand, those who employ bauxite for the production of abrasives or of refractory material, which use is very large and rapidly increasing, prefer or are at least willing to use the class of ore to which the aluminium manufacturers object.

The non-metallic minerals in an ore deposit are often as important as the metallic. They may assist the smelting, or may be saleable when removed by dressing, or they may be injurious and perhaps incapable of removal. There are many cases where a mineral deposit is useless on account of the presence of perhaps a small amount of other material which becomes concentrated with the valuable mineral. Such is sometimes the case with zinc blende associated with barytes or fluor-spar, which are difficult to remove by wet dressing, and may become concentrated in the dressed product to an extent which results in so heavy a penalisation as to render the whole proposition unremunerative.

G. T. H.

1915.

ELEMENTS OF MINERALOGY

INTRODUCTORY

THE NATURE OF MINERALS

The Mineral Kingdom.—Nature has been divided into three great departments, called the animal, vegetable, and mineral kingdoms. It is to the last exclusively that the science of Mineralogy relates. Whether or not any definite boundary line exists between these kingdoms is a point which remains to be investigated.

The different members of the animal and vegetable kingdoms are characterised by the development of special organs, or of certain peculiarities of structure, by means of which they pass through a series of changes known as life and growth. This latter phenomenon takes place by the absorption, or taking-in, of various kinds of matter, which then undergoes assimilation (or conversion by chemical processes into substances similar to those of which the animal or plant is composed), and serves to replace the waste which accompanies life. The bones and shells of animals consist, to a great extent, of mineral matter, Plants are capable of deriving earthy substances from the soil on which they grow. But mineral matter, which has thus been utilised by organisms, passes, in the most rigid interpretation of the term, beyond the pale of Mineralogy; for it assumes a structure, governed by the nature and requirements of the animal or plant, such as it would not possess under ordinary conditions. In this way the pearl would be regarded as an organic substance and not a true mineral, although it consists of mineral matter. Again, coal, being a substance derived from decomposition of vegetable matter, would not rigidly be classed with minerals. Thus, even at the outset, the difficulty of giving any satisfactory definition of a mineral is apparent. The most important characteristic of a mineral, and the one upon which any definition should be based, is the possession of a definite chemical composition, and in order to fix ideas the following definition may be stated:

Definition of a Mineral.—*A mineral is a substance having a definite chemical composition and formed by inorganic processes.*

Although this may be regarded as a sufficient definition, there are yet other differences between the mineral and the organic kingdoms. For instance, a mineral increases by the addition of matter to its exterior, while animals and plants grow, as has already been pointed out, by the assimilation of fresh matter which is taken into their interior. Again, animal and vegetable forms are bounded by curved surfaces, while minerals in their most highly developed or *crystallised* state are, with one or two exceptions, bounded by plane or flat surfaces. If we follow rigidly the above definition of a mineral, we are bound to include gases in the mineral kingdom. Similarly, water, snow, and ice, are minerals, since they consist of the two gases, hydrogen and oxygen, chemically combined, and are therefore homogeneous. Air, on the other hand, must not be regarded as a mineral. For, though it consists of two gases, nitrogen and oxygen, yet as they are not chemically combined, but exist simply in a state of mechanical admixture, it is not homogeneous. The so-called "mineral oils" are mixtures of several hydrocarbons, and therefore cannot be considered a mineral species, though it is necessary for completeness to treat of them in a textbook of mineralogy.

Bodies in no way to be distinguished from actual minerals have at various times been artificially formed, either purposely in the laboratory, or by accident in industrial processes; but although identical (except in mode of occurrence) with true minerals of like chemical composition, in crystallisation, and in other physical properties, they are the outcome of processes controlled by human agency, and consequently are not included among minerals. They have, nevertheless, a profound interest for the mineralogist inasmuch as they serve to a certain degree to elucidate the conditions under which corresponding minerals have been formed.

Rocks.—There are in nature innumerable mechanical mixtures of minerals which are called *rocks;* hence, rocks are not minerals because they are not homogeneous. For example, consider the well-known rock granite. It can be seen by inspection of a hand-specimen of this rock that it is made up of three constituents—one white or pink and cleavable, which is the mineral *orthoclase;* another, clear, glassy, and with no cleavage, which is the mineral *quartz;* and a third, glistening, scaly, and soft, which is the mineral *mica*. Hence, the three *minerals*, orthoclase, quartz, and mica, are aggregated together to form the *rock* granite, and the three constituents occur in varying proportions in different granites and even in different parts of the same granite mass.

Scope of the term "Mineral."—The term "mineral" is capable of different expressions according to the point of view. To the ultra-scientific person, a mineral is a substance of definite chemical composition formed solely by the processes of inorganic nature; to the miner a mineral is anything of economic value that can be extracted from the earth, and these two definitions are not always compatible one with the other. For example, the Home Office list of "Minerals raised in the United Kingdom," includes chalk, clay, and igneous rocks. In this book it is proposed to discuss not only those substances which fulfil the terms of the rigid definition, but also some few materials whose origin may not always be free from organic causes, but which, nevertheless, cannot be excluded from any book on mineralogy. Coal, mineral oils, limestone, and some phosphate, are examples of such substances. It must therefore be remembered that any definition of a mineral is more or less wrong, or more or less right, according to the critic, but that most definitions contain the essentials for most minerals.

PART I

THE PROPERTIES OF MINERALS

CHAPTER I

THE CHEMISTRY OF MINERALS

Elements.—Substances which have hitherto defied the efforts of the chemist to decompose are termed "Elements." About seventy elements are at present known, but many are extremely rare and of little importance to the mineralogist. It has been estimated that the crust of the earth is composed of 47 per cent. oxygen, 28 per cent. silicon, 7·8 per cent. aluminium, 4·4 per cent. iron, 3·4 per cent. calcium, 2·5 per cent. potassium, 2·4 per cent. sodium, 2·3 per cent. magnesium. Thus, 98 per cent. of the earth's crust is composed of but eight elements, and most of the elements of economic value are absent from this list.

Atom.—It is possible to break down the matter of an element into smaller and smaller particles, but there is a limit to this process, and the final minute, indestructible particle is called an "atom." Chemical combination is the binding together of atoms, and hence a useful definition is: *An atom is the smallest part of an element that can enter into a chemical combination with another element.*

Molecule.—To the subdivision of a chemical compound, such as the mineral calcite, there is also a limit, beyond which any further subdivision would destroy the identity of the compound. This smallest part of a compound is called a "molecule," which may be defined as *the smallest part of a substance that can have an independent existence and still retain the characters of the substance.* Subdivision of a molecule breaks it up into its constituent atoms. Molecules may consist of atoms all of one kind or of different kinds; thus a molecule of oxygen is composed of two atoms of that element, and a molecule of calcite contains five atoms—one of calcium, one of carbon, and three of oxygen.

Atoms unite with one another in definite proportions, though the same atom may unite with any given atom in two or more different proportions. For example, the carbon atom combines with the oxygen atom to form two different molecules, in one there being one atom of oxygen combined with one of carbon, and in the other two atoms of oxygen with one of carbon.

Symbols and Formulæ.—For convenience, an atom of every element is represented by a letter called a "symbol," which is usually the initial letter of the English or Latin name of the element. The molecule of a substance is represented by a formula. Thus, O is the symbol of an atom of oxygen, O_2 is the formula of a molecule of oxygen, and $CaCO_3$ the formula of a molecule of calcite.

Atomic and Molecular Weight.—The atomic weight of an element is the weight of its atom compared with the weight of an atom of hydrogen.

The molecular weight of a substance is the sum of the atomic weights of the atoms composing the substance. For instance, the atomic weight of calcium is 40, of carbon is 12, and of oxygen is 16; therefore the molecular weight of calcite ($CaCO_3$) is $(40 + 12 + 3 \times 16) = 100$.

Valency.—The valency of an element is measured by the number of its atoms which will combine with or replace one atom of hydrogen. Thus, chlorine combines with one atom of hydrogen, and is therefore monovalent; calcium replaces two atoms of hydrogen, and is therefore divalent, and so on.

Monovalent elements	H, Cl, Br, I, F, K, Na.
Divalent „	Ca, Ba, Sr, Mg, Hg, O, Zn, Fe.
Trivalent „	Al, Sb, As, Bi, B, N, P, Fe.
Quadrivalent „	C, Si.
Pentavalent „	P, N, etc.

INTERNATIONAL ATOMIC WEIGHTS, 1915.

(*The asterisks denote changes made by the International Committee on Atomic Weights since* 1911.)

ELEMENT.	SYMBOL.	ATOMIC WEIGHT. O=16.
Aluminium	Al	27·1
Antimony	Sb	120·2
Argon	A	39·88
Arsenic	As	74·96
Barium	Ba	137·37
Bismuth	Bi	208·0
Boron	B	11·0
Bromine	Br	79·92
Cadmium	Cd	112·40
Cæsium	Cs	132·81
Calcium*	Ca	40·07
Carbon	C	12·00
Cerium	Ce	140·25
Chlorine	Cl	35·46
Chromium	Cr	52·0
Cobalt	Co	58·97
Columbium	Cb	93·5
Copper	Cu	63·57
Fluorine	F	19·0
Glucinum	Gl	9·1
Gold	Au	197·2
Helium	He	3·99
Hydrogen	H	1·008
Iodine	I	126·92
Iridium	Ir	193·1
Iron*	Fe	55·84
Lead	Pb	207·10
Lithium	Li	6·94
Magnesium	Mg	24·32

International Atomic Weights—*Continued.*

ELEMENT.	SYMBOL.	ATOMIC WEIGHT. O=16.
Manganese	Mn	54·93
Mercury*	Hg	200·6
Molybdenum	Mo	96·0
Nickel	Ni	58·68
Niobium (see Columbium)		
Nitrogen	N	14·01
Osmium	Os	190·9
Oxygen	O	16·00
Palladium	Pd	106·7
Phosphorus	P	31·04
Platinum	Pt	195·2
Potassium	K	39·10
Radium	Ra	226·4
Rhodium	Rh	102·9
Rubidium	Rb	85·45
Ruthenium	Ru	101·7
Selenium	Se	79·2
Silicon	Si	28·3
Silver	Ag	107·88
Sodium	Na	23·00
Strontium	Sr	87·63
Sulphur	S	32·07
Tantalum*	Ta	181·5
Tellurium	Te	127·5
Thallium	Tl	204·0
Thorium	Th	232·4
Tin	Sn	119·0
Titanium	Ti	48·1
Tungsten	W	184·0
Uranium	U	238·5
Vanadium*	V	51·0
Yttrium	Yt	89·0
Zinc	Zn	65·37
Zirconium	Zr	90·6

Metals and Non-Metals.—The elements are divided into two classes, metals and non-metals. There is no hard-and-fast line of division between the two classes, and the semi-metals or metalloids combine characteristics of both divisions. The physical distinction between the two classes is readily understood with reference to lustre, malleability, conduction of heat and electricity, etc.; but, as will be seen later, this division is of great chemical importance also.

Metals: Al, Sb, As, Ba, Bi, Cd, Ca, Cr, Co, Cu, Au, Fe, Pb, Mg, Mn, Hg, Mo, Ni, Pt, K, Ag, Na, Sr, Sn, Ti, W, Zn.

Non-Metals: B, Br, C, Cl, F, H, I, N, O, P, S, Si, etc.

The elements can be further divided into groups which have, to a certain degree, similar chemical properties. Examples of such groups are—

1. Na, K, Li.
2. Ca, Sr, Ba.
3. Fe, Mn, Co, Ni, Cr, U, etc.

The elements in each group are found replacing one another in varying degree in minerals. Compounds of each element in any one group tend to crystallise in similar forms, and to have similar molecular arrangements; they occur together in nature, and seem to be formed by similar processes.

Acids.—An acid is formed by the combination of hydrogen with a non-metal, or with a group of non-metallic elements, the hydrogen being capable of replacement by a metal. The group of molecules combined with the hydrogen is termed the "acid radicle." Examples of acids are—Hydrochloric acid (HCl), sulphuric acid (H_2SO_4), orthosilicic acid (H_4SiO_4).

Bases.—Bases may be considered to be combinations of the metals with oxygen and hydrogen, or of the metallic oxides with water. Examples of bases are—caustic soda ($NaOH$), calcium hydrate [$Ca(OH)_2$].

Salts.—By the combination of an acid and a base the hydrogen of the acid is replaced by the metal of the base, and the result is the formation of a salt. Thus the result of the action of hydrochloric acid (HCl) on the base caustic soda ($NaOH$) is to produce the salt, sodium chloride ($NaCl$), and water (H_2O), as shown in the equation below:

$$HCl + NaOH = NaCl + H_2O.$$

Acids and Salts in Mineralogy. — The great majority of minerals are salts, and the most important acids and salts from this point of view are tabulated below:

NAME OF ACID.	NAME OF SALT.	EXAMPLE OF SALT.
Hydrochloric (HCl)	Chloride	Rock salt ($NaCl$)
Hydrobromic (HBr)	Bromide	Bromyrite ($AgBr$)
Hydriodic (HI)	Iodide	Iodyrite (AgI)
Hydrofluoric (HF)	Fluoride	Fluor-spar (CaF_2)
Nitric (HNO_3)	Nitrate	Nitre (KNO_3)
Sulphuric (H_2SO_4)	Sulphate	Barytes ($BaSO_4$)
Sulphuretted hydrogen (H_2S)	Sulphide	Galena (PbS)
Carbonic (H_2CO_3)	Carbonate	Calcite ($CaCO_3$)
Pyroboric ($H_2B_4O_7$)	Borate	Borax ($Na_2B_4O_7$) Aq.
Phosphoric (H_3PO_4)	Phosphate	Apatite [$Ca_3(PO_4)_2$]
Orthosilicic (H_4SiO_4)	Orthosilicate	Willemite (Zn_2SiO_4)
Metasilicic (H_2SiO_3)	Metasilicate	Rhodonite (Mn_2SiO_3)
Polysilicic ($H_4Si_3O_8$)	Polysilicate	Orthoclase ($KAlSi_3O_8$)

It will be seen from the composition of orthoclase, for instance, that it is not necessary that the hydrogen of an acid should be replaced by one metal alone.

Oxides.—Compounds of oxygen with another element are called "oxides," and are a very important class of minerals. As examples may be given corundum (Al_2O_3), tinstone (SnO_2), quartz (SiO_2), etc. The chemical composition of complex minerals is most easily remembered by writing the substance as a combination of various oxides, but it must be understood that this does not mean that the oxides are present as such in the mineral. For example, orthoclase ($KAlSi_3O_8$) may be written as $K_2O.Al_2O_3.6SiO_2$.

Water of Crystallisation.—When certain minerals crystallise they combine with a number of molecules of water, which are loosely attached to the compound, and do not enter into its inner chemical constitution. This water is called "water of crystallisation," and can be driven off from the compound at a moderate heat. Gypsum has two molecules of water of crystallisation, as $CaSO_4 + 2H_2O$; borax has ten, as $Na_2B_4O_7 + 10H_2O$.

Oxidation and Reduction.—A chemical change by which oxygen is added to an element or compound is called "oxidation." The term "reduction" is applied to a change in which the oxygen or other non-metal is taken away from a compound.

When metallic copper is heated it is changed into a black oxide of copper, as in the following equation:

$$2Cu + O_2 = 2CuO.$$

Here oxidation of the copper has taken place. The reverse process may be studied by heating the copper oxide in a current of hydrogen, with the result that metallic copper and water are formed. This is a case of reduction, and the changes may be represented as—

$$CuO + H_2 = Cu + H_2O.$$

Oxidation and reduction are of very great importance in the blowpipe analysis of minerals.

Isomorphism.—It is found that certain minerals have a very similar molecular construction, and crystallise in forms showing close relation one with another. Such minerals are said to be isomorphous, and to exhibit isomorphism. The calcite group of minerals is an example of an isomorphous group, consisting of the following members: Calcite ($CaCO_3$), dolomite [$(CaMg)CO_3$], ankerite [$CaCO_3.(Mg,Fe)CO_3$], magnesite ($MgCO_3$), mesitite ($2MgCO_3.FeCO_3$), siderite ($FeCO_3$). This list shows the presence of links or isomorphous mixtures between the simple compounds. The plagioclase felspars (see p. 191) are another excellent example of an isomorphous series, which shows a gradation in chemical composition, crystalline form, specific gravity, and refractive index, from one extreme (albite) to the other (anorthite). Thus, in isomorphous mixtures one element replaces another, and this finds expression in the formulæ for such mixtures. The olivine group varies from pure magnesium silicate, forsterite (Mg_2SiO_4), to pure iron silicate, fayalite (Fe_2SiO_4). A slightly ferriferous olivine would be written as $(Mg,Fe)_2SiO_4$, whereas an olivine in which iron predominated would be written $(Fe,Mg)_2SiO_4$.

The members of isomorphous groups are salts of those metals which are contained in the same chemical group as established on p. 11.

Synthesis and Analysis.—The building up of a compound by the union of one element with others is termed "synthesis"; the splitting up of such a compound into its constituent elements is called "analysis." It is by means of synthesis and analysis that all the operations of the chemist are carried on.

Analysis.—The first step in analysis consists in determining the nature of the elementary substances contained in a compound, the next in determining the amount of these constituents. The former is called "qualitative," and the latter "quantitative," analysis.

In making a qualitative analysis, the recognition of the constituents hinges upon the fact that certain bases and certain acids produce well-marked phenomena in the presence of known substances, or preparations termed "reagents." The characteristic effect produced by reagents is spoken of as a reaction. Thus hydrochloric acid is a reagent, and in clear solutions containing salts of lead, silver, or mercury, produces a dense white precipitate, consisting of the chlorides of those metals, and therefore denoting at once the presence of one or more of them. This is a reaction, and it must be supplemented by other reactions in order to determine which of the three substances is present.

Such investigations conducted in solutions are called "analyses by the wet way." There is, however, a "dry way" which is extremely convenient for the purposes of the mineralogist, although practice and skill are requisite before accurate results are likely to be obtained.

THE BLOWPIPE.

Description.—For examining a mineral in the dry way, the blowpipe is an invaluable instrument. It consists essentially of a tube bent at right angles, one extremity having a mouthpiece, the other terminated in a finely perforated jet. The tube should bulge out between the two extremities into a cavity, in which the condensed moisture from the breath may lodge, so as not to be carried through the jet into the assay. It is important that the aperture of the nozzle of the blowpipe should be small and circular. This can be obtained by nearly closing the aperture by gently tapping on an iron surface and then inserting a square needle, and by rotation producing a hole of the required size and shape.

Production of Blast.—In using the blowpipe the operator will probably experience at first some difficulty in keeping up a steady, continuous blast. Practice will, however, soon enable him to use the instrument easily. While blowing, the cheeks should be kept inflated and the air expelled by their action only, fresh supplies of air being drawn in through the nose. Trial will teach far better than any description, and practice should be resorted to until a steady and uninterrupted blast can be kept up for a space of some minutes. A gas-flame is very convenient for blowpipe experiments, but the flame of a spirit lamp, an oil lamp, a paraffin-wax lamp, or a candle, will also answer the purpose. When a lamp or a candle is used, the wick should be bent in the direction in which the flame is blown. Many portable blowpipe lamps are on the market for use in the field.

The Two Kinds of Flames.—In blowpipe analysis it is necessary to be able to produce and to recognise two types of flame, in one of which oxidation of the substance under examination is brought about, and in the other reduction.

1. *The Oxidising Flame.*—An oxidising flame is produced when the nozzle of the blowpipe is introduced into the flame to about one-third the breadth of the flame. It is advisable to blow somewhat more strongly than in the production of the reducing flame. The oxidising flame is blue and feebly illuminating, and in it the air from the blowpipe is well mixed with the gases from the flame, and complete combustion ensues. There are two positions in this flame at which operations useful to the experimenter are performed. The hottest part is just outside the inner blue cone, and is called "the point of fusion." The best position for oxidation—the point of oxidation—is just beyond the visible part, for at this point the assay is heated surrounded by air, and hence oxidation takes place. The oxidising flame is shown in Fig. 1, in which the position of the point of fusion (*F*) and the point of oxidation (*O*) are seen.

2. *The Reducing Flame.*—The reducing flame is produced when the nozzle of the blowpipe is placed a small distance from the flame. The

reducing flame is bright yellow and luminous, ragged and noisy. In this flame the stream of air drives the whole flame rather feebly before it, and there is little mixture of air with the gases from the flame. The result is that these gases are not completely burnt, and hence they readily combine with the oxygen of any substance introduced into their midst. It will be seen, therefore, that the assay must be completely surrounded by the reducing flame, but care should be taken not to introduce the assay too far into the flame, or a deposit of soot will be formed which interferes with the heating of the substance. The reducing flame is shown in Fig. 2, and the point of reduction is at (*R*).

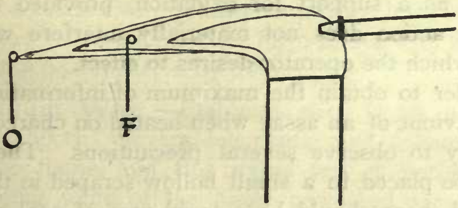


FIG. 1.—OXIDISING FLAME, SHOWING POSITION OF BLOWPIPE, AND POINTS OF OXIDATION (*O*) AND OF FUSION (*F*).

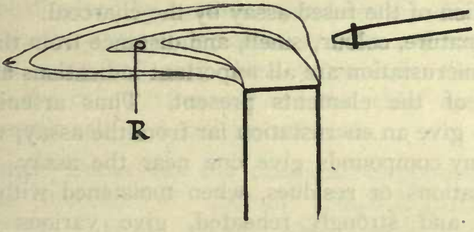


FIG. 2.—REDUCING FLAME, SHOWING POSITION OF BLOWPIPE AND POINT OF REDUCTION.

Supports.—The substance under examination may be supported in various ways according to the requirements of each particular case.

Charcoal.—Charcoal forms a good support by reason of its infusibility, feeble capacity for conducting heat, and its reducing action. The carbon, of which the charcoal consists, readily combines with the oxygen which the assay may contain. The reduction of many metallic oxides to the metals may be effected by heating on charcoal in the reducing flame. In other cases charcoal may be used as a support for oxidation, provided that its reducing action does not materially interfere with the results which the operator desires to effect.

In order to obtain the maximum of information from the behaviour of an assay when heated on charcoal, it is necessary to observe several precautions. The assay should be placed in a small hollow scraped in the charcoal, and there should be a large area of cool charcoal beyond the hollow, so that the best condition for the deposition of any encrustation may be provided. Should the assay crackle or fly about, a fresh assay must be made by powdering the substance and mixing it into a thick paste with water. Flaming or easy burning of the assay should be noted, together with easy fusion, or absorption of the fused assay by the charcoal.

The nature, colour, smell, and distance from the assay of the encrustation are all important indications as to the nature of the elements present. Thus arsenic compounds give an encrustation far from the assay, whereas antimony compounds give one near the assay. White encrustations or residues, when moistened with cobalt nitrate and strongly reheated, give various colours characteristic of certain elements. Compounds containing some few metals—lead, mercury, and bismuth—give coloured encrustations when heated on charcoal with potassium iodide and sulphur.

Platinum-Tipped Forceps.—These forceps are useful for holding small splinters of minerals in the blowpipe flame. When substances are examined in this way the colour of the flame should be noted and the degree of fusibility of the mineral compared with Von Kobell's Scale of Fusibility (see after, p. 46). A platinum wire may be used with excellent results for nearly all the operations usually carried out by the forceps. In the use of platinum, whether foil, forceps, or wire, care should be taken that minerals containing iron, lead, antimony, and other metals that form alloys with platinum, should not be supported by its means.

Platinum Wire.—Platinum wire is an extremely useful support. Several elements give colours to the blowpipe flame, and this flame test is performed by introducing some of the finely powdered assay, either alone or moistened with hydrochloric acid, into the flame on a platinum wire. The several very important bead tests (see p. 23) are carried out by fusing a flux in a loop at the end of the platinum wire.

Fluxes.—Certain substances are added to the assay for the purpose of effecting a more rapid liquefaction than could be obtained by heat alone, and are especially useful when the constituents of the assay form a characteristic coloured compound with these substances. Such substances are called "fluxes," and the chief are borax, microcosmic salt, and sodium carbonate.

Borax.—Borax has the chemical composition of a hydrous biborate of sodium ($Na_2B_4O_7, 10H_2O$, or $Na_2O.2B_2O_3.10H_2O$). Borax, when used as a blowpipe reagent, should be finely powdered after having been deprived by heat of the greater part of its water. To make a borax bead the operator should first bend one end of the platinum wire into a small loop. The loop should then be heated to redness in the blowpipe flame, and immediately dipped into the powdered borax, some of which will adhere to the wire. Upon heating the loop in the blowpipe flame, the powder froths up or intumesces, owing to the disengagement of the water still remaining in it, and gradually fuses to a clear, transparent bead. If now some of the powdered substance to be examined is allowed to touch the hot bead, it sticks to it. The bead should be heated again by a well-sustained blast; its colour and other characters noted, both when hot and cold; and these observations should be made both with the oxidising and the reducing flames. Some minerals should be added to the bead in very minute quantities, otherwise the reaction may be masked or rendered obscure, and difficulty be experienced in determining the colour. Borax serves principally to reduce substances to the state of oxides, and it is by the colour and other properties which these oxides impart to the borax bead that we are able to ascertain to a certain extent the nature of the substance under examination.

Borax also serves to reduce metallic ores in such a way that a minute globule of the pure metal may be separated from the other substances with which, in the state of ore, it is combined and mixed. It is also useful in this way for the separation of certain metals when they are combined with sulphur, arsenic, etc. These compounds, however, mostly dissolve with difficulty in borax. The behaviour of such sulphides and arsenides in the borax bead differs materially from that of the oxides of the same metals, and hence it is advisable to roast the substance on charcoal in the oxidising flame before applying the usual borax bead test.

Microcosmic Salt.—Microcosmic salt is a hydrated sodium ammonium hydrogen phosphate ($Na_2NH_4HPO_4 + 4H_2O$). Microcosmic salt is so fluid when it first fuses that it generally drops from the platinum wire. It is best, therefore, either to heat it on charcoal or platinum foil until the water and ammonia are expelled, when it can be easily taken up on the platinum loop, which should be made rather small, or else to add the salt to the bead in small quantities at a time. The substance to be examined is added just in the same way as with the borax bead, and the whole fused in the blowpipe flame.

The action of microcosmic salt is to convert the oxides of metals into phosphates of a complex nature, imparting characteristic colours to the bead when hot and cold, which often differ with the nature of the flame used, whether oxidising or reducing.

Sodium Carbonate.—Sodium carbonate has the chemical formula $Na_2CO_3,10H_2O$. When it is mixed with finely powdered oxides or sulphides of metals, together with powdered charcoal, and placed upon charcoal before the blowpipe flame, it serves to reduce them to the metallic state. The mixture should be slightly moistened before it is placed on the charcoal. Sodium carbonate is also valuable as a flux in the analysis of silicates, as it then parts with carbonic acid, and becomes converted into a silicate of sodium.

Manganese and chromium give a characteristic colour when introduced into the sodium carbonate bead, owing to the formation of sodium manganate and chromate.

Tube Tests.—Reactions using the closed and open tubes are of great importance in blowpipe analysis. A very small quantity of the assay is introduced into a small, hard glass tube, heated, and the result noted. In most cases a deposit, called the "sublimate," is formed on the cooler parts of the tube, and the colour and nature of this sublimate may indicate one or more of the elements present in the assay. By heat, again, the assay may be converted into the oxides of the metals present, and some of these oxides have characteristic colours and properties. Thus brown limonite $(2Fe_2O_3 + 3H_2O)$ may be converted into black magnetic magnetite (Fe_3O_4) by the expulsion of water which collects on the cooler parts of the tube.

In the tube, open at both ends, the assay is oxidised, and either characteristic smells or sublimates are formed.

Reactions.—The detection of several of the acid radicles present in minerals depends on the use of reagents, such as the usual acids, powdered magnesium, granulated tin, etc. For instance, carbonates give off carbon dioxide on being treated with hydrochloric acid; some silicates gelatinise on being heated with the same acid. These and other reactions are given in the Tables of Blowpipe Analysis.

TABLES OF BLOWPIPE ANALYSIS.

FLAME TEST.

Substance heated alone on the platinum wire or moistened with HCl, HNO_3, or H_2SO_4.

Calcium	Brick red
Strontium	Crimson
Sodium	Yellow
Potassium	Violet (masked by Na, use indigo glass)
Barium	Yellow-green
Copper	Emerald-green with HNO_3; sky-blue with HCl

Indefinite blue flames are given by lead, arsenic, and antimony; and indefinite green flames by zinc, phosphorus, boron, and molybdenum. These elements are more satisfactorily detected by other tests.

BORAX BEAD TEST.

ELEMENT.	OXIDISING FLAME.	REDUCING FLAME.
Iron	Yellow	Bottle-green
Copper	Blue	Opaque red
Chromium ...	Green	Green
Manganese ...	Reddish-violet	Colourless
Cobalt	Deep blue	Deep blue
Nickel	Reddish-brown	Opaque grey
Uranium	Yellow	Pale green

MICROCOSMIC BEAD TEST.

ELEMENT.	OXIDISING FLAME.	REDUCING FLAME.
Iron	Colourless to brownish-red	Reddish
Copper	Blue	Opaque red
Chromium ...	Green	Green
Manganese ...	Violet	Colourless
Cobalt	Blue	Blue
Nickel	Yellow	Reddish-yellow
Uranium	Yellow-green	Bright green
Tungsten	Colourless	Blue-green
Molybdenum ...	Bright green	Green
Titanium	Colourless	Violet
Silica	Remains undissolved in microcosmic bead	
Chlorine	Saturate microcosmic bead with copper oxide. Add powdered chloride. Rich blue flame surrounds bead	

SODIUM CARBONATE BEAD TEST.

Element.	Oxidising Flame.
Manganese ...	Opaque blue-green
Chromium ...	Opaque yellow-green

REACTIONS ON CHARCOAL.

1. **Oxidation.**—Substance heated alone in oxidising flame on charcoal :—

Element.	Encrustation.
Arsenic	White; far from assay; smell of garlic
Antimony	White; near assay
Zinc	White, cold; yellow, hot
Lead	Yellow, cold; dark yellow, hot
Bismuth	Orange, cold; darker, hot
Sulphur	Smell of sulphur dioxide
Tin	White or pale yellow, cold; darker yellow, hot
Molybdenum	White, cold; yellow, hot; in reducing flame, blue

White encrustations and residues moistened with cobalt nitrate and strongly reheated :—

ELEMENT.	COLOUR.
Zinc	Encrustation, grass green
Tin	,, blue-green
Antimony	,, dirty green
Magnesium	Residue, pink
Aluminium	,, blue and unfused
Fusible silicates, phosphates, and borates	,, blue, fused, and glassy

Substance heated in oxidising flame with potassium iodide and sulphur :—

ELEMENT.	ENCRUSTATION.
Lead	Brilliant yellow
Bismuth	Scarlet, yellow near assay
Mercury	Greenish-yellow and greenish-yellow fumes

2. **Reduction.**—Substance mixed with charcoal and sodium carbonate and heated in oxidising flame :—

ELEMENT.	BEAD.
Lead	Soft, malleable, metallic bead ; easily fused ; marks paper
Tin	Tin-white bead ; soft and malleable ; not marking paper
Silver	Silver-white bead ; malleable

ELEMENT.	BEAD.
Gold	Yellow bead; soft and malleable
Bismuth	Silver-white bead; brittle
Copper	Red, spongy mass
Iron	Strongly magnetic residue
Cobalt	Feebly " "
Nickel	" " "

SPECIAL REDUCTION TESTS FOR TITANIUM AND TUNGSTEN.

Fuse with sodium carbonate and charcoal; boil residue with HCl and few grains of granulated tin:—

METAL.	COLOUR OF SOLUTION.
Titanium	Violet
Tungsten	Prussian blue

Fuse with sodium carbonate and charcoal; dissolve residue in concentrated H_2SO_4 with equal volume of water added. Cool; add water; then add hydrogen peroxide:—

METAL.	COLOUR OF SOLUTION.
Titanium	Amber-coloured solution

CLOSED TUBE TESTS.

Assay heated in closed tube, either alone, or with sodium carbonate and charcoal, or with magnesium:—

ELEMENT.	OBSERVATION.
Sulphur	Orange sublimate
Arsenic	Black sublimate; smell of garlic
Mercury (with sulphur)	Black sublimate; red on rubbing
Arsenic (with sulphur)	Reddish-yellow sublimate; deep red while fused
Antimony (with sulphur)	Brownish-red sublimate; black while hot
Mercury	Heat with sodium carbonate and charcoal; globules of mercury as encrustation
Arsenic	Heat with sodium carbonate and charcoal; black mirror of arsenic
Phosphates	Heat with magnesium; add water. Characteristic smell of phosphoretted hydrogen

OPEN TUBE TESTS.

Assay heated in open tube. Nature of encrustation noted:—

ELEMENT.	ENCRUSTATION.
Sulphur	Sulphurous fumes of sulphur dioxide
Arsenic	White sublimate, far from assay; garlic odour
Antimony	White sublimate near assay

REACTIONS FOR ACID RADICLE.

ACID RADICLE.	TEST.
Carbonate ...	With hydrochloric acid, carbon dioxide evolved
Sulphide (some)	With hydrochloric acid, sulphuretted hydrogen evolved. Also indicated by closed tube, open tube, and charcoal tests, *q.v.*
Fluoride ...	With sulphuric acid, greasy bubbles of hydrofluoric acid evolved. White film of silica deposited on drop of water held at mouth of tube
Chloride ...	With sulphuric acid and manganese dioxide, greenish chlorine evolved. Also detected by copper oxide—microcosmic bead test, *q.v.*
Bromide ...	With sulphuric acid and manganese dioxide, brown bromine evolved
Iodide ...	With sulphuric acid and manganese dioxide, violet iodine evolved
Nitrate ...	With sulphuric acid, brown nitrous fumes evolved
Silicates (some)	With hydrochloric acid gelatinise. (Silica insoluble in microcosmic bead)
Sulphate ...	Heat substance on charcoal with sodium carbonate and carbon; place on silver coin and moisten. Black stain
Phosphate ...	Heat with magnesium in closed tube; add water; phosphoretted hydrogen evolved. Also detected by giving fused blue mass in cobalt nitrate charcoal test, *q.v.*

SUMMARY OF TESTS FOR METALS.

Aluminium ...	Cobalt nitrate test—blue colour
Antimony ...	Roast on charcoal—white encrustation near assay Open tube—white sublimate Closed tube—red-brown sublimate, black when hot
Arsenic ...	Roast on charcoal—encrustation far from assay ; garlic odour Open tube—white substance, volatile Closed tube (with Na_2CO_3)—arsenic mirror
Barium ...	Flame test—yellow-green
Bismuth ...	Reduction on charcoal—brittle bead. Roast with KI and S—yellow encrustation near assay ; scarlet outer parts
Calcium ...	Flame test—brick red
Chromium ...	Borax bead—green Microcosmic bead—green Sodium carbonate bead — yellow-green, opaque
Cobalt	Borax bead—deep blue Microcosmic bead—deep blue
Copper ...	Flame test—emerald-green Reduction on charcoal—red metallic copper Borax bead—green-blue
Iron	Borax bead—bottle green Microcosmic bead—yellow Reduction on charcoal—magnetic residue

SUMMARY OF TESTS FOR METALS—*Continued.*

Lead	Reduction on charcoal—malleable bead, marking paper Roast with KI and S—yellow encrustation
Magnesium ...	Cobalt nitrate test—pink residue
Manganese ...	Borax bead—violet to colourless Microcosmic bead—violet to colourless Sodium carbonate bead—blue-green, opaque
Mercury ...	Closed tube with Na_2CO_3 and C—metallic mercury mirror
Molybdenum ...	Microcosmic bead — in reducing flame, dirty green, hot; fine rich green, cold
Nickel	Borax bead — violet-brown, hot; opaque grey, cold Reduction on charcoal — slightly magnetic residue
Potassium ...	Flame test—violet
Silver	Reduction on charcoal—silver bead
Sodium ...	Flame test—yellow
Strontium ...	Flame test—crimson
Tin	Reduction on charcoal—tin bead
Titanium ...	Microcosmic bead — violet in reducing flame Reduction with tin—violet solution Hydrogen peroxide test — amber solution
Tungsten ...	Microcosmic bead—blue-green Reduction with tin—blue solution
Zinc	Cobalt nitrate test—green encrustation Heating—yellow, hot; white, cold

CHAPTER II

THE PHYSICAL PROPERTIES OF MINERALS

INTRODUCTION

Besides the chemical characters described in the preceding pages, minerals possess certain other properties which may be classified as follows:

I. Colour, lustre, transparency, translucency, refraction, polarisation, pleochroism, and phosphorescence.
II. Taste, odour, and feel.
III. State of aggregation (form, pseudomorphism, hardness, brittleness, malleability, flexibility, elasticity, fracture, cleavage, surface tension, etc.).
IV. Specific gravity.
V. Fusibility.
VI. Magnetism, electricity, and radio-active properties.

I. COLOUR, LUSTRE, ETC.

Colour.—Colour depends on the extinction of some and reflection of other of the coloured rays or vibrations which compose ordinary white light. When a body reflects light to so small an extent as not to affect the eye, it appears black; but if it reflect all the vibrations of the different colours which compose white light, the body will appear white. Again, if it reflect the red vibrations of ordinary light and extinguish all the other vibrations, it will appear red; and so on for the other colours.

The colours of minerals vary very greatly, even in the same species specimens being found having very different colours. Quartz is commonly colourless or white, but it is also found of pinkish-yellow, green, brown, and amethystine colours, and sometimes quite black. Corundum is also found of many colours, varying from pale brown to deep red and dark blue; the two latter varieties being known by the names of ruby and sapphire. The same crystal, even, may exhibit different colours, as in some specimens of tourmaline.

The *streak* of a mineral is the colour of its powder, and may be quite different from that of the mineral in mass. For instance, black micaceous hematite gives a red powder.

Some minerals, when turned about or looked at in different directions, display a changing series of prismatic colours, such as are seen in the rainbow, or on looking through a glass prism. This is called a *play of colours*, the colours being produced by the splitting up of a ray of light as it enters and emerges from a medium denser than the air. The splitting of the ray is caused by the unequal bending of the coloured constituents of white light, to which, under these circumstances, it is subject. The diamond and opal afford examples. *Change of colour* is a somewhat similar phenomenon extending over broader surfaces, the succession of colours taking place slowly when the specimen is turned, as in labradorite.

Opalescence is a somewhat pearly or milky appearance. Opal and moonstone are examples.

Iridescence is a display of colours due to the refraction and interference of rays of light in minute fissures which wall in thin films of air or liquid. These fissures are often the result of incipient fracture. Iridescence may sometimes be seen in quartz, calcite, and mica.

Schiller is the nearly metallic lustre observed in certain directions in hypersthene, etc., and is due to the reflection from minute parallelly arranged enclosed plates or cavities.

Some minerals tarnish on the surface when exposed to the air, sometimes exhibiting iridescent colours. This tarnish may result either from oxidation, or from the chemical action of sulphur and other elements which are generally present in the atmosphere in minute quantities. Tarnish may be distinguished from the true colour by chipping or scratching the mineral, when the superficial nature of the tarnish will be at once revealed. Copper pyrites often tarnishes to an iridescent mixture of colours, and is then called peacock copper ore. Erubescite tarnishes readily on exposure to the air.

The property possessed by some crystals of displaying different colours when viewed in different directions by transmitted light, and more particularly by polarised light, is called *pleochroism* (see p. 101). Some crystals under these different conditions exhibit two colours, others three, the former being dichroic, the latter trichroic. Cordierite is an example of a pleochroic mineral. A fuller consideration of pleochroism is reserved for Chapter V.

Lustre.—The lustre of minerals differs both in intensity and in kind. There are six kinds of lustre:

1. **Metallic.**—The ordinary lustre of metals. When, however, it is feebly displayed, it is termed "submetallic." Gold, iron pyrites, and galena have a metallic lustre; chromite and cuprite a submetallic lustre.

2. **Vitreous.**—The lustre of glass. When less perfect it is termed "subvitreous lustre." Quartz, sanidine, and rock salt afford examples of vitreous, calcite of subvitreous, lustre.

3. **Resinous.**—The lustre of resin. Zinc blende, opal, amber, are examples.

4. **Pearly.**—The lustre of a pearl. Talc, brucite, and selenite have a pearly lustre.

5. **Silky.**—The lustre of silk. This lustre is peculiar to minerals having a fibrous structure. The fibrous form of gypsum, satin-spar, and the variety of asbestos termed "amianthus," are good examples of silky lustre.

6. **Adamantine.**—The lustre of the diamond.

The lustre of minerals may be of different degrees of intensity, according to the amount of light reflected from their surfaces. Thus, when the surface of a mineral is sufficiently brilliant to reflect objects distinctly, as a looking-glass would do, it is said to be splendent. When the surface is less brilliant and objects are reflected indistinctly, it is described as shining. When the surface is still less brilliant and incapable of affording any image, it is termed glistening, and glimmering describes a still more feeble lustre.

Transparency.—A mineral is transparent when the outlines of objects seen through it appear sharp and distinct. Rock crystal (quartz) and selenite are good examples. Minerals are said to be subtransparent or semitransparent when the objects seen through them appear indistinct.

Translucency.—If it is impossible to see through a mineral which, nevertheless, is capable of transmitting light, the mineral is translucent. This condition is very common among minerals. When no light is transmitted, a mineral is opaque, but it must be noted that this refers only to the appearance as ordinarily seen. A large number of apparently opaque minerals become translucent when cut into very thin sections, and this property is largely used for the identification of minerals in rocks (see Chapter V.). Many minerals which are opaque in the mass, are translucent on the sharply broken edges and in splinters, as, for example, the common black flints from the Chalk.

Refraction and Polarisation.—These properties together with pleochroism will be considered in Chapter V.

Phosphorescence and Fluorescence.—Phosphorescence is the property which some substances possess of emitting light under certain conditions, as when heated or rubbed. Pieces of quartz when rubbed together in a dark room emit a phosphorescent light. Some varieties of fluor-spar, when powdered and heated on an iron plate, display a bright phosphorescence. Exposure to sunlight or even ordinary diffused light will elicit a phosphorescence from many minerals, which may be observed by transferring them rapidly to a dark room.

Some minerals when exposed to certain electrical radiations emit light. This phenomenon is best exhibited by fluor-spar, whence the term fluorescence.

II. TASTE, ODOUR, AND FEEL.

Taste.—Characters of minerals dependent upon taste are only perceptible when the minerals are soluble in water.

Saline	The taste of common salt.
Alkaline	The taste of potash and soda.
Cooling	The taste of nitre, potassium chlorate, etc.
Astringent	The taste of green vitriol.
Sweetish astringent	The taste of alum.
Bitter	The taste of Epsom salts.
Sour	The taste of sulphuric acid.

Odour.—Some minerals have characteristic odours when struck, rubbed, breathed upon, or heated.

Alliaceous	Odour of garlic—arsenic.
Horse-radish	Odour of decaying horse-radish—selenium.
Sulphurous	Odour of burning sulphur—sulphur and sulphides.
Fœtid	Odour of rotten eggs—sulphuretted hydrogen and some quartz and limestones.
Argillaceous	Odour of clay when breathed upon.

All, with the exception of the last, may be elicited by heat or friction.

Feel.—Smooth, greasy or unctuous, harsh or meagre or rough, are kinds of feel of minerals that may aid in identification.

III. STATE OF AGGREGATION.

Gases and Liquids.—Oxygen, nitrogen, and carbon dioxide are examples of natural gases; and water, mercury, petroleum, are examples of natural liquids.

Solids.—With the exception of mercury and the natural mineral oils, all the minerals with which we have to deal are found in the solid state, and the properties dependent on their state of aggregation are now considered.

Form.—Under favourable circumstances minerals assume certain definite geometrical forms called crystals, the recognition of which is a valuable aid in the identification of minerals. Crystals are considered in Chapter III. The following general descriptive terms are associated with the crystal character of the mineral.

Crystallised.—When definite geometrical forms are developed.
Crystalline.—When no definite crystals are developed, but merely a confused aggregate of imperfectly formed crystals.
Cryptocrystalline.—A general term to denote the possession of mere traces of crystalline structure or of microscopic crystalline structure.

The indeterminate forms, not necessarily dependent on crystal character, which minerals assume, are described by various names, which are given in the following list:

Acicular.—When the mineral consists of fine needle-like crystals—natrolite.
Amorphous.—Without any definite form—opal.
Amygdaloidal.—Almond-shaped, occupying the steam cavities in lavas, etc.—zeolites.
Bladed.—Cyanite.
Botryoidal. — Consisting of spheroidal aggregations, somewhat resembling a bunch of grapes—chalcedony.

Capillary.—When exhibiting a fine hair-like structure—millerite.

Columnar.—With a structure obscurely resembling prisms—hornblende.

Concretionary and Nodular.—Terms applied to minerals which are found in detached masses, the forms being sometimes spherical, sometimes irregular—flint.

Dendritic and Arborescent.—Tree-like or moss-like forms—manganese oxide.

Fibrous.—Consisting of fine thread-like strands—satin-spar.

Foliated.—Consisting of thin and separable lamellæ, or leaves ("micaceous")—mica.

Granular.—When in grains, either coarse or fine—crystalline limestone.

Lamellar.—When separable into plates—wollastonite.

Lenticular.—Lens-shaped. When the mineral assumes the form of flattened balls or pellets—coal-balls.

Mammillated.—When large spheroidal surfaces are displayed—malachite.

Radiating or Divergent.—When crystals or fibres are arranged round a centre point—stibnite.

Reniform.—Kidney-shaped. When the rounded surfaces resemble those of kidneys—hematite.

Reticulated.—In cross meshes, like a net—rutile needles.

Scaly.—When the plates of the mineral are small—tridymite.

Stellate.—When crystals are so compounded as to produce star-like forms—wavellite.

Tabular.—When broad, flat surfaces are shown—wollastonite.

Tuberose.—When very irregular rounded surfaces are exhibited, often giving rise to gnarled, root-like shapes—flos-feri.

Wiry or Filiform.—When in thin wires, often twisted like the strands of a rope—native copper.

Pseudomorphism.—Pseudomorphism is the assumption by a mineral of a form other than that which really belongs to it. Pseudomorphs may be formed in several ways.

1. A pseudomorph by investment is produced by a superficial encrustation of one mineral on the crystal of another.

2. A pseudomorph by infiltration occurs when the cavity, which has been previously occupied by a crystal, is refilled by the deposit of different mineral matter from the infiltration of a solution.

3. A pseudomorph by replacement is caused by a slow

and gradual substitution of particles of new and different mineral matter for the original particles, which are successively removed by water or other solvents. This kind of pseudomorphism differs from the preceding merely in the circumstance that the new tenant enters before the old tenant has entirely evacuated his quarters.

4. A pseudomorph by alteration is due to gradual chemical change which crystals sometimes undergo, their composition becoming so altered that they are no longer the same minerals, although they still retain the old forms.

Pseudomorphs may generally be recognised by a want of sharpness in the angles of the crystals, while their faces usually present a dull and somewhat granular or earthy aspect.

Dimorphism.—When the same chemical compound is capable of crystallising in two different systems, it is said to be dimorphous—*e.g.*, carbonate of lime, which as calc-spar is rhombohedral, while as aragonite it is orthorhombic in crystallisation. Sulphur is also dimorphous, since it crystallises both in the orthorhombic and monoclinic systems.

When a compound is capable of crystallising in three different types of crystals, it is then said to be trimorphous—*e.g.*, titanic oxide. Crystallisation of any compound in a still greater number of systems is spoken of as polymorphism.

Hardness.—Hardness varies very greatly in minerals, and is one of the most important tests—in fact the first—which should be made in determining a mineral. Hardness should be tested by rubbing the specimen over a tolerably fine-cut file, and noting the amount of powder and the degree of noise produced by so doing.

The less the powder and the greater the noise, the harder will be the mineral. On the other hand, a soft mineral will yield much powder and but little noise. The noise and amount of powder should be compared with that produced by minerals which are used as standard examples for hardness tests. The scale in general use, and known by the name of Mohs' scale, is here appended, and the student would do well to commit it to memory. It is important to note, however, that these minerals do not advance in any definite or regular ratio of hardness.

1. Talc ...	... Common foliated variety.
2. Rock salt	... Or gypsum.
3. Calc-spar	... Transparent variety.
4. Fluor-spar	... Crystallised variety.
5. Apatite ...	... Transparent crystallised variety.
6. Felspar ...	... (Orthoclase) cleavable variety.
7. Quartz ...	... Transparent variety.
8. Topaz ...	... Transparent crystal.
9. Sapphire ...	... Cleavable variety, or corundum.
10. Diamond.	

The trial may also be made by endeavouring to scratch the specimens enumerated in the list with the mineral under examination. If, for example, the mineral will scratch felspar and will not scratch quartz, it will have a hardness between 6 and 7, which would be written 6·25, 6·5, 6·75, according to whether it approaches more nearly to felspar or quartz in hardness.

Hardness may also be tested by means of a penknife, or even the finger-nail; the former scratching up to 6·5, and the latter to 2·5. (Finger-nails, however, vary in hardness.)

Window-glass may be used in an emergency as a substitute for apatite, and flint for quartz. During these trials the colour and lustre of the streak or scratch and the colour of the powder should also be noticed. To determine the latter, in doubtful cases, it is well to rub some of the powder on a piece of white paper, or scratch the mineral upon a piece of unglazed porcelain or roughened glass.

Tenacity.—Minerals possess certain properties dependent upon their tenacity, of which the following are the most important:

(*a*) *Sectility.*—A mineral is said to be sectile when it may be cut with a knife, but is not malleable. Example: graphite, steatite, etc.

(*b*) *Malleability.*—Minerals are malleable when slices cut from them may be flattened out under a hammer. Example: native gold, silver, copper, platinum, etc.

(*c*) *Ductility.*—Minerals are ductile when they can be drawn out into wires, and these properties belong only to metallic minerals, and, of those, only to native metals. Ductile minerals are always malleable.

(*d*) *Flexibility* is the property of bending. In some minerals it can be observed by experimenting upon their plates or laminæ only. A flexible mineral remains bent after the pressure is removed. Example: talc, selenite, elaterite, etc.

(*e*) *Elasticity* differs only from flexibility in the portion bent springing back to its former position. Example: mica.

(*f*) *Brittleness* is a character common to many minerals, and is shown by their crumbling or flying to powder instead of yielding a slice. Example: iron-pyrites, native arsenic, apatite, augite, fluor-spar, etc.

Fracture.—It is very important to note the character of fracture, as displayed on the broken or chipped surfaces of minerals. It is also equally important that the student should distinguish between the smooth, flat surfaces, resulting from the cleavage of a mineral, and the irregular surfaces characterising true fracture, and which are totally independent of cleavage.

The observer may here note the colour of the mineral, which should always be judged from a recent fracture, and not from a surface which has been long exposed to the action of the air. By this, however, it is not implied that he should break or chip good crystals, as crystalline form is a far more valuable and constant character by which to determine a mineral than its colour, and, in many cases, than its fracture.

Fracture is said to be—

1. *Conchoidal*—when the minerals break with a curved concave or convex fracture. It often shows concentric and gradually diminishing undulations towards the point of percussion, somewhat resembling the lines of growth on a shell. Conchoidal fracture is well shown in quartz, flint, and obsidian.
2. *Even*—when the fracture-surface is flat or nearly flat, as in chert.
3. *Uneven*—when the fracture-surface is rough by reason of minute elevations and depressions. Example: copper-pyrites, etc.
4. *Hackly*—when the surface is studded with sharp and jagged elevations, as in cast-iron when broken.
5. *Earthy*—as in the fracture of chalk, meerschaum, reddle, etc.

Cleavage.—Closely related to crystalline form is the tendency to split along definite planes possessed by many minerals, which in each cleavable mineral species bears a constant relation to a certain face, or to certain faces, of the form in which the mineral crystallises. It is important to distinguish between fracture and cleavage, as the former is irregular and not connected with the crystalline form of the mineral. Minerals may cleave in one, two, three, or more directions, but one cleavage is generally to be obtained with greater ease than the others. In the plane of cleavage the molecules composing the mineral are closely packed together, whilst at right angles to this plane the packing is not so close. This last direction is, therefore, a direction of least cohesion, and hence splitting or cleavage easily occurs along it. Cleavage is often of great assistance in determining minerals which closely resemble one another in crystalline form, and in other external characters. In geology, certain rocks, such as slate, which split across their planes of bedding are said to be cleaved, but this cleavage is the result of molecular change produced by pressure, and has no connection with the cleavage which exists in minerals. Rock-salt, galena, calc-spar, fluor-spar, selenite, mica, hornblende, felspar, etc., afford good examples of cleavage.

Gliding planes and secondary twinning are related to cleavage, and are produced in a mineral by pressure—*e.g.*, during the preparation of a thin slice of calcite, the pressure of grinding the mineral always causes the mineral to show an excellent cleavage and some secondary twinning.

Surface Tension.—The difference in adhesive power of various liquids to different minerals has formed the basis for numerous processes of ore separation and concentration. The surface tension between various metallic sulphides and oil is greater than that between the gangue minerals quartz, calcite, etc., and the same medium. In the original *Elmore Process* a paste of sulphide and gangue is mixed with oil and water and agitated; the oil settles into a layer above the water and carries with it the sulphides. Somewhat of the same principle underlies the method of extracting diamonds from blue-ground, by causing them to adhere to grease upon shaking tables. The various *Flotation Processes* depend on surface tension. In these, bubbles of gas or air attach themselves to zinc-blende and float this mineral to the surface, leaving other sulphides and gangue material at the bottom of the liquid.

IV. SPECIFIC GRAVITY.

The specific gravity of a body is the ratio of the weight of the body to that of an equal volume of water. This latter weight varies with the temperature, but since its variation is very small, it is neglected in determinations of the specific gravity of minerals.

The cardinal principle employed in most determinations of specific gravity is that the loss in weight of a body immersed in water is the weight of a volume of water equal to that of the body. Suppose that W_a is the weight of the body in air, W_w its weight in water. Therefore $W_a - W_w$ is the weight of the water displaced by the body. Hence the specific gravity is given by—

$$\frac{W_a}{W_a - W_w}.$$

Methods of Determining Specific Gravity.

1. By means of an ordinary balance.
2. Walker's steelyard (for large specimens).
3. Jolly's spring balance (for very small specimens).
4. By measuring the displaced water.
5. The pycnometer.
6. By means of heavy liquids.
7. Of liquids, by means of the specific gravity bottle, hydrometer, etc.

1. *By Means of an Ordinary Balance.*—For taking specific gravities with a balance one of the scale-pans should be removed, and an exact counterpoise, terminating below in a small hook, should be substituted for it. The mineral to be weighed should be suspended from the hook of this counterpoise either by a hair, a fine fibre of silk, or a piece of extremely fine wire. The weight of the hair, silk, or wire should be taken into consideration before suspending the mineral, and a corresponding counterpoise should be placed in the scale-pan. After carefully weighing the suspended mineral in the air, a tumbler of water should be placed so that the mineral is well immersed beneath the

surface of the water, taking care that no bubbles of air are adhering to, or imprisoned by, the mineral. The weight will then be found to be less. If now the weight of the mineral in air be divided by the difference of its weight in air and water, the result will give its specific gravity.

2. *Walker's Steelyard.*—This instrument is useful for determining the specific gravity of large specimens, and is shown in Fig. 3. The essential part of the apparatus is the long graduated beam which is pivoted near one end, and is counterbalanced by a heavy weight suspended to the short arm. The specimen is suspended and moved along the beam until it counterbalances the constant weight. The reading (a) is taken. The specimen is then immersed in water and moved along the beam until the constant weight is again balanced. A second reading (b) is obtained. (a) and (b) are inversely proportional to the weights of the body in air and in water respectively.

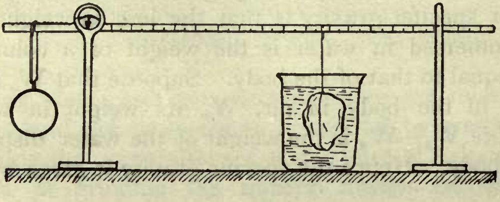


FIG. 3.—WALKER'S STEELYARD.

Hence—

$$\text{Specific gravity} = G = \frac{\frac{1}{a}}{\frac{1}{a} - \frac{1}{b}} = \frac{b}{b-a}.$$

Therefore the second reading (b), divided by the difference between the second and first readings, gives the specific gravity.

3. *Jolly's Spring Balance.*—This instrument consists of a spring suspended vertically against a graduated scale. To the lower end of the spring are attached two scale-pans, one below the other, the lower scale-pan being always immersed in water. Fig. 4 shows a Jolly balance. The reading (a) of the bottom of the spring on the scale is obtained. The mineral (a small fragment) is placed in the upper pan, and a second reading (b) taken. The specimen is then transferred into the lower pan, and a third reading (c) taken.

Then $b-a$ is proportional to the weight in air, and $b-c$ to the loss of weight in water.

Therefore—

$$\text{Specific gravity} = G = \frac{b-a}{b-c}.$$

4. *By Measuring the Displaced Water.*—The specific gravity of a large number of pieces of a mineral may be simultaneously and rapidly ascertained with a fair amount of accuracy by half filling with water a graduated cylinder of suitable size, and placing therein the previously weighed specimens, and noting the increase of volume.

The weight in grammes of the mineral in air, divided by the increase of volume in cubic centimetres, gives the specific gravity.

5. *The Pycnometer.*—A very light glass bottle, capable of holding an exact known weight of distilled water, is sometimes used for taking specific gravities, and is preferable to the other methods when the mineral happens to be porous. The mineral is roughly pulverised and accurately weighed. The bottle is filled with water. Both the mineral and the filled bottle are placed in the same scale-pan, and their combined weight ascertained. The mineral is then put into the bottle, from which it will displace an equal bulk of water. The weight is again determined. This last weight, when subtracted from the preceding weight, gives the weight of the water displaced. The weight of the mineral in air, divided by the weight of the water it displaces, gives the specific gravity of the mineral. Specific gravity is a very useful test at all times, but it is especially convenient for determining gems when cut and polished, as it often serves to distinguish them when other tests could not be applied without injuring the specimens.

6. *Heavy Liquids.*—This method is of great practical use for testing such material as gem gravel and detrital sediments in general. The method adopted is to agitate the sample in a solution of known specific gravity, and collect separately the material which floats and that which sinks, the latter being again tested in a solution of greater specific gravity, and the process continued until the sample has been separated into pure fractions.

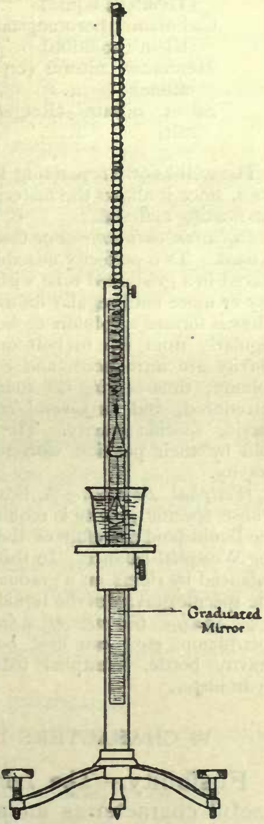


FIG. 4.—JOLLY'S SPRING BALANCE.

The following are some of the materials used in this process :

Bromoform	2·9	Diluted with benzine.
Methylene iodide	3·33	
Mercury potassium iodide (Thoulet's liquid)	3·17	Diluted with water.
Cadmium borotungstate (Klein's solution)	3·28	
Mercurous nitrate (crystalline)	4·3 (melts at 70° C.)	
Silver nitrate (Retger's salt)	4·5 (melts at 75° C.)	

The well-known separating funnel is useful for heavy liquid separations, since it allows the material which has sunk to be drawn off from the floating material.

Diffusion Column.—For testing small samples the diffusion column is used. Two perfectly miscible liquids of different specific gravity are placed in a graduated tube without mixture, and allowed to stand for a day or more until regular diffusion of the two liquids has taken place. Thus is formed a column of liquid in which the specific gravity varies regularly from top to bottom. Small fragments of known specific gravity are introduced, and come to rest at particular points in the column, thus serving as indices. The finely powdered sample is introduced, and its several constituents are separated into bands of varying specific gravity. The specific gravity of these bands can be told by their position with regard to the indices of known specific gravity.

Westphal Balance.—A heavy liquid is diluted until the mineral whose specific gravity is required just floats. The specific gravity of the liquid (and therefore of the mineral) is conveniently determined by the Westphal balance. In this a sinker is immersed in the liquid and balanced by riders on a graduated arm. The arm is so graduated that the specific gravity of the liquid can be read off directly.

7. *Specific Gravity of Liquids.*—The specific gravity of liquids (petroleum, etc.) can best be determined by means of the specific gravity bottle, Westphal balance, or by the use of the common hydrometer.

V. CHARACTERS DEPENDENT UPON HEAT.

Fusibility.—The relative fusibility of minerals is a useful character as an aid in their determination by the blowpipe. A scale of six minerals, of which the temperature of fusion was supposed to increase by somewhat equal steps, was suggested by Von Kobell. These minerals are stibnite, natrolite, almandine, actinolite, orthoclase, bronzite. All that can be said of these minerals is that stibnite is easily fusible, whilst bronzite can hardly be fused in the ordinary blowpipe.

VI. MAGNETISM, ELECTRICITY, AND RADIO-ACTIVITY.

Magnetism.—Magnetite, and in a less degree pyrrhotine, are the only minerals affected by an ordinary magnet, but a large number of minerals are attracted in varying degrees by the electromagnet. Minerals containing iron are generally magnetic, but not necessarily so, and the degree of magnetism displayed does not, in all cases, depend on the iron content. Minerals containing no iron may also be sufficiently magnetic to permit of their separation from non-magnetic material—*e.g.*, monazite and some other cerium-bearing minerals. The electromagnetic separation of minerals is an important ore-dressing process. By varying the strength of the electromagnet, minerals of varying magnetism can be separated from one another. Examples of such separation are the purification of magnetite from apatite, etc., the separation of pyrites from blende, chalybite from blende, wolfram from tinstone, and monazite from magnetite and garnet. It is sometimes necessary to roast the ore in order to convert feebly magnetic materials, such as pyrites and chalybite, into strongly magnetic material.

Highly Magnetic.—Magnetite, pyrrhotine.
Moderately Magnetic.—Chalybite, iron-garnet, chromite, ilmenite, hematite, wolfram.
Weakly Magnetic.—Tourmaline, spinels, monazite.
Non-Magnetic.—Quartz, calcite, felspar, topaz, corundum, cassiterite.

Electricity.—Electricity may be developed in minerals either by friction or heat, and in the latter case the mineral is said to be *pyro-electric*. Tourmaline is an example of a pyro-electric mineral. The degree of electrification varies widely among minerals, and this variation has recently been applied to separate by the *Electrostatic Separation Process*. In one type of this process the fine crushed and dried ore is dropped on to a rotating iron cylinder, electrically charged. Good conductors become charged and are repelled from the cylinder, bad conductors are repelled to a less degree, and hence the shower of ore is separated out into several minor showers which can be separately collected. For example, blende (a bad conductor) is separated from pyrite (a good conductor) in this way.

Good Conductors.—Native metals, graphite, sulphides (except blende).

Bad Conductors.—Blende, quartz, calcite, barytes, fluor.

Radio-Activity.—Many minerals containing elements of high atomic weight are radio-active, and emit an emanation that will affect a photographic plate, and which may be rendered visible by means of a sensitive phosphorescent screen.

The chief radio-active elements are—radium itself, uranium, and thorium. Pitchblende is the most important radio-active mineral; others are autunite, monazite, thorite, and carnotite.

CHAPTER III

CRYSTALLOGRAPHY

Introduction.—It was noticed by the ancient Greeks that a certain mineral, Quartz, usually occurred in forms having a characteristic shape, being bounded by flat faces. From the transparency of this mineral and the occurrence in it of included material, it was thought that Quartz resulted from the freezing of water under intense cold, and hence the name *Crystallos*—meaning *clear ice*—was given to the substance. However, there were numerous other minerals known to the ancients which occurred in forms bounded by flat faces, and so, by a natural extension of the term, *crystallos* came to signify any mineral limited by flat faces.

By the researches of Steno, De l'Isle and Hauy, the science of crystallography gradually evolved from mere speculation. It is to Hauy that we are indebted for an illuminating theory of the *structure* of crystals. Hauy argued that crystals were built up of minute *bricks* of the mineral, different modes of arrangement of the bricks producing different crystal forms. By more recent investigations Hauy's notion of the arrangement of material bricks has been replaced by that of the arrangement of atomic groups or molecules. It is therefore apparent that chemical constitution has an important influence on crystalline form, and, indeed, Von Fedorov has recently issued a list of over ten thousand substances, the chemical composition of which he is able to tell with absolute certainty from an examination of their crystals.

Professor Judd, in his Presidential Address to the Geological Society for 1887, instituted an interesting comparison between crystals and living matter. Life has been defined as "*a series of definite and successive changes, both of structure and composition, which take place in an individual without changing its identity.*" It is obvious that under this definition crystals "*live.*" Crystals grow by a series of definite and successive changes, both of structure and composition, without altering their identity. Crystals can retain their vitality for countless ages, can, under suitable conditions, develop into shapes exactly similar to those of living organisms, can absorb food from their surroundings, can propagate their kind, can respond to changes in their environment, can renew and repair themselves. Indeed, it has been suggested that the first formed organic matter was developed from a carbonaceous slime which had the properties of an ordinary crystallising substance.

Crystallography.—Crystallography is the study of crystals. Crystals are bodies bounded by surfaces, usually flat, arranged upon a definite plan which is an expression of the internal arrangement of the molecules, and are formed by the change of a mineral from the gaseous or liquid state into the solid state.

Characteristics of Crystals.

Faces.—Crystals are bounded by surfaces which are usually plane, but may be curved, as in chalybite, diamond, etc. These surfaces are called *faces*. Like faces have the same properties, and unlike faces have different properties.

Form.—A crystal having all of its faces like faces is termed a *simple form*. For example, the cube and the octahedron are each of them simple forms, since all the faces of each have the same properties. A crystal which consists of two or more simple forms is called a *combination*. In Fig. 5 the cube and the octahedron are shown as simple forms, and also as a combination such as occurs in crystals of galena.

Edge.—An *edge* is formed by the intersection of any two adjacent faces.

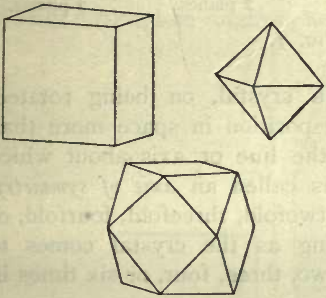


FIG. 5.—SIMPLE CUBE AND SIMPLE OCTAHEDRON. A COMBINATION OF THE CUBE AND OCTAHEDRON AS FOUND IN CRYSTALS OF GALENA.

Solid Angle.—A *solid angle* is formed by the intersection of three or more faces.

Interfacial Angle.—The angle between any two faces of a crystal is termed the *interfacial angle*, and is, in crystallography, the angle between the normals to the two faces.

Symmetry.—In a crystal there is a certain regularity of position of like faces, edges, etc., and this regularity constitutes the *symmetry* of the crystal.

The criteria of symmetry are three: a *Plane of Symmetry*, *Axis of Symmetry*, and *Centre of Symmetry*.

Plane of Symmetry. — A *plane of symmetry* divides a crystal into two similar and similarly placed halves. In other words, such a plane divides the crystal so that one half is the reflection of the other half.

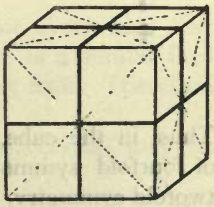
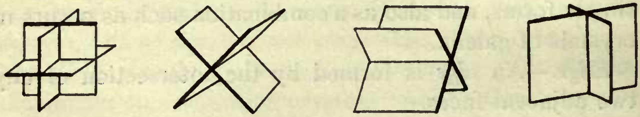


FIG. 6.

Fig. 6 shows the planes of symmetry of a cube. These dissected planes are displayed in Fig. 7.



3 planes. 2 planes. 2 planes. 2 planes.

FIG. 7.

Axis of Symmetry.—If a crystal, on being rotated, comes to occupy the same position in space more than once in a complete turn, the line or axis about which rotation has taken place is called an *axis of symmetry*. An axis of symmetry is of twofold, threefold, fourfold, or sixfold symmetry, according as the crystal comes to occupy the same position two, three, four, or six times in a complete rotation.

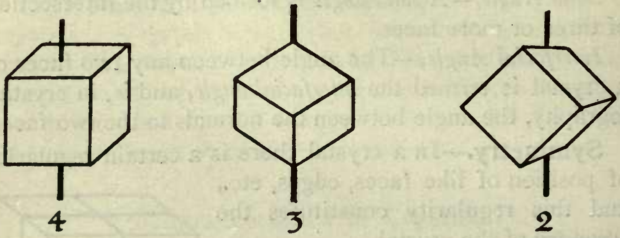


FIG. 8.

Thus, in the cube, as shown in Fig. 8, there are axes of fourfold symmetry, of threefold symmetry, and of twofold symmetry.

Centre of Symmetry.—A crystal has a *centre of symmetry* when like faces are arranged in pairs in corresponding positions and on opposite sides of a central point.

The Symmetry of Gypsum.—A crystal of gypsum may be taken to illustrate these definitions of symmetry. The usual form of such a crystal is shown in Fig. 9.

There is one plane which divides the crystal into two similar and similarly placed halves. This plane is the only plane of symmetry for this crystal. At right angles to this plane is an axis of symmetry. Rotation about this axis causes the crystal to take up the same position *twice* in a complete rotation, and this axis is therefore an axis of twofold symmetry. Lastly, for every face that occurs in one half of the crystal there is a similar face in a corresponding position in the other half. Therefore the crystal has a centre of symmetry.

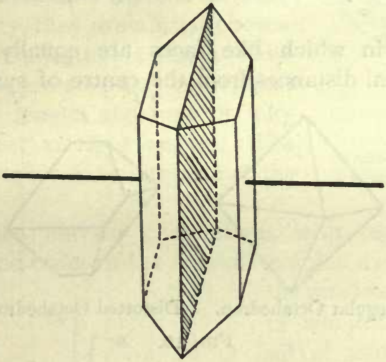


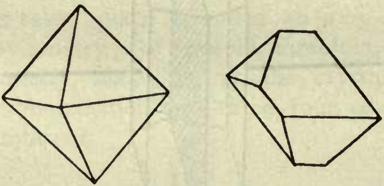
FIG. 9.—A GYPSUM CRYSTAL, SHOWING THE ONE PLANE OF SYMMETRY AND THE ONE AXIS OF SYMMETRY CHARACTERISTIC OF THIS MINERAL.

Thus the symmetry of this gypsum crystal may be expressed as follows:

Planes of symmetry, 1.
Axes of symmetry, 1^{II}.
Centre of symmetry.

Crystallographic and Geometrical Symmetry.—Crystallographic symmetry must not be confused with geometrical symmetry. Crystallographic symmetry depends solely upon the molecular arrangement of the crystal, and since this arrangement is the same for parallel planes, it follows that the angular position is the only factor concerned, and that the sizes of like faces and their distance from the plane or centre of symmetry are of no importance in this connection. This is illustrated in Fig. 10 below, which shows a regular and a distorted octahedron.

Crystals in which like faces are equally developed and are equal distances from the centre of symmetry are very rare; but for the convenience of study and of representation by diagrams, it is necessary to deal with crystals in their simplest and most intelligible form, and that is when they have perfect geometrical symmetry.



Regular Octahedron. Distorted Octahedron.

FIG. 10.

Most crystals occur in *distorted forms*, having like faces not of the same size or not in the same geometrically symmetrical position. The crystallographic symmetry can, however, be made out by the fact that like faces have like properties. Etch-marks, the behaviour towards heat and electricity, the hardness, lustre, etc., of the faces, will reveal the true symmetry of a distorted crystal. This is well seen in the quartz crystal in Fig. 11, in which the etch-marks are similar on like faces.

Crystallographic Axes. — In solid geometry the position of a plane in space is given by the intercepts that the plane makes on three given lines, called axes. This method of treatment is employed in crystallography, and the axes are termed *crystallographic axes.* Whenever there is present a suitable number of axes of symmetry, they are always chosen as the crystallographic axes. The crystallographic axes may be of equal or unequal length, and may or may not intersect at right angles. The crystallographic axes intersect at the *origin.*

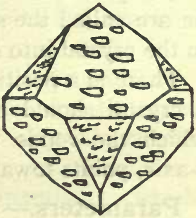


FIG. 11.—QUARTZ CRYSTAL, SHOWING SIMILAR ETCH-MARKS ON LIKE FACES.

There are certain conventions with regard to the lettering and order of the crystallographic axes. Taking the most complex case, in which the axes are all of unequal length and none at right angles, the axis which is taken as the vertical axis is called *c*, that running from right to left is *b*, and that running from front to back is *a*. One end of each axis is positive, and the other end is negative, and the rule with regard to this is illustrated in Fig. 12.

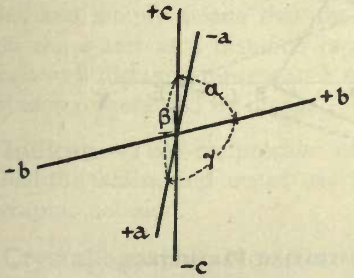


FIG. 12.—FIGURE ILLUSTRATING AXIAL CONVENTIONS.

The angle between *a* and *b* is called γ, that between *b* and *c* is called α, and that between *c* and *a* is β.

If two of the axes are equal, they are both called *a*, and the third is *c*; if all three axes are equal, they are all called *a*. The hexagonal system has *four* crystallographic axes; every other system has three.

The planes in which two of the crystallographic axes lie are called the *axial planes*, and divide the space within the crystal into eight *octants*.

There is a position called the *reading position*, in which a crystal should be placed to be drawn or studied, in which the *c*-axis is vertical, and one lateral axis, the *a*-axis, points towards the observer.

Parameters.—The *parameters* of a crystal face are the ratios of the distances from the origin at which the face cuts the crystallographic axes—that is, the parameters are the ratios of the intercepts.

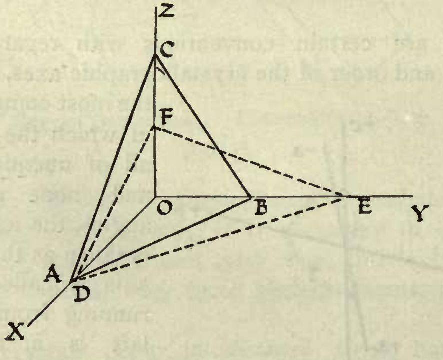


FIG. 13.—ILLUSTRATING PARAMETERS.

In Fig. 13, OX, OY, OZ, represent the crystallographic axes, and ABC is a crystal face making intercepts of OA on OX, OB on OY, and OC on OZ. The parameters of the face ABC are given by the ratio of OA, OB, and OC, and thus the position of the face ABC is known.

It is therefore convenient to take the relative intercepts of this face as standard lengths for the purpose of representing the position of any other face, such as *DEF*. In the case of the face *DEF*, *OD* is equal to *OA*, *OE* is twice *OB*, and *OF* is half *OC*, and therefore $\frac{1}{1}$, $\frac{2}{1}$, $\frac{1}{2}$ are the parameters of *DEF*, with reference to the standard face *ABC*.

The form whose face is taken as intersecting the axes at unit lengths is called the *fundamental* or *unit* form. The selection of a suitable unit form depends on the properties or nature of the crystal. A form well developed, or commonly occurring, or parallel to which there is a good cleavage, is usually selected for this purpose.

The parameters of the unit form can be obtained by measurement, and can be expressed as multiples of one of their number. Take, for example, gypsum. It is found that the most commonly occurring form in gypsum crystals which cuts all three axes does so in the ratio of 0·6899 : 1 : 0·4124. This expression is called the *axial ratio*, and simply means that the standard or unit form cuts the *a*-axis at a distance represented by 0·6899, the *b*-axis at a distance represented by 1, and the *c*-axis at a distance represented by 0·4124.

Indices.—The reciprocals of the parameters are called the *indices*, and are of use for purposes of crystallographic notation.

Crystallographic Notation.—Crystallographic notation is a concise method of writing down the relation of any crystal face to the crystallographic axes. The most widely used systems depend upon either parameters or indices. Of these systems of notation, the chief are two—The Parameter System of Weiss, and the Index System of Miller (modified by Bravais).

The Parameter System of Weiss.—In this system of crystallographic notation, the axes are taken in the order explained above—that is, a, b, c for unequal axes, a, a, c for two axes equal, and a, a, a for three axes equal. The intercept that the crystal face under discussion makes on the a-axis is then written before a, the intercept on the b-axis before b, and the intercept on the c-axis before c. Thus the most general expression for a crystal face in the Weiss notation is—

$$na, mb, pc,$$

where n, m, p are the intercepts made by the face on the a, b, c axes. It is usual to reduce either n or m to unity.

If a crystal face is parallel to an axis, it can be imagined as cutting that axis at an infinite distance, and accordingly the sign of infinity, ∞, is placed as its parameter before the corresponding axial letter. Thus a face cutting the a-axis at a distance 1 unit, the b-axis at a distance 2 units, and which is parallel to the c-axis, has the Weiss symbol—

$$a, 2b, \infty c.$$

Index System of Miller.—In this system of notation the indices, or reciprocals of the parameters, are used. They are written in the axial order, a, b, c, and are always given in their most simple form by clearing of fractions. For example, consider the crystal face having the Weiss symbol—

$$a, 2b, \infty c.$$

The reciprocals of the parameters are—

$$1, \tfrac{1}{2}, 0.$$

Clearing of fractions the Miller symbol is—

$$2, 1, 0,$$

which is read as two, one, nought.

A face parallel with an axis will contain the symbol O, the reciprocal of infinity. The most general Miller symbol is—

$$h, \; k, \; l.$$

Referring again to the unit form of gypsum, although this form cuts the three axes at unequal distances, its Miller symbol will be (111), since the unit form has been defined as cutting the axes at the standard distances.

Again, in Fig. 13 the symbols of *ABC*, *DEF*, will be—

	Weiss.	*Miller.*	
ABC	*a*, *b*, *c*.	111	... unit form.
DEF	*a*, 2*b*, ½*c*.	214.	

Conventions in Notation.—Several conventions in crystallographic notation are worthy of consideration. When it is required to indicate a crystal *form*, it is usual to enclose the symbols in a bracket thus (*h*, *k*, *l*), whereas, if the crystal face is indicated, the bracket is removed, thus—*h*, *k*, *l*.

The convention with regard to the sign of the ends of the crystallographic axes is of great importance in notation, since by adding the proper sign to the symbol, it is possible to indicate any required face of a crystal form. Consider the *form* (111). This is made up of the *faces* 111, 111, $1\bar{1}\bar{1}$, $11\bar{1}$, $\bar{1}11$, $\bar{1}\bar{1}1$, $\bar{1}\bar{1}\bar{1}$, $\bar{1}1\bar{1}$, as shown in Fig. 14.

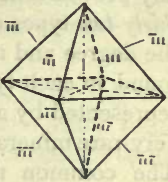


FIG. 14.—THE FORM (111).

Law of Rational Indices.—The study of crystals has established the law that the intercepts that any crystal face makes on the crystallographic axes are either infinite, or small rational multiples of the intercepts of the unit form. Thus the symbol $a, \sqrt{2a}, \infty a$, is an impossibility.

The Three Laws of Crystallography.

It is now possible to enunciate the three fundamental laws of crystallography.

I. Law of Constancy of Symmetry.—All crystals of any one mineral have the same symmetry.

II. Law of Constancy of Interfacial Angle.—The angle between two like faces of a given form is constant for all crystals of a given mineral. The interfacial angle is therefore of great use in the detection of minerals.

III. Law of Rational Indices.—All crystal faces make intercepts on the crystallographic axes, which are either infinity, or small rational multiples of the intercepts made by the unit form.

Classification of Crystals.—It has been mathematically proved that there are possible among crystals only *thirty-two* types of symmetry, differing from each other in the degree and nature of the three elements of symmetry found in each type. Of these thirty-two types, some are represented by artificially prepared compounds, some by very rare minerals, and some have no representative at all. The common minerals are found in *eleven groups* only. The first classification of crystals is therefore into the *symmetry groups*.

In studying crystals it is necessary to refer the forms to the crystallographic axes, and it is found that crystals of different symmetry can be referred to the same set of crystallographic axes. All the crystal forms, of whatever symmetry, that can be referred to the same set of axes fall in one *crystal system*.

The second classification of crystals is therefore into the *crystal systems*.

The Crystal Systems.

1. *Cubic.*—Three equal axes at right angles (*aaa*).

2. *Tetragonal.*—Two equal *lateral* axes, one *vertical* axis, at right angles (*aac*).

3. *Hexagonal.*—Three equal *lateral* axes, making angles of 120° with each other, a *vertical* axis at right angles to the plane containing the lateral axes (*aaac*).

4. *Orthorhombic.*—Three unequal axes, all at right angles (*abc*).

5. *Monoclinic.*—Three unequal axes, one vertical, one at right angles to the vertical axis, the third making an oblique angle with the plane containing the other two (*abc*).

6. *Triclinic.*—Three unequal axes, none at right angles (*abc*).

Holohedral Forms.—Those forms in any system which present the full number of faces requisite to show the complete symmetry of the system are termed *holohedral* forms.

Hemihedral Forms.—In these forms only *half* the number occurring in the corresponding holohedral form are present, by the development either of alternate faces or alternate groups of faces.

Tetartohedral Forms.—These forms exhibit only a *quarter* of the number of faces required by the symmetry of the system.

COMPOSITE AND TWIN CRYSTALS.

1. **Irregular Aggregates.**—In an irregular crystal aggregate there is no relation between the orientation of any two individual crystals.

2. **Parallel Growths.**—In a parallel growth the individuals have the same orientation, like edges and

faces of the different crystals being parallel, as in Fig. 15, in which several crystals of quartz are shown, all of which have their axes parallel to one another.

3. Twin Crystals.—Intermediate between the absolute absence of orientation of irregular aggregates, and the parallel orientation of parallel growths, there are crystals in which the orientation is partially the same. These are *twin crystals*, and in them one or two axes of one individual are parallel to the corresponding axes in the other individual. In twin crystals one part is in reverse position to the other part, and the twin may be conceived as produced by the revolution of one half through an angle of 180°. The twin of gypsum in Fig. 16 exhibits this.

FIG. 15.—GROUP OF QUARTZ CRYSTALS.

Fig. 16, *A* shows a crystal of gypsum viewed from the side. If such a crystal were divided along the dotted line and one half turned through 180°, the result would be the twin crystal shown in Fig. 16, *B*.

Twin-Plane.—The plane of revolution is called the *twin-plane* (*PP* in Fig. 16).

Twin-Axis.—The axis about which rotation has taken place is the *twin-axis*, and is perpendicular to the twin-plane (*aa* in Fig. 16).

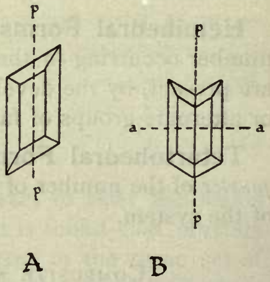


FIG. 16.

Composition-Plane.—The plane along which the two halves of the twin are joined is called the *composition-plane.* This is coincident with the twin-plane in Fig. 16.

Twin crystals can be recognised by re-entrant angles, corresponding edges being not all parallel, and the symmetry of the twin being higher than that of the individual. A plane of symmetry can never be a plane of twinning, since revolution of one half through 180° would simply leave the crystal as it was at first.

There are various types of twins, the following being the most important.

Simple Twin.—One half of the crystal has been rotated through 180°, as above.

Penetration Twin.—The two halves of the twin are completely interpenetrated.

Repeated or Polysynthetic Twin.—A twin produced by the repetition of twinning according to the same law. This is well seen in plagioclase felspar.

Compound Twin.—A twin in which twinning has taken place on two or more laws.

The Study of a Crystal of Orthoclase.

In order to give precision to the ideas of crystallography set out above, it is advisable to study the complete crystallography of some suitable mineral, and for this purpose orthoclase has been selected.

Orthoclase.

System.—Monoclinic—two axes at right angles, the third inclined.

Axial Ratio.—$a : b : c = 0{\cdot}6585 : 1 : 0{\cdot}5554$. $\beta = 63° \, 57'$. (See Fig. 17.)

Common Habit.—The common shape of an orthoclase crystal is shown in Fig. 18.

Forms Present.—m (110) $(a, b, \infty c)$.
c (001) $(\infty a, \infty b, c)$.
b (010) $(\infty a, b, \infty c)$.
y (201) $(a, \infty b, 2c)$.

Faces seen in Fig. 18.—*b* 010.
c 001.
m 110.
m 1$\bar{1}$0.
y 20$\bar{1}$.

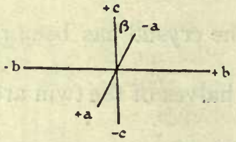


FIG. 17.—THE AXES OF ORTHOCLASE, SHOWING THE β ANGLE AND THE LENGTHS OF THE AXES CUT OFF BY THE UNIT PYRAMID (111).

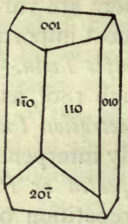
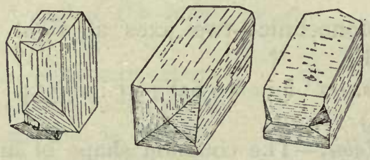


FIG. 18.—COMMON CRYSTAL OF ORTHOCLASE.

Twinning.—Orthoclase twins on three common laws:—

1. *Carlsbad Type.*
   Composition plane *b* (010).
   Twin axis *c*.
2. *Baveno Type.*
   Twin and composition plane *n* (021).
3. *Manebach Type.*
   Twin and composition plane *c* (001).



Carlsbad Twin. Baveno Twin. Manebach Twin.

FIG. 19.—ORTHOCLASE TWINS.

CHAPTER IV

IMPORTANT CRYSTAL GROUPS.[1]

I. ISOMETRIC OR CUBIC SYSTEM.

Axes.—Three equal axes at right angles, interchangeable, and all denoted by *a*. The reading position is one axis vertical (a_3), one running right and left (a_2), and the third front and back (a_1).

This system contains *three* symmetry groups, each characterised by a common mineral:

(1) Galena Group, (2) Pyrite Group, (3) Tetrahedrite Group.

1. GALENA, OR NORMAL TYPE.

Symmetry.—This group contains crystals of the highest symmetry. This symmetry is made out from the cube, and may be summarised as follows:

$$\textit{Planes}, 9 \begin{cases} 3 \text{ axial.} \\ 6 \text{ diagonal.} \end{cases}$$

$$\textit{Axes}, 13 \begin{cases} 3^{\text{IV.}} \text{ (crystallographic axes).} \\ 4^{\text{III.}} \\ 6^{\text{II.}} \end{cases}$$

A centre of symmetry.

Forms.

(i.) *Cube.*—A six-faced solid formed by faces which cut one axis and are parallel to the other two. The symbol is therefore (100).

---

[1] The only intelligent manner of studying the crystal systems is with the help of actual crystals, models, and drawings. The student should constantly refer to the diagrams on pp. 88-93, and to the drawings of crystals under the mineral species in Part II. of this book.

(ii.) *Rhombdodecahedron.*—A solid having twelve rhomb-faces, each face cutting two axes at equal distances and parallel to the third, and having therefore the symbol (110).

(iii.) *Octahedron.*—A solid having eight triangular faces, each face cutting all three axes at equal distances, and having therefore the symbol (111).

(iv.) *Tetrahexahedron.* — A solid having twenty-four faces, each face an isosceles triangle, and formed by a four-faced pyramid on each face of the cube. Each face is parallel to one axis, and cuts the other axes at unequal lengths, the symbol being therefore ($h\ k\ 0$), and a commonly occurring example being (210). Since h and k can vary, this form is called a *variable form.* When either h or k is zero, the form becomes a cube; when $h = k$, the form becomes a rhombdodecahedron. This is expressed by saying that the *limiting forms* of the tetrahexahedron are the cube and the rhombdodecahedron.

(v.) *Trisoctahedron.*—A solid having twenty-four faces, each face an isosceles triangle, and formed by a three-faced pyramid on each face of the octahedron. Each face cuts two axes at an equal length, and the third axis at a *greater* length. The Weiss symbol for this form is therefore (a, a, pa), the Miller symbol is ($h\ h\ l$), and a commonly occurring form is (221). The limiting forms are the octahedron and the rhombdodecahedron.

(vi.) *Trapezohedron.*—A solid having twenty-four faces, each face a trapezium. Each face cuts two axes at an equal length, and the third at a *smaller* length. The Miller symbol is therefore ($h\ l\ l$), and a common example is (211). The limiting forms are the cube and octahedron.

(vii.) *Hexoctahedron.*—A solid having forty-eight faces, each face a scalene triangle. Each face cuts the three axes at unequal lengths. The symbol is therefore ($h\ k\ l$)

and a common example is (321). The hexoctahedron is the most general form of the galena type, and its limiting forms are the cube, octahedron, and rhombdodecahedron.

Common Galena Type Minerals.

Galena.—Galena occurs commonly as combinations of the cube and octahedron, as shown in Fig. 5.

Fluor, Rock Salt, Sylvine.—These minerals occur as simple cubes.

Leucite, Analcime.—Leucite and analcime occur as simple trapezohedra (see p. 88).

Spinel, Magnetite.—These minerals occur as simple octahedra. The cleavage of *fluor* is parallel to the faces of the octahedron.

Garnet.—Common crystals of garnet are either the rhombdodecahedron or the trapezohedron, or combinations of the two (see Figs. 76 and 77).

2. PYRITE TYPE.

Symmetry.—The symmetry of the pyrite type is that of the characteristic form, the pyritohedron (Fig. 20). This symmetry is—

Planes, 3 axial.

Axes, $7\begin{cases} 3^{\text{II.}} \text{ (crystallographic axes).} \\ 4^{\text{III.}} \end{cases}$

A centre of symmetry.

Forms.

(i.) *Pyritohedron.*—A solid bounded by twelve pentagonal faces. Each face cuts two axes at unequal lengths, and is parallel to the third, thus having a typical symbol of (210), similar to the tetrahexahedron (210) from which it is produced by the development of alternate faces of each pyramid, as shown in Fig. 20.

There will obviously be *two* pyritohedra produced from the tetrahexahedron by the development of the *two* sets of faces.

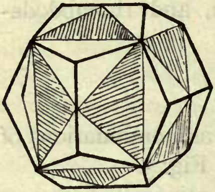


FIG. 20. — PYRITOHEDRON, SHOWING ITS DEVELOPMENT FROM TETRAHEXAHEDRON.

(ii.) *Diploid.*—A solid bounded by twenty-four faces. Each face is a trapezium, and the faces are grouped in pairs. Each face cuts all three axes at unequal lengths, and a commonly occurring form is that having the symbol (321). The diploid is produced from the hexoctahedron (321) by the development of alternate faces.

The other five forms—cube, octahedron, rhombdodecahedron, trisoctahedron, and trapezohedron — are geometrically similar to those of the galena type, but have a lower crystallographic symmetry. This lower symmetry is evident in the case of the striated cube of pyrites shown in Fig. 21. It will be noticed that the striations on the three pairs of faces lie in three directions at right angles, parallel to the crystallographic axes. Any one of these axes is an axis of *twofold* symmetry, whereas, in the cube of galena, a crystallographic axis is an axis of *fourfold* symmetry. A striated cube of pyrite results from what is known as an *oscillatory combination,* both the cube and the pyritohedron having endeavoured, as it were, to assert their respective forms during crystallisation.

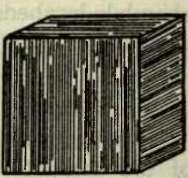


FIG. 21.

Common Pyrite Type Minerals.

Pyrites.—Pyrites commonly occurs in the striated cube, the pyritohedron, or combinations of the pyritohedron with the cube, octahedron, or diploid.

Cobaltite, *Smaltite*, and *Chloanthite* are other pyrite type minerals.

3. Tetrahedrite Type.

Symmetry.—The typical form of this type is he *tetrahedron*, and the symmetry is—

Planes, 6 diagonal.

Axes, $7\begin{cases}3^{\text{II.}} \text{ (crystallographic axes).}\\ 4^{\text{III.}}\end{cases}$

No centre of symmetry.

Forms.

(i.) *Tetrahedron.*—A four-faced solid, each face meeting the axes at equal distances, and therefore the symbol of the form is (111). The tetrahedron is a hemihedral form, produced from the octahedron (111) by the development of alternate faces, as shown in Fig. 22.

Note that the crystallographic axes of the tetrahedron join the centres of the opposite edges. There are *two* tetrahedra possible—a positive one (111) and a negative one (1$\bar{1}$1), produced by developing the *two* sets of faces of the octahedron.

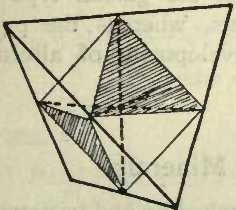


Fig. 22.—Tetrahedron, showing its Development from the Octahedron.

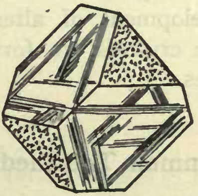


Fig. 23.

Fig. 23 shows the two tetrahedrons in combination, but the faces of the positive form present different etch-markings from those on the negative faces.

(ii.) *Deltoid-Dodecahedron.*—This solid has twelve faces, each face being a deltoid, and cutting two axes at an equal length and the third at a greater length. A typical symbol is (221), and this hemihedral form is produced from the trisoctahedron by the development of alternate *octants.*

(iii.) *Tristetrahedron.*—This solid is the hemihedral form bounded by a three-faced pyramid on each face of the tetrahedron, and is produced from the trapezohedron by the development of alternate *octants.* Hence a typical symbol is (211).

(iv.) *Hexatetrahedron.*—This solid has twenty-four triangular faces, and is produced from the hexoctahedron by the development of alternate *octants.* A common symbol is (321).

The other forms occurring are the cube, rhombdodecahedron and tetrahexahedron, giving seven forms in all. These tetrahedrite type forms differ from the galena type forms by their lower symmetry, which finds expression by the distribution of etch-marks, striations, or by pyroelectricity.

It should be noted that the hemihedral tetrahedrite type crystals are formed from the galena type by development of alternate octants, whereas the pyrite type crystals are formed by development of alternate faces.

Common Tetrahedrite Type Minerals.

Tetrahedrite.—Tetrahedron, tetrahedron and tristetrahedron, cube and tetrahedron.

Diamond.—Diamond occurs in octahedra, which are probably made up of the positive and negative tetrahedra.

Zinc Blende.—Tetrahedra.

Boracite.—Combinations of the cube, tetrahedron, and rhombdodecahedron.

II. Tetragonal System.

Axes.—Two equal lateral axes, one unequal vertical axis, all at right angles. The lateral axes are interchangeable, and are denoted each by a, the vertical axis by c. The reading position is c vertical, and one lateral axis running right and left. The *axial ratio* is determined from the intercepts made by the fundamental form on the axes. The intercept on the c axis is given in terms of that on a lateral axis—*e.g.*, for zircon, the axial ratio is expressed by $c = 0{\cdot}64037$.

This system contains one common symmetry group, that characterised by *Zircon.*

Zircon Group.

Symmetry.—From an examination of the axes, the following symmetry can be made out:

$$\textit{Planes},\ 5\ \begin{cases} 3 \text{ axial.} \\ 2 \text{ diagonal.} \end{cases}$$

$$\textit{Axes},\ 5\ \begin{cases} 4^{\text{II.}} \\ 1^{\text{IV.}} \end{cases}$$

A centre of symmetry.

Forms.

(i.) *Basal Pinacoid or Plane.*—This form consists of two faces only, which are parallel to the plane containing the lateral axes, and is therefore an *open* form, since it cannot occur alone in a crystal. Its symbol is (001).

(ii.) *Tetragonal Prism of the Second Order.*—This is an open form consisting of four faces, each parallel to the vertical axis and to one lateral axis, the crystallographic axes emerging from the *middle* of the *faces.* The symbol is therefore (100).

(iii.) *Tetragonal Prism of the First Order.*—This is an open form of four faces, each face being parallel to the vertical axis and cutting the two lateral axes. The symbol is (110). The axes emerge at the *centres* of the vertical *edges.*

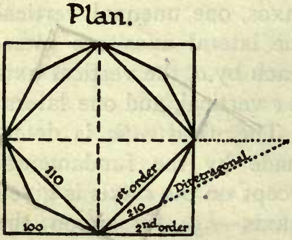


FIG. 24.

(iv.) *Ditetragonal Prism.*—This form has eight faces, and is an open form. Each face is parallel to the vertical axis, and cuts the lateral axes at unequal lengths. The symbol is (*h k o*), and a typical example is (210).

The relation between the three prisms is shown in Fig. 24.

(v.) *Tetragonal Pyramid of the Second Order.*—This form consists of eight faces, each face cutting the vertical axis and one lateral axis, being parallel to the other lateral axis. A common symbol is therefore (101).

(vi.) *Tetragonal Pyramid of the First Order.*—This form consists of eight faces, each face cutting all three axes. A typical symbol is (111).

(vii.) *Ditetragonal Pyramid.*—This form consists of sixteen faces, each face cutting all three axes at unequal distances—the symbol being (*h k l*), and a typical form being (321).

Common Zircon Type Minerals.

The commonest minerals of the zircon type are—zircon, rutile, cassiterite, anatase, idocrase, and apophyllite. The crystals show combinations of pyramids, prisms, and basal plane, and are exemplified by the crystal of idocrase shown in Fig. 25.

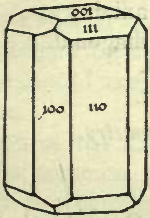


FIG. 25.—IDOCRASE, SHOWING THE FORMS, PRISMS OF FIRST AND SECOND ORDER, PYRAMID FIRST ORDER, BASAL PLANE.

III. HEXAGONAL SYSTEM.

Axes.—Three lateral axes making angles of 120° with each other, a vertical axis perpendicular to the plane containing the lateral axes. The axial nomenclature and polarity are shown in Fig. 26.

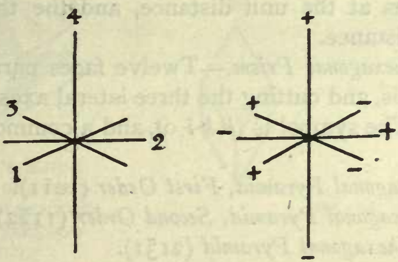


FIG. 26.

The axial ratio is expressed as for the zircon type.

This system contains four important symmetry groups: *Beryl*, *Calcite*, *Tourmaline*, and *Quartz* types. The Beryl type is not of importance except for the illustration of the normal hexagonal type of symmetry. The Beryl type is exactly similar to the zircon type, except, of course, in its hexagonal symmetry, and will not be considered in detail here (see p. 90).

1. Beryl Type.

Symmetry.

Planes, 7 $\left\{\begin{array}{l}4 \text{ axial.}\\ 3 \text{ diagonal.}\end{array}\right.$

Axes, 7 $\left\{\begin{array}{l}6^{II}.\\ 1^{VI}.\end{array}\right.$

A centre of symmetry.

Forms.

(i.) *Basal Pinacoid* (0001).—Cuts vertical axis only. Two faces.

(ii.) *Hexagonal Prism, First Order, or Unit Prism* $(10\bar{1}0)$.—Six faces parallel to vertical axis and one lateral axis; cuts other two lateral axes.

(iii.) *Hexagonal Prism, Second Order, or Diagonal Prism* $(11\bar{2}0)$.—Six faces parallel to vertical axis, meeting two lateral axes at the unit distance, and the third at one half this distance.

(iv.) *Dihexagonal Prism.*—Twelve faces parallel to the vertical axis, and cutting the three lateral axes at unequal lengths. The symbol is $(h\ k\ \bar{i}\ 0)$, and a common example is $(21\bar{3}0)$.

(v.) *Hexagonal Pyramid, First Order* $(10\bar{1}1)$.

(vi.) *Hexagonal Pyramid, Second Order* $(11\bar{2}2)$.

(vii.) *Dihexagonal Pyramid* $(21\bar{3}1)$.

2. Calcite Type.

Symmetry.—The symmetry of the Calcite type is given by that of the characteristic form, the rhombohedron, and is summarised below:

Planes, 3 vertical diagonal.

Axes, 4 $\left\{\begin{array}{l}1^{III}: \text{ vertical crystallographic axis.}\\ 3^{II}: \text{ lateral crystallographic axes.}\end{array}\right.$

A centre of symmetry.

Forms.

(i.) *Rhombohedron.* — The rhombohedron is a solid bounded by six rhomb faces. The *c*-axis joins the two solid angles formed by the obtuse angles of the rhomb faces, and the lateral axes join the middles of the pairs of opposite edges.

The position of the axes is seen from Fig. 27. The symbol of the common rhombohedron is $(10\bar{1}1)$. The rhombohedron is a hemihedral form developed from the hexagonal pyramid, as shown in Fig. 27. There are therefore possible two rhombohedra, positive and negative—the positive rhombohedron having a face uppermost, the negative rhombohedron an edge uppermost, as shown in Fig. 28.

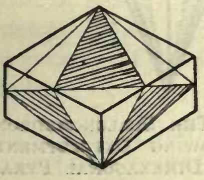


Fig. 27.—Plus Rhombohedron, showing its Development from the Hexagonal Pyramid.

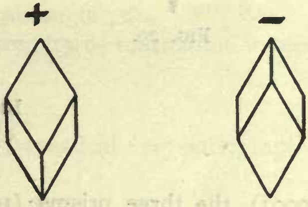


Fig. 28.

(ii.) *Scalenohedron.* — The scalenohedron is a solid bounded by twelve faces, each face being a scalene triangle. The terminal edges are alternately blunt and sharp, and the lateral edges zig-zag round the crystal, as shown in Fig. 29. A common symbol of the scalenohedron is $(21\bar{3}1)$. The scalenohedron is developed from the dihexagonal pyramid, as shown in Fig. 30.

The five remaining forms of the calcite type are geometrically similar to those of the beryl type, but have a lower molecular symmetry. They are the basal plane

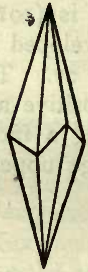


FIG. 29.

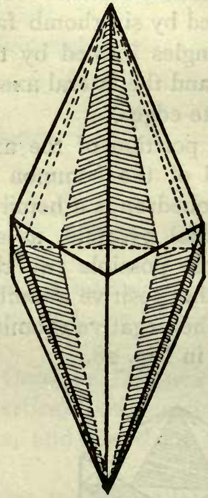


FIG. 30. — THE SCALENOHEDRON $(21\bar{3}1)$, SHOWING DEVELOPMENT FROM THE DIHEXAGONAL PYRAMID.

(0001), the three prisms $(10\bar{1}0)$, $(11\bar{2}0)$, (*h k i* 0), and pyramids like $(11\bar{2}1)$.

Common Calcite Type Minerals.

Calcite.—Calcite occurs in various combinations of prisms, rhombohedra, and scalenohedra. Fig. 31 shows a common crystal, in which are present the prism $(10\bar{1}0)$, the scalenohehron $(21\bar{3}1)$, and the rhombohedron $(01\bar{1}2)$.

Calcite gives by cleaving the unit rhombohedron $(10\bar{1}1)$ (see Fig. 27).

Dolomite.—Dolomite occurs in the unit rhombohedron, commonly with curved faces (see Fig. 50).

Chalybite.—Chalybite occurs in forms like those of dolomite.

Corundum.—Corundum occurs as combinations of rhombohedron, prism and basal plane. The crystals are often barrel-shaped by the presence of many rhombohedra (see Fig. 56).

Hematite. — Hematite occurs in thin tabular crystals, usually showing the basal plane and a rhombohedron.

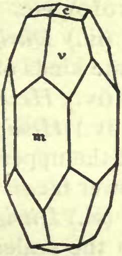


FIG. 31.—CALCITE, SHOWING THE FORMS, PRISM (*m*), SCALENOHEDRON (*v*), AND NEGATIVE RHOMBOHEDRON (*e*).

3. TOURMALINE TYPE.

Symmetry.—This group is a hemimorphic group, characterised by the occurrence, at the two ends of the vertical axis, of sets of faces having different symmetry. With this modification of the symmetry of calcite the symmetry of tourmaline is seen to be—

Planes, 3 vertical diagonal.
Axis, 1 of threefold (vertical crystallographic axis).
No centre of symmetry.

Forms.

(i.) *Trigonal Unit Pyramid.*—This form contains three faces. Each form is derived from the rhombohedron, and, from a consideration of the symmetry given above, it will be seen that there are four such forms—one composed of the three upper faces of the positive rhombohedron, one of the three lower faces of the same rhombohedron, and two others composed of the corresponding faces of the negative rhombohedron. Symbols: $(10\bar{1}1)$, etc.

(ii.) *Trigonal Unit Prism.*—A form made up of three alternate faces of the hexagonal prism. Symbols: (10$\bar{1}$0), etc.

(iii.) *Ditrigonal Prism.*—A six-sided form with two alternate kinds of angles.

(iv.) *Hexagonal Prism of the Second Order* (11$\bar{2}$0).

(v.) *Hemimorphic Hexagonal Pyramid.*—Two forms, one of the upper faces of the hexagonal pyramid, one of the lower faces.

(vi.) *Ditrigonal Pyramid.*—Four forms which correspond to the scalenohedron, in the same way as the trigonal pyramids correspond to the rhombohedron—that is, one form is made up of the upper faces of the positive scalenohedron, one of the lower faces of the same scalenohedron, and two others of the corresponding faces in the negative scalenohedron.

(vii.) *Basal Plane.*—Since there is no horizontal plane of symmetry in the tourmaline type, the two faces of the basal plane are different forms.

(vii.*a*) Upper basal plane (0001).
(vii.*b*) Lower basal plane (000$\bar{1}$).

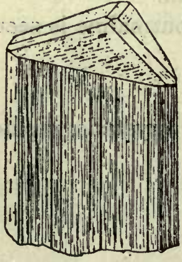


FIG. 32.—TOURMALINE.

Common Tourmaline Type Minerals.

Tourmaline.—Tourmaline commonly occurs in prismatic crystals, having the two trigonal prisms (10$\bar{1}$0) and (01$\bar{1}$0), usually unequally developed, and terminated differently at the two ends by the several trigonal pyramids, as shown in Fig. 32.

4. QUARTZ TYPE.

Symmetry.—The commonest crystals of quartz occur in the form of a hexagonal prism bounded above and below by hexagonal pyramids. Thus it would appear that quartz belonged to the beryl type, and therefore possessed the highest symmetry of the hexagonal system. However, quartz is proved to have a symmetry much lower than that of beryl, by two main considerations. First, etch-marks prove that the pyramidal or prism faces are not all of the same kind (see Fig. 11). Secondly, the occurrence on some crystals of quartz of faces of *tetartohedral* forms—the trigonal pyramid and the trigonal trapezohedron—show that the characteristic form is not a simple pyramid or prism.

The symmetry of quartz is therefore given by that of the lowest form, the trigonal trapezohedron.

Planes, none.

Axes, $4 \begin{cases} 3^{\text{II}}: \text{lateral crystallographic axes.} \\ 1^{\text{III}}: \text{vertical crystallographic axis.} \end{cases}$

No centre of symmetry.

Forms.

(i.) *Trigonal Trapezohedron.*—This solid is bounded by six trapezium-shaped faces, and the relation of its faces to the crystallographic axes is apparent from its general symbol $(h\ k\ i\ l)$. A commonly occurring form is $(51\bar{6}1)$.

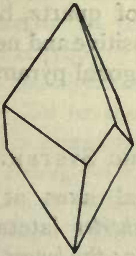


FIG. 33.

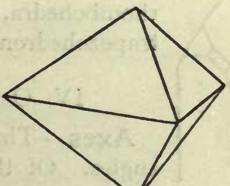


FIG. 34.

Fig. 33 shows a positive right-handed trigonal trapezohedron.

(ii.) *Trigonal Pyramid.*—This form is bounded by the faces of a double pyramid, the base of which is an equilateral triangle, and the sides are isosceles triangles. A trigonal pyramid having the symbol $(11\bar{2}2)$ is shown in Fig. 34.

In quartz crystals it is possible to recognise these two tetartohedral forms by the shape of the faces, the trigonal trapezohedron face being either triangular or trapezohedral, the trigonal pyramid face being diamond-shaped.

(iii.) *Rhombohedron.* — The ordinary rhombohedron $(10\bar{1}1)$. In crystals both positive and negative rhombohedra occur, producing together a form like that of the hexagonal pyramid.

(iv.) *Trigonal Prism.* — A prism of three faces; a common symbol is $(11\bar{2}0)$.

(v.) *Ditrigonal Prism.*—A prism of six faces, a common symbol being $(21\bar{3}0)$.

(vi.) *Hexagonal Prism of the First Order.*—A prism of six faces, a common symbol being $(10\bar{1}0)$.

(vii.) *Basal Plane.*—The basal plane (0001).

Common Minerals in the Quartz Type.

Quartz and cinnabar are the commonest quartz type minerals. Fig. 35 shows a crystal of quartz, being a combination of prism, positive and negative rhombohedra, and the trigonal pyramid and trapezohedron.

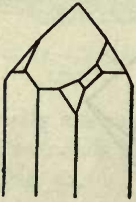


Fig. 35.

IV. Orthorhombic System.

Axes.—Three unequal axes at right angles. Of these, the *shorter* lateral axis is the *a*-axis, or *brachy*-axis; the *longer* lateral axis is the *b*-axis, or *macro*-axis; and the third is the *c*-axis, or vertical axis. The intercept that the fundamental form makes on the *b*-axis is taken as unity and therefore the expression for the axial ratio is exemplified by that of barytes below:

$$a : b : c = 0{\cdot}8152 : 1 : 1{\cdot}3136,$$

which expresses the fact that the fundamental form having the symbol (111) cuts the *a*-axis at 0·8152 units, the *b*-axis at unity, and the *c*-axis at 1·3136 units.

There is only one important symmetry group in the orthorhombic system, namely, the *Barytes* type.

BARYTES TYPE.

Symmetry.—From a consideration of the axes of the orthorhombic system, the following symmetry can be made out:

Planes, 3 axial.
Axes, $3^{\text{II.}}$ (crystallographic axes).
A centre of symmetry.

Forms.

(i.) *Basal pinacoid.*—This is an open form of two faces, which are parallel to the plane containing the lateral axes, and therefore has the symbol (001).

(ii.) *Macropinacoid.*—An open form of two faces, which are parallel to the vertical and the macro-axes. The symbol is (100).

(iii.) *Brachypinacoid.*—An open form of two faces which are parallel to the vertical and the brachy axes. The symbol is therefore (010).

(iv.) *Prism.*—An open form consisting of four faces, each face parallel with the vertical axis and cutting the two lateral axes. The symbol of the unit prism is (110).

(v.) *Macrodome.*—A macro-dome is an open form of four faces, which are parallel to the macro-axis, but cutting the other two axes. A common symbol is (101).

(vi.) *Brachydome.*—An open form of four faces, which are parallel to the brachy-axis, and cut the other two axes. A common symbol is (011).

(vii.) *Pyramid.*—A closed form of eight faces, each face cutting all three axes. The unit pyramid has the symbol (111).

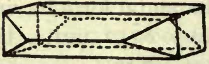


FIG. 36. — CRYSTAL OF BARYTES, SHOWING THE FORMS, PRISM (110), BRACHYPINACOID (010), BASAL PINACOID (001), AND MACRODOME (101).

Common Barytes Type Minerals.

Many common minerals crystallise in this type. Examples are barytes, olivine, enstatite, andalusite, topaz, anhydrite, aragonite, sulphur, staurolite, brookite, etc. Fig. 36 shows a crystal of barytes. The forms present are prism (110), basal plane (001), macrodome (101), and brachypinacoid (010).

V. MONOCLINIC SYSTEM.

Axes.—Three axes, one lateral axis perpendicular to the vertical axis, the other inclined. The *c*-axis is vertical; the *b*-axis, or *ortho*-axis, is at right angles to the *c*-axis; and the inclined axis is the *a*-axis, or *clino*-axis. A monoclinic crystal is in the reading position when the clino-axis runs up and away from the observer, the ortho-axis runs right and left, and the vertical axis is vertical. The acute angle between the clino-axis and the vertical axis is of importance, and is given in the axial formula, thus:

Gypsum—$a : b : c = \cdot690 : 1 : \cdot412. \quad \beta = 80^{\cdot}42°.$

The normal and most common symmetry group of this system is that characterised by *Gypsum.*

GYPSUM TYPE.

Symmetry.—The symmetry of gypsum has been already worked out in Fig. 9.

Planes, 1 (contains vertical and clino-axes).
Axis, 1^{II} ortho-axis.
A centre of symmetry.

Forms.

(i.) *Basal Pinacoid* (001).—Two faces parallel to ortho-axis and clino-axis.

(ii.) *Clinopinacoid* (010).—Two faces parallel to clino-axis and vertical axis.

(iii.) *Orthopinacoid* (100).—Two faces parallel to ortho-axis and vertical axis.

(iv.) *Prism* (110).—Four faces, each face parallel to vertical axis, and cutting both clino-axis and ortho-axis.

(v.) *Clinodome* (011).—Four faces, each face parallel to clino-axis, and cutting both vertical and ortho-axes.

(vi.) *Hemi-Orthodomes* (101, etc.).—No form which is parallel to the ortho-axis and cuts the other axes can have *four* faces, since the orthopinacoid is not a plane of symmetry. Only *hemi-orthodomes* therefore are possible. These are two in number, consisting of two faces each, each face being parallel to the ortho-axis, and cutting both clino-axis and vertical axis. A hemi-orthodome is *positive* if it lies in the acute angle between the vertical and clino-axis—that is, in the angle β—and *negative* if it lies in the obtuse angle. This is shown in Fig. 37.

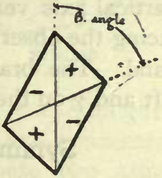


FIG. 37.

(vii.) *Hemipyramids* (111, etc.).—These are forms of four faces which cut all three axes, and their sign depends on their position with regard to the β angle, as do the signs of hemi-orthodomes.

Common Gypsum Type Minerals.

Gypsum.—This mineral occurs in crystals having the forms clinopinacoid (010), prism (110), and pyramid (111) (see Fig. 9).

Orthoclase.—See Fig. 19.

Augite, hornblende, micas, sphene, etc., also crystallise in this group (see Figs. 62 and 64).

VI. TRICLINIC SYSTEM.

Axes.—Three axes all unequal, and none at right angles. The axes are called the short or brachy-axis (a), the long or macro-axis (b), and the vertical axis (c). The angles between the axes are given with the axial ratio as below:

Axinite.—$a : b : c = 0{\cdot}49 : 1 : 0{\cdot}48$.
$\alpha = 82° \ 54'$; $\beta = 91° \ 52'$; $\gamma = 131°$.

The reading position of a triclinic crystal is the vertical axis vertical, the macro-axis lying in the plane facing the observer, and having the α-angle on the right hand. The brachy-axis is placed so that β is on the left and γ on the right.

Symmetry.

Planes, none.
Axes, none.
A centre of symmetry.

Since there is only a centre of symmetry, the presence of any one face necessitates only the presence of an opposite parallel face. Each form, therefore, consists of *two* faces.

Forms.—The forms are analogous to those of the orthorhombic symmetry, but each form is limited to two faces.

(i.) *Basal pinacoid*, (001).
(ii.) *Macropinacoid*, (100).
(iii.) *Brachypinacoid*, (010).
(iv.) *Hemi-prisms*, (110), $(1\bar{1}0)$, etc.
(v.) *Hemi-macrodomes*, (101), $(\bar{1}01)$, etc.
(vi.) *Hemi-brachydomes*, (011), $(0\bar{1}1)$, etc.
(vii.) *Quarter Pyramids*, (111), $(\bar{1}11)$, $(\bar{1}\bar{1}1)$, $(1\bar{1}1)$, etc.

Common Axinite Type Minerals.

Axinite.—Fig. 38 shows a crystal of axinite, and the forms present are hemi-prisms, macropinacoid, hemi-macrodome, and quarter pyramids.

Plagioclase Felspar.—See Part II.

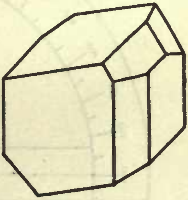


Fig. 38.

Measurement of Angles of Crystals.—The interfacial angles of crystals are measured by the goniometer (or angle-measurer). Two forms of goniometer are used for this purpose, the one is termed the contact, the other the reflecting goniometer.

The contact goniometer consists of two straight-edged arms movable on a pivot or screw, and connected by a graduated arc (see Fig. 39). These two arms are brought accurately into contact with adjacent faces of the crystal, and the angle read off on a graduated scale, as shown in the figure.

The reflecting goniometers are rather elaborate optical instruments, and are used with crystals possessing perfectly smooth faces. In general, the smaller the crystal, the more suitable for this operation will it be.

A common form of reflecting goniometer consists of a vertical circle, graduated and capable of rotation, and a horizontal arm fixed at right angles to the plane of the circle. A mirror is fixed on the horizontal arm. The crystal is placed at the centre of the graduated circle and parallel with the horizontal arm. The image of a distant signal is observed by reflection from the mirror, and also by reflection from the crystal face. By rotating the graduated circle, and with it the crystal, the two images are made to be in the same straight line. The circle is then rotated until an image is obtained by reflection from the adjacent face. The amount of rotation gives the angle between the normals to the two crystal faces, and hence this angle is the supplement of the internal angle between the two faces.

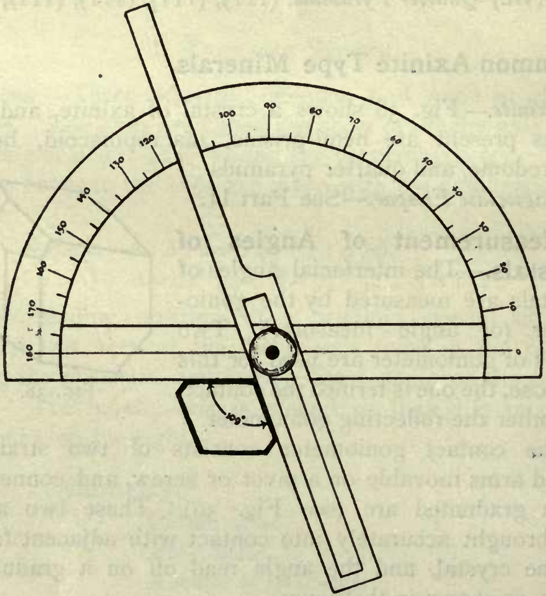
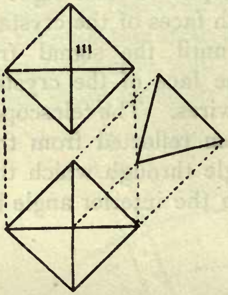


FIG. 39.—CONTACT GONIOMETER.

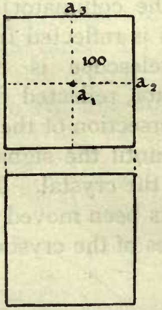
In another well-known reflecting goniometer, the crystal is placed at the centre of a horizontal graduated circle, about which swing two telescopes—an arrangement similar to the ordinary spectrometer. One telescope (the collimator) is clamped so that light passing along it is reflected from both faces of the crystal. The other telescope is moved until the signal from the collimator, reflected from one face of the crystal, is on the intersection of the cross-wires. The telescope is now moved until the signal is seen reflected from the other face of the crystal. The angle through which the telescope has been moved is twice the interior angle between the faces of the crystal.

CUBIC SYSTEM.

I. Galena Type.



Octahedron (111).



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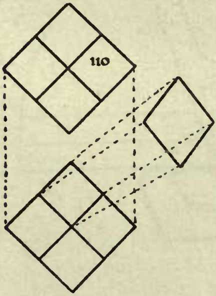
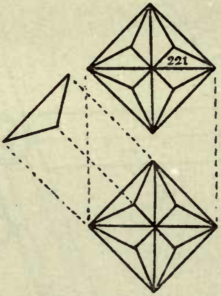
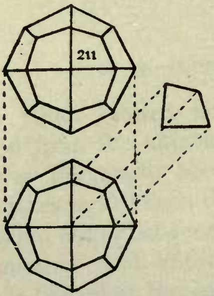


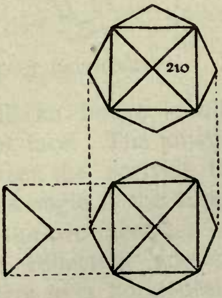
Rhombdodecahedron (110).



Trisoctahedron (221).



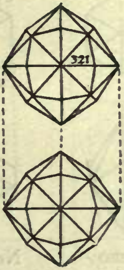
Trapezohedron (211).



Tetrahexahedron (210).

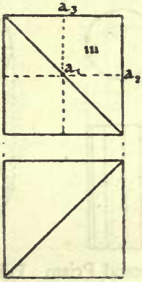
CUBIC SYSTEM—*Continued.*

Galena Type—*continued.*



Hexakisoctahedron (321).

II. Tetrahedrite Type.



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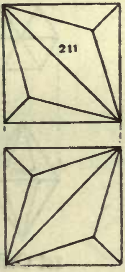
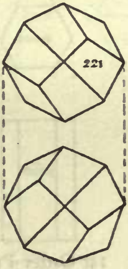
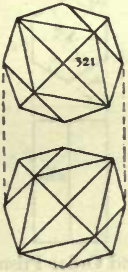


Tristetrahedron (211).

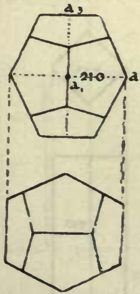


Deltoid (221).

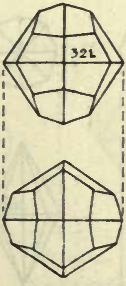


Hexatetrahedron (321).

III. Pyrite Type.



Pyritohedron (210).



Diploid (321).

HEXAGONAL SYSTEM.

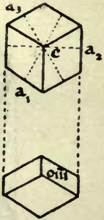
I. Beryl Type.


Dihexagonal Prism and Basal Plane.

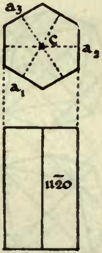

Dihexagonal Pyramid.

II. Calcite Type.

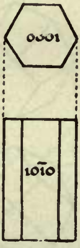

Scaleno hedron.



Negative Rhombohedron.



2nd Order Prism and Basal Plane.



1st Order Prism and Basal Plane.

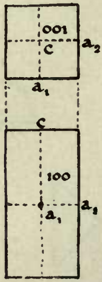
1st Order Pyramid,

TETRAGONAL SYSTEM.

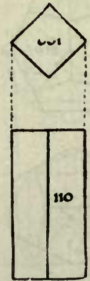
Zircon Type.

Ditetragonal Prism and Basal Plane.

Ditetragonal Pyramid.



2nd Order Prism and Basal Plane.

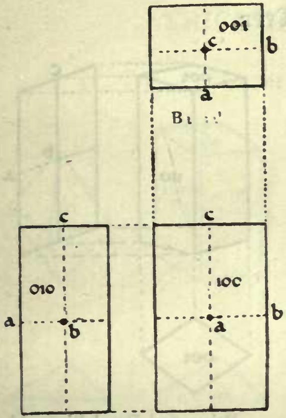


1st Order Prism and Basal Plane.

1st Order Pyramid.

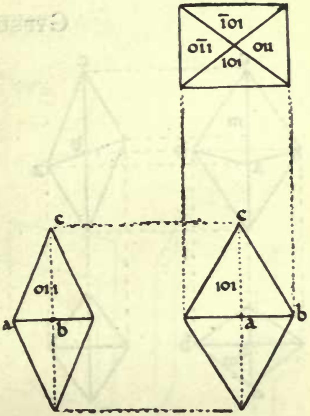
ORTHORHOMBIC SYSTEM:

BARYTES TYPE.



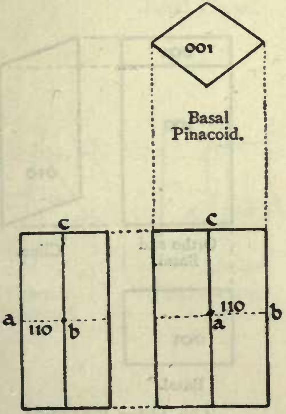
Brachy. Macro.

The Three Pinacoids.



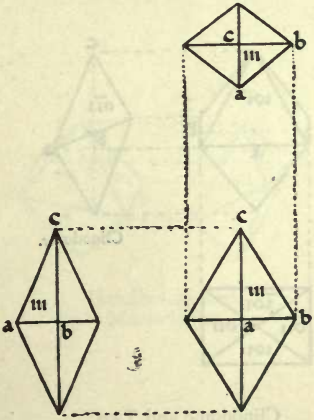
Brachy. Macro.

The Two Domes.



Prism.

Prism and Basal Pinacoid.

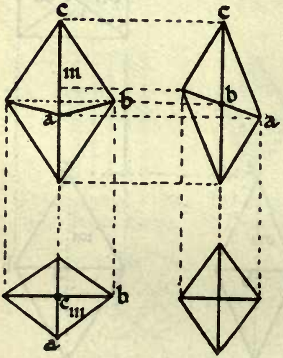


Pyramid.

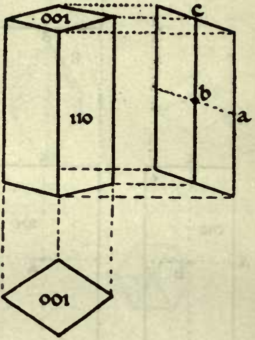
The Pyramid.

MONOCLINIC SYSTEM.

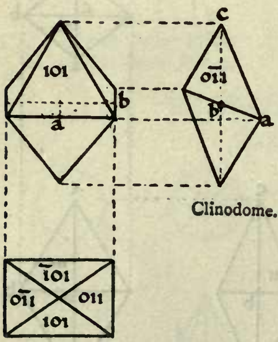
Gypsum Type.



Two Hemipyramids.

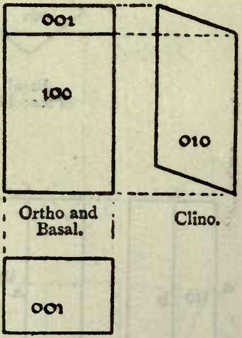


Prism and Basal Pinacoid.



Clinodome.

Clinodome and Two Hemiorthodomes.



Ortho and Basal.

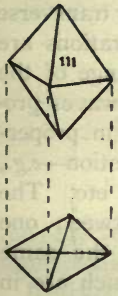
Clino.

Basal.

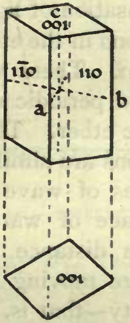
The Three Pinacoids.

TRICLINIC SYSTEM.

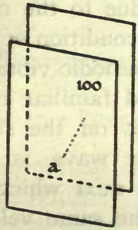
Axinite Type.



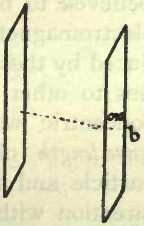
Four Quarter Pyramids.



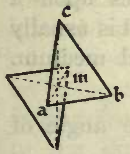
Two Hemiprisms and Basal Plane.



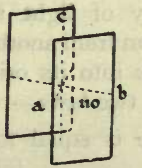
Macropinacoid.



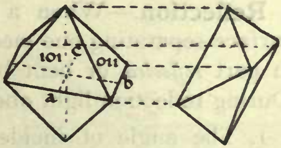
Brachypinacoid.



Quarter Pyramid.



Hemiprism.



Hemibrachy and Macrodomes.

CHAPTER V

OPTICAL PROPERTIES OF MINERALS

Nature of Light.—The sensation of light is given to the retina of the eye by vibrations in the ether transverse to the direction of propagation. These vibrations are believed to be due to the rapid periodic change of the electromagnetic condition of the ether. The waves produced by these periodic vibrations are similar in properties to other and familiar types of wave motion—*e.g.*, concentric waves on the surface of water, etc. The *wave-length* of a wave is the distance between one particle and the next which are moving in the same direction with the same velocity—that is, which are in the same *phase.* The time required for the disturbance to travel one wave-length is called the *periodic time.*

For violet light the wave-length is 0·00040 mm. and for red light 0·00076 mm. Red light has therefore a longer wave-length and a lower frequency than violet light.

Reflection.—When a ray of light strikes upon a surface separating one medium from another, it is usually in part *reflected* or bent back into its original medium. During reflection light obeys two laws—

1. The angle of incidence is equal to the angle of reflection.
2. The incident and reflected rays lie in the same plane as the normal to the surface at the point of reflection.

Fig. 40 below shows a ray of light AB incident on the surface XX at B. It is reflected along the path BC

so that the angle between AB and the normal at B, BN, equals the angle between BC and the normal BN. Or, $\angle ABN = \angle CBN$. Furthermore, the incident ray AB,

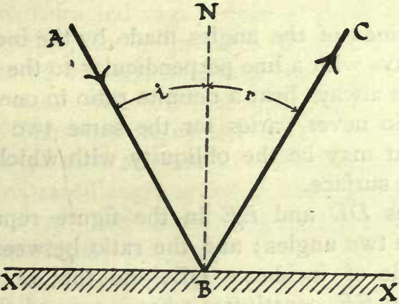


FIG. 40.—REFLECTION AT A SURFACE XX.

the reflected ray BC, and the normal BN, all lie in the same plane, that of the paper, NXX.

Refraction.—When a ray of light passes obliquely through media of different density, it becomes bent or refracted. But if it fall perpendicularly upon the surfaces of different media it undergoes no refraction.

Suppose AA (Fig. 41) to represent the section of a plate of glass, BB' a ray of light falling obliquely upon its surface. The ray BB', instead of passing straight on, is refracted to B'', and on emerging from the glass is again refracted to B''', parallel to the direction it pursued before entering the glass. The amount of refraction which a ray of light undergoes in different media varies according to their density, the direction of refraction depending on the velocity

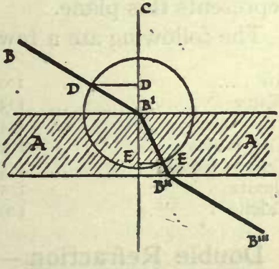


FIG. 41.—REFRACTION.

with which the medium permits the light to travel through it.

The two following are the laws which govern simple refraction:

1. The sines of the angles made by the incident and refracted rays with a line perpendicular to the surface of the medium always bear a definite ratio to one another.

This ratio never varies for the same two media, no matter what may be the obliquity with which the light falls on the surface.

The lines *DD* and *EE* in the figure represent the sines of the two angles; and the ratio between the sine of the angle of incidence *DD*, and that of the angle of refraction *EE*, constitutes what is termed the ***index of refraction***, or amount of the ray's divergence for that particular medium. This law may therefore be mathematically stated as—

$$\frac{\sin\ i}{\sin\ r} = \text{constant} = \text{index of refraction.}$$

2. The incident and the refracted ray are in the same plane, which is perpendicular to the surface separating the two media.

The paper upon which the preceding figure is printed represents this plane.

The following are a few observed indices of refraction:

Air	1·00	Olivine	1·68
Water	1·33	Ruby	1·76
Fluor-spar	1·43	Garnet (pyrope) ...	1·77
Crown glass	1·53	Zircon	1·95
Canada balsam ...	1·54	Diamond	2·42
Quartz	1·55	Rutile	2·76
Calcite	1·60	Cinnabar	3·02

Double Refraction.—This is the power which some minerals possess of refracting light in two directions, so that a single object appears double when seen through them. The property is best seen in Iceland spar, a very pure form of calcite (crystallised carbonate of lime).

Double refraction is the splitting up of a single incident ray into two refracted rays. One of these is a simply refracted ray; the sine of its angle of incidence and that of its angle of refraction always bearing a constant relation to each other for the same media, as before explained. The other refracted ray, however, does not observe this constant relation to the incident ray, and is termed the extraordinary ray, while the images produced by these two rays are named respectively the ordinary and the extraordinary images.

The refractive indices of the ordinary and extraordinary rays differ, the index of the one being sometimes greater, sometimes less, than that of the other. When the index of the ordinary is greater than that of the extraordinary ray, the crystal is said to be negative. When the index of the extraordinary ray is the greater, the crystal is then spoken of as positive.

Isotropic Minerals.—This class includes all non-crystalline (amorphous) minerals and those crystallising in the isometric system. In such substances, rays of light emanating from a point within the body travel with equal velocity in all directions, and hence there is no double refraction or, in other words, such minerals are singly refracting.

Uniaxial Minerals.—Crystals belonging to the tetragonal and the hexagonal systems fall in this class. In them two rays of light can generally be transmitted in a given direction, but with different velocities; the vibrations causing the disturbance occur all in one plane for one ray, and all in a plane at right angles to this first plane for the second ray. One of these rays, on emergence, obeys the ordinary laws of refraction; the other ray is extraordinary. The ordinary rays travel in the crystal with the same velocity whatever the direction, whereas the extraordinary rays travel with different velocities in different directions.

There is one direction in this type of crystal, however, along which the ordinary and extraordinary rays travel with equal velocities. This direction is called the *Optic Axis*, and is parallel with the principal crystallographic axis. There is only *one* direction in this type of crystal along which no double refraction occurs, and therefore such crystals are said to be *Uniaxial*. An interesting experiment with Iceland spar illustrates these.

If a thick black line is drawn on a piece of paper, and a cleaved rhombohedron of Iceland spar placed over the line, two lines will then be seen instead of one. If the crystal is slowly turned, the lines will gradually approach, until one of them is over the other. Substituting a dot for a line, two dots will be seen at different distances from the surface; and as the crystal is turned, one dot will be seen to travel round the other, but the dots will never coincide. There is, however, one direction through the crystal in which the dots would be seen to coincide, namely, the direction of the principal crystallographic axis. For this, the two solid angles of the rhomb through which this crystallographic axis passes must be ground down into two parallel faces at right angles to the axis, and these faces must be polished. In this direction, the optic axis, the ordinary and extraordinary rays, travel with equal velocities, and a single image is seen.

Biaxial Minerals.—Crystals belonging to the orthorhombic, monoclinic, and triclinic systems (*i.e.*, those crystals whose lateral axes are unequal) exhibit optical characters which differ from those met with in uniaxial crystals. Crystals belonging to these systems have two directions along which there is no double refraction, that is, along which light can travel with equal velocity; such crystals are therefore termed *Biaxial.* For such a crystal there are two directions at right angles to each other, for vibrations along which the refractive indices have respectively a maximum and a minimum value, and in a third direction at right angles to each of these directions, the refractive index has a certain intermediate value.

Birefringence—1. *Uniaxial Minerals.*—In uniaxial minerals the maximum difference between the refractive index of the ordinary ray and that of the extraordinary ray is called the birefringence. Take calcite as an example:

Refractive index of ordinary ray = 1·658
Refractive index of extraordinary ray = 1·486

Birefringence = 0·172

2. *Biaxial Minerals.*—If the maximum value of the refractive index in a biaxial mineral be denoted by γ and the minimum value by α, the birefringence is given by $\gamma - \alpha$.

Take orthoclase as an example:

$$\gamma = 1{\cdot}525$$
$$\alpha = 1{\cdot}520$$

Birefringence = 0·005.

Polarisation.—Polarisation results from the extinction of a certain set of vibrations in a ray of light, causing the ray of light to be transmitted by vibrations which lie, in plane polarised light, all in one plane. When a ray of light falls upon a polished surface of glass or wood at a certain angle, it acquires an altered character, and is said to be polarised. It is no longer capable of undergoing reflection in all directions, for if the polarised ray be made to impinge upon a surface of glass set at the same angle as the surface from which it was polarised, it will be found, upon turning the glass plate slowly round, without disturbing its inclination to the polarised ray, that there are two positions (namely, those in which the planes of incidence are at right angles) when no light will be reflected.

Both the ordinary and extraordinary rays which traverse doubly refracting crystals are polarised, and if such crystals be properly sliced and examined, the light polarised by one plate may be analysed by the other in such a way that on rotation of the analysing plate (or analyser, as it is termed), a gradual diminution, succeeded by a total extinction, of light ensues; while, upon continuing the rotation, light is once more transmitted, and again gives place to obscurity and darkness as the revolution continues.

For ordinary purposes a little instrument termed the tourmaline pincette is used. This consists of two plates of tourmaline cut parallel to the principal axis of the crystal, and mounted in little discs, which turn in collars formed by the bent extremities of a piece of wire. The arrangement is such that the two discs press against each other, but can be squeezed apart so as to permit the interposition of moderately thin plates of any mineral whose optical properties require investigation. So long as the two plates of tourmaline have their principal axes parallel, they transmit light freely; but if one of them be turned until its principal axis is at right angles to that of the other, light will no longer be transmitted where the plates cross. If, while they are in this position, a polarising substance be interposed, light will again pass through them; but if the interposed minerals do not polarise, darkness will continue, and no change will be observed.

Plates of tourmaline, however, are usually of very dark colour, and as the effects of polarisation are thereby rendered somewhat obscure, rhombohedral pieces of Iceland spar are used in preference.

These rhombohedral prisms are bisected longitudinally in a plane running through their obtuse angles. They are then recemented with Canada balsam, *CB* (Fig. 42). The inclination of this film is such as to cause the total reflection of the ordinary ray while allowing the extraordinary ray to be transmitted, so that when a pencil of light (*IR*) enters one end of the prism, only the extraordinary ray (*ER*) emerges at the other end; the ordinary ray (*OR*), meeting the balsam surface at an angle greater than the critical angle, undergoes total reflection, so that it is driven on one side, and does not emerge at the other end at all.

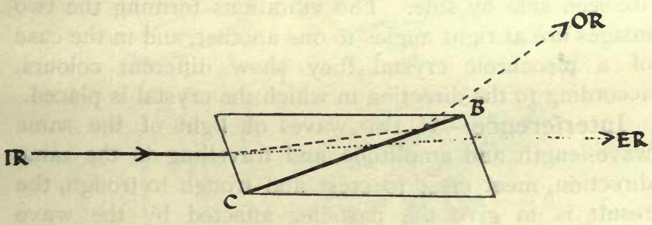


FIG. 42. — NICOL PRISM, SHOWING ORDINARY RAY TOTALLY REFLECTED BY THE LAYER OF BALSAM WHILST THE EXTRAORDINARY RAY IS TRANSMITTED.

Prisms so constructed are termed "Nicol's prisms," and may be used either as analysers or polarisers.

Pleochroism.—Pleochroism is due to the unequal absorption by the crystal of light rays vibrating in different planes. In most instances the absorption is for certain colours, only the residual colour being transmitted; but in some cases nearly the whole of the light is absorbed, as in tourmaline and biotite.

Dichroism occurs in uniaxial crystals, such as sapphire and ruby; while trichroism may occur in biaxial crystals, such as cordierite. Cordierite appears deep blue when viewed in the direction of the vertical axis, and pale blue or yellow when viewed in the direction of the other two axes. This property of pleochroism is of special value in the determination of gems, for which purpose use is made of a little instrument called a dichroscope, which consists of a cleavage prism of Iceland spar contained in a tube provided with a square aperture at one end and a lens at the other. On looking through the lens of the instrument at a transparent crystal placed over the aperture at the other end, two images of the aperture are seen side by side. The vibrations forming the two images are at right angles to one another, and in the case of a pleochroic crystal they show different colours, according to the direction in which the crystal is placed.

Interference.—If two waves of light of the same wave-length and amplitude, and travelling in the same direction, meet crest to crest and trough to trough, the result is to give the particles affected by the wave double amplitude. If, however, the waves meet crest to trough and trough to crest, the particles are motionless, and the waves are said to *interfere* and extinguish one another. If ordinary white light is used, the waves overlap by interference, and the colours of the spectrum are seen.

The Microscope.—The type of microscope used in the study of thin sections of minerals and rocks is shown in Fig. 43. The essential parts of the instrument are E, the lens of the eyepiece; O, the lens of the objective; P, the polariser, a Nicol prism placed below the stage Z; A, the analyser which, when in use, is put above the eyepiece E. The mirror, M, is used to throw a beam of light up through the polariser (if in use)

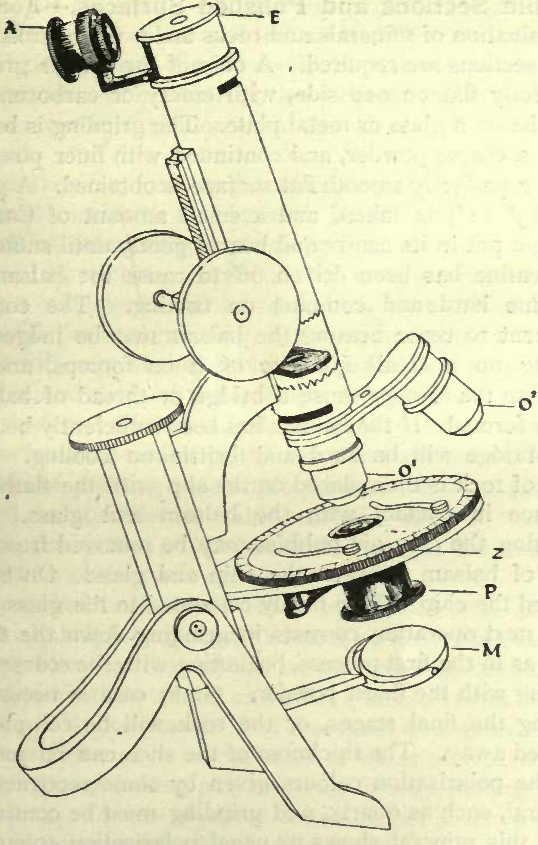


FIG. 43.—THE MICROSCOPE.

through the thin slice of the mineral on the stage, and hence through the objective, and the mineral is viewed by the eyepiece, which is fitted with two cross-wires at right angles.

Thin Sections and Polished Surfaces.—For the examination of minerals and rocks under the microscope, thin sections are required. A chip of the rock is ground perfectly flat on one side, with emery or carborundum powder on a glass or metal plate. The grinding is begun with a coarse powder, and continued with finer powders until a perfectly smooth flat surface is obtained. A glass slip (3″ × 1″) is taken, and a small amount of Canada balsam put in its centre and heated gently until sufficient turpentine has been driven off to cause the balsam to become hard and compact on cooling. The correct moment to cease heating the balsam may be judged by taking up a small quantity of it on forceps, and by opening the forceps cause a bridge or thread of balsam to be formed. If the balsam has been sufficiently heated, this bridge will be hard and brittle on cooling. The chip of rock is then placed on the slip with the flattened surface in contact with the balsam and glass. By pressing the chip air bubbles may be removed from the film of balsam between the chip and glass. On being cooled the chip will be firmly cemented to the glass slip. The next operation consists in grinding down the thick chip as in the first process, beginning with the coarse and ending with the finest powder. Great care is necessary during the final stages, or the rock will be completely rubbed away. The thickness of the slice can be judged by the polarisation colours given by some recognisable mineral, such as quartz, and grinding must be continued until this mineral shows its usual polarisation colours—for quartz, grey and yellow of the first order. After the final grinding the section must be carefully washed, and all remaining balsam scraped from around the rock. The slice is then covered with fresh balsam and heated again, to a slightly less extent than before. When the balsam is of the right consistency, a very thin sheet of glass—the cover-slip—is carefully placed over the rock and pressed down so that no air bubbles are present. Any balsam round the cover-slip is removed by methylated spirit. The result of these operations is what is known as a thin section or a thin slice of the rock or mineral.

The above process requires much patience and skill for good results to be obtained, but in the field some amount of information concerning igneous rocks can be obtained by rubbing down the chip on a grindstone and using a whetstone, carborundum file, or water of Ayr stone, for the final grinding. By these and other methods which will suggest themselves to the practical man there are obtained slices of rocks which, though thick, uneven, scratched, and all that is bad, from the point of view of the professional maker of thin sections, are nevertheless capable of yielding much information. With a pocket lens it is possible to make out from such a "thin" section the nature of the minerals present, the texture and nature of the rock, etc.

A polished surface of a rock or mineral may prove extremely helpful, especially when the observer is dealing with problems of ore deposition, the order of consolidation of minerals in a lode, and other questions of an allied nature. The rock can be first smoothed on a grindstone and then flattened on a whetstone or water of Ayr stone, and the final polishing performed by briskly rubbing the surface on a piece of damp wash-leather over which rouge or putty powder has been sprinkled. The polished surface can be examined by a lens or microscope, or may be subjected to the etching effects of the various acids. This method is especially applicable to opaque minerals, such as ores and vein minerals generally, and both it and the preceding method of rough thin sections are all too little practised by the prospector.

EXAMINATION OF MINERALS UNDER THE MICROSCOPE.

The examination of minerals in thin section under the microscope consists, for all elementary purposes, of three operations, namely—

1. Those carried out by using ordinary light.
2. Those by using the polariser.
3. Those by using crossed nicols.

1. **Ordinary Light.**—In order to examine thin sections of minerals in ordinary light, both polariser and analyser are removed. The following properties of the mineral can then be observed:

(*a*) *Crystalline Form.*—By observing the form of the mineral some conclusions as to the crystalline form can be made. Accurate conclusions as to the crystalline nature of a mineral can only be arrived at after the observation of a large number of sections.

As an example, nepheline is a hexagonal mineral, and in thin sections appears as hexagonal cross sections and rectangular longitudinal sections, characters which suffice to distinguish nepheline from other minerals in thin sections.

(*b*) *Cleavage.*—Cleavage in a mineral appears as one or more sets of parallel cracks in thin section. The number of cleavage cracks, the number of sets of cleavages and their inclination one to another, depend on the direction in which the section is cut.

Thus the prismatic cleavage of hornblende appears in transverse sections as two sets of lines meeting at angles approximately 120°, whereas longitudinal sections show only one set of cleavages.

(*c*) *Inclusions.*—In some minerals included material is arranged on a definite plan, and serves as a useful diagnostic character. In leucite, inclusions occur in concentric and radial patterns. The well-known cross-shaped inclusions in chiastolite are another example.

(*d*) *Transparency*.—Most minerals are transparent in thin section; some few, such as magnetite and pyrites, are opaque.

(*e*) *Colour*.—The mineral may be colourless, as in quartz, or coloured, as in biotite, and in most cases the colour is distinctive of a given mineral. One mineral may show sometimes several colours or several shades of the same colour, owing to its being a pleochroic mineral which has been cut in several different crystallographic directions in the same slide.

(*f*) *Refractive Index*.—If the mineral has a refractive index markedly different from that of the medium in which it is mounted, it will have well-marked borders; any cleavage cracks it possesses will be boldly shown, and its surface will exhibit a pitted or shagreened appearance. Thus garnet (refractive index = 1·77), mounted in Canada balsam (refractive index = 1·54), shows strongly marked borders and cracks, and its surface is pitted.

2. **With the Polariser.** — In order to examine minerals with the polariser, the lower nicol or polariser is put into place between the mirror and the stage.

Pleochroism.—A mineral is said to be pleochroic when it shows change in quality or quantity of colour when rotated in polarised light. Pleochroism is due to the unequal absorption by the mineral of light vibrating in different planes. As an example, consider a longitudinal section of biotite. If the polarised light vibrates parallel with the cleavages, the mineral is a deep brown, and sometimes almost black in colour; if the polarised light vibrates across the cleavages, the mineral is a light brown. Pleochroism is best observed by rotating the polariser and watching for changes of tint in the mineral under examination.

Another phenomenon that can be observed in polarised light is that of "twinkling," well shown by calcite. For calcite the value of the refractive index of the ordinary ray is 1·66, for the extraordinary ray is 1·49. The refractive index of Canada balsam is 1·54. If a granular mosaic of calcite is examined in polarised light, it is obvious that some grains will transmit the ordinary ray and some the extraordinary ray. Those grains transmitting the ordinary ray have a refractive index much greater than that of balsam, and therefore their borders will be well marked; those grains transmitting the extraordinary ray have a refractive index a little lower than that of balsam, and their borders will not be so strongly marked. Hence, when the polariser is rotated beneath the slice of calcite, the mineral has alternately strongly marked and slightly marked borders, and a "twinkling" effect is noticed.

3. **Crossed Nicols.**—For the examination of minerals between crossed nicols both polariser and analyser are used, and the nicols are so arranged that their vibration planes are at right angles one to another or are *crossed*.

(*a*) *Isotropism and Anisotropism.* — If a transparent mineral remains black when rotated between crossed nicols, it is said to be *isotropic*. A mineral which does not remain black is *anisotropic*. Singly refracting substances have no effect on polarised light, which they transmit unaltered. Slices of singly refracting substances will therefore have no effect on the optical condition when placed between crossed nicols. Similarly, transverse sections of uniaxial minerals are singly refracting, and hence are isotropic between crossed nicols.

(*b*) *Extinction and Polarisation Colours.* — When a section of an anisotropic mineral is examined between crossed nicols, it is found to become black or to extinguish in four positions 90° apart during one rotation. Extinction occurs when the vibration directions of the crystal are parallel to the vibration plane of the nicol. Extinction may occur parallel to a crystal edge, or to a prominent cleavage, when the crystal is said to have *straight extinction.* Also, extinction may occur when a crystal edge or cleavage makes an angle with the cross-wires.

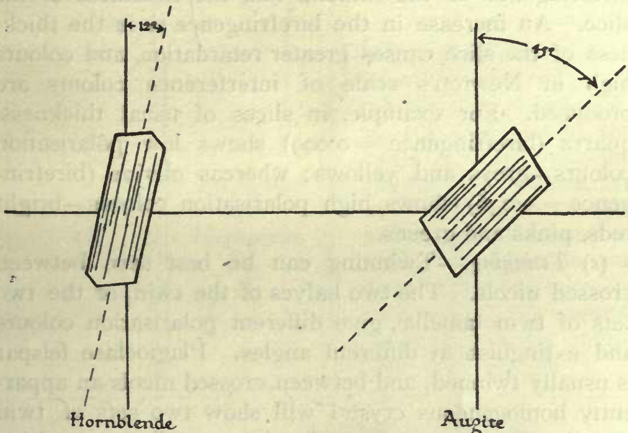


FIG. 44.—HORNBLENDE: EXTINCTION ANGLE, 12°. AUGITE: EXTINCTION ANGLE, 45°.

This is *oblique extinction,* and the angle made between the crystal edge and the cross-wires is called the *angle of extinction,* and is of some diagnostic value. Oblique extinction of augite and hornblende is shown in Fig. 44.

In positions intermediate between the positions of extinction the mineral will show polarisation colours. These colours are caused by the interference of light traversing the crystal. Light vibrating in one plane leaves the lower nicol and enters the plate of mineral, where it is split up into vibrations along two directions, the vibration directions of the crystal. These two rays leave the crystal and enter the analyser, where each ray is split up into an ordinary and an extraordinary ray. The two ordinary rays are thrown out by the nicol, the two extraordinary rays interfere and produce colour. The colour produced depends on the amount of retardation which occurs, and this is dependent upon the birefringence of the mineral and the thickness of the slice. An increase in the birefringence or in the thickness of the slice causes greater retardation, and colours high in Newton's scale of interference colours are produced. For example, in slices of usual thickness, quartz (birefringence = 0·009) shows low polarisation colours—greys and yellows; whereas olivine (birefringence = 0·036) shows high polarisation colours—bright reds, pinks and greens.

(*c*) *Twinning.*—Twinning can be best seen between crossed nicols. The two halves of the twin, or the two sets of twin lamellæ, give different polarisation colours and extinguish at different angles. Plagioclase felspar is usually twinned, and between crossed nicols an apparently homogeneous crystal will show two sets of twin lamellæ, each set extinguishing in a different position from that of the other.

(*d*) *Alteration.*—Alteration can be observed in ordinary light, but the nature of this alteration can best be ascertained between crossed nicols. An altered mineral is usually turbid or cloudy, and alteration products may be developed along cleavages, cracks, or otherwise. Between crossed nicols altered minerals usually show *aggregate polarisation*, because the originally homogeneous crystal has been converted by alteration into a multitude of irregularly arranged crystals of the alteration product.

TABLE SHOWING THE OPTICAL PROPERTIES OF CRYSTALS.

Systems.		Optical Properties.
Isotropic ...	*Cubic or Isometric*	Never pleochroic Isotropic, except under abnormal conditions
Uniaxial ...	*Tetragonal and Hexagonal*	Doubly refracting Dichroic if coloured Transverse sections—*i.e.*, at right angles to the optic axis—are isotropic Longitudinal sections are anisotropic, give straight extinction. Sections of tetragonal minerals usually have multiples of *four* sides, of hexagonal minerals usually multiples of *three* sides
Biaxial ...	*Orthorhombic, Monoclinic, and Triclinic*	Doubly refracting Trichroic if coloured No sections isotropic *Orthorhombic.*—All sections give straight extinction *Monoclinic.*—Transverse and orthopinacoidal sections give straight extinction; clinopinacoidal sections give oblique extinction *Triclinic.*—All sections give oblique extinction

PART II

DESCRIPTION OF MINERAL SPECIES

DESCRIPTION OF MINERAL SPECIES

Classification of Minerals.

MINERALS may be classified in several ways, nearly all of which are dependent, however, either upon their chemical composition, or the forms of their crystals. In this work they are simply divided into metallic and non-metallic groups, and then arranged in subdivisions according to the elements which form their prominent constituents. This arrangement into two main groups, metallic and non-metallic, merely implies the presence of metallic lustre and of high specific gravity in the first group. It should be noted, moreover, that the minerals of certain metallic elements—the alkaline earths, aluminium, etc.—are more conveniently considered in the non-metallic section.

Abbreviations used.

Composition	*Comp.*
Crystal System	*Cryst. Syst.*
Common Form	*Com. Form.*
Cleavage	*Cleav.*
Fracture	*Fract.*
Hardness	*H.*
Specific Gravity	*Sp. Gr.*
Optical Properties	*Opt. Props.*
Special Properties	*Spec. Props.*

I. THE NON-METALLIC MINERALS.

CARBON (C).

Carbon is known in three different conditions: transparent and crystallised as diamond; scaly and crystalline as graphite ; and amorphous as lamp-black, charcoal, soot, etc. These different forms vary in hardness, specific gravity, and other physical properties, but chemically they are identical. Amorphous carbon enters largely into the composition of coals.

Carbon forms with oxygen and hydrogen many series of compounds, which occur naturally as the very important bitumens and petroleums.

Carbonic acid is a combination of carbon, oxygen, and hydrogen, and has the chemical formula H_2CO_3. The carbonates, the salts of this acid, are very common, and exist in the rocks of the earth in enormous quantities. Calcium carbonate ($CaCO_3$) forms the common limestones, magnesium-calcium-carbonate ($MgCO_3CaCO_3$)—the dolomites, iron carbonate ($FeCO_3$) is the mineral chalybite, and a host of other economically important carbonates are known. The carbonates are here described under the headings of the metallic elements occurring in them.

DIAMOND.

Comp.—Pure carbon, C.

Cryst. Syst.—Cubic.

Com. Form.—Octahedron, probably a combination o two tetrahedra. Crystals often with curved faces ; commonly twinned. Also in water-worn grains in alluvial deposits.

Cleav.—Octahedral and perfect.

Colour.—White or colourless, sometimes yellow, red, etc. ; very rarely blue or black. Those most free from colour are termed diamonds of the first water, and are the most valuable.

Lustre.—Brilliantly adamantine. Transparent ; when dark coloured, translucent.

Fract.—Conchoidal.

H.—10. *Sp. Gr.*—3·52.

Opt. Props.—Refractive index, extremely high. On this property depends the sparkle of the diamond.

Varieties.—Bort and carbonado are compact varieties of diamond occurring in granular or rounded aggregates, and though of no value as gems, are used extensively for abrasive and cutting purposes in jewellery, and for the cutting edges of diamond drills, etc.

Occurrence.—Diamond occurs in alluvial deposits associated with other minerals of high specific gravity and extreme obduracy, as in Brazil and India (Koh-i-noor, etc.). Diamond is also found in an ultra-basic breccia (*blue-ground*) at Kimberley, the breccia occurring in pipes in black shale, and is probably of volcanic origin. Diamonds have also been found in peridotite in Arkansas, and dolerite in New South Wales. The Kimberley diamond fields are by far the most important.

GRAPHITE : Plumbago, Black Lead. (Greek, *grapho*, to write.)

Comp.—Pure carbon; sometimes contaminated with a small amount of silica, iron oxides, clay, etc.

Cryst. Syst.—Hexagonal; may be monoclinic.

Com. Form.—Crystals uncommon; usually occurs in scales, laminæ, or columnar masses; sometimes granular, and rarely earthy.

Cleav.—A perfect basal cleavage parallel to the large surfaces of the scales. Thin laminæ flexible. Sectile.

Colour.—Iron black to dark steel grey. Opaque.

Streak.—Black and shining.

Lustre.—Metallic. Feels cold like metal when handled, owing to its high conducting power for heat.

H.—1–2. *Sp. Gr.*—2–2·3, depending upon the purity of the material.

Spec. Prop.—Graphite resembles molybdenite in most of its physical properties, but is distinguished by its jet black streak, whereas the streak of molybdenite is greenish-black.

Occurrence.—Graphite occurs in three main ways: (1) Veins of a true fissure character, as in Ceylon, Borrowdale, and Irkutsk; (2) bedded masses of a lenticular and patchy nature in gneiss, etc., as in Eastern Canada; (3) disseminations through the country rock in the neighbourhood of a vein, as in Eastern America, Germany, etc. These disseminations usually occur in ancient gneisses, crystalline limestones, etc. Ceylon produces the most graphite, and in this island the mineral occurs as branching veins in a metamorphic rock. Austria and the United States produce large amounts of graphite.

Uses.—Graphite is used in the manufacture of pencils, crucibles, and other articles of a refractory nature, and as a lubricant. Also used for giving a black polished and preservative surface to metals, and in electro-plating to provide a conducting surface on non-metallic substances which are to be plated. Its principal use, however, is for crucibles and as electrodes for the electric furnace. For crucibles the flaked graphite is almost essential, while for electrodes purity is of more importance. The flaky Ceylon graphite therefore commands the highest price; artificial graphite prepared in the electric furnace is preferred for electrodes and many other purposes. The physical qualities and freedom from grit are more important than the amount of actual carbon present.

HYDROCARBONS: Coal and Bitumen.

In this group is considered a variety of substances which differ very widely among themselves, in mode of occurrence, physical properties and chemical compositions, but which all agree in consisting of carbon and hydrogen with oxygen, in the main. Such substances are here considered in two groups—the coals and the bitumens.

COALS.

This name is applied to a number of different substances, largely made up of carbon, oxygen, and hydrogen, which have this point in common, that they are more or less altered remains of old land vegetation, forest growth, peaty or swamp material, etc., transformed by slow chemical changes (principally the elimination of hydrogen and oxygen from the original woody tissue) into a material richer in carbon. Two theories have been put forward to explain the origin of coal. The first of these, the *growth in place theory*, supposes coal to be the result of the geological entombment of vegetable matter decaying in the place in which it grew—this explanation is held to fit the origin of pure well-bedded extensive coals, such as common coal; but a second theory, the *drift theory*, has been advanced to explain the formation of impure current-bedded local coal, such as cannel. Cannel coal is thought to be the result of the burying of drifted vegetable matter in a delta. According to the vicissitudes which it has undergone, coal has varying amounts of carbon, hydrogen, oxygen, and nitrogen; the less altered varieties, such as lignite, containing large amounts of the gases; and the highly altered varieties, such as anthracite, containing as much as 95 per cent. of carbon. Hence, several distinct varieties of coal exist. The analyses of the main varieties are given in the table, and they are described below. Whatever may be the origin of any particular coal, the processes of organic decay have largely influenced its final character.

Coal occurs in true beds of various geological ages.

The Carboniferous System is by far the most important of the coal-bearing rocks, and the coal of Great Britain, Pennsylvania, Germany, India, etc., is of this age. The Carboniferous rocks have been gently folded, and, though the coal has in most cases been removed from the crests of these folds, it has been preserved in the troughs or coal basins. In England, examples of such basins are afforded by the Lancashire coalfield and the Yorkshire coalfield, which occupy the troughs on either side of the crest of the Pennines.

There are, however, extensive deposits of coal at geological horizons other than the Carboniferous, though these deposits are usually less valuable both in quality and thickness. Cretaceous coals occur extensively in United States and the continent of Europe, and even more recent deposits consisting of lignite are worked.

COMPOSITION OF COALS.*

	C.	H.	N.	O.
Wood	100	12·5	87·0	1·8
Peat	100	11·3	64·1	3·1
Lignite	100	7·2	28·1	1·8
Bituminous coal	100	6·6	10·3	1·8
Anthracite ...	100	3·0	2·9	1·3

VARIETIES OF COAL.

Peat.—Peat results from the accumulation of vegetable matter, chiefly mosses and other bog plants, and forms extensive surface beds in Ireland, Russia, etc. The organic nature of the deposits is evident throughout the entire mass, although the bottom layers may become compressed into a compact homogeneous substance.

Lignite. *Brown Coal.*—A further stage in the altera-

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* *Bulletin Geological Survey, U.S.A.*, No. 330, p. 658.

tion of a vegetable deposit is marked by lignite, which, though compact and having a brilliant lustre, shows, nevertheless, distinct traces of its origin by containing impressions and remains of vegetable fragments, leaves, etc. Lignite occurs in beds at many horizons in the more recent geological formations, as in Germany, Hungary, and the Mississippi Valley. The name "brown coal" is usually restricted to a coal of which the vegetable origin is not so evident as that of lignite.

Jet is a resinous, hard, coal-black variety of lignite, capable of taking a high polish, and hence suitable for ornaments. It is found at Whitby, in Yorkshire, and elsewhere.

Bituminous Coals.—Bituminous coals vary considerably in character, but they all burn with a smoky flame, and during combustion soften and swell up in a manner resembling the fusion of pitch or bitumen. This, however, is only a first step in their destructive distillation, and there is no actual bitumen present. These coals have a bright pitchy lustre, and their specific gravity varies from 1·14 to 1·40. Several varieties of bituminous coals are distinguished by their manner of burning—for example, caking coal, non-caking coal, and a rather anomalous type, cannel coal.

Cannel Coal.—A variety of coal which burns with a smoky flame, and hence one of the bituminous coals, but differing from the usual types of such coals in its texture, lustre, fracture, colour, and composition. It is dense, has no lustre, its fracture is conchoidal, its colour is dull-grey or black, and contains a large amount of gas. It ignites in the candle flame.

Torbanite: *Boghead Coal.*—Torbanite is found at Torban, Boghead, and other localities in Linlithgowshire, and gave rise to a celebrated lawsuit which involved an accurate definition of the term "coal." It occurs also in lenticular deposits in New South Wales, and is considered to be a variety of cannel formed by the deposition of vegetable matter in lakes.

Anthracite.—Anthracite is a black or brownish-black, sometimes iridescent variety of coal. Its streak is black, and it does not soil the fingers. Its lustre is usually brilliant, and it breaks with a conchoidal or uneven fracture. The hardness varies from 0·5 to 2·5, and the specific gravity from 1 to 1·8. Anthracite contains up to 95 per cent. of carbon, the gases, hydrogen, oxygen, and nitrogen being present in very small quantity. It is less easily kindled than other coals, and burns with but little flame, and during combustion gives out much heat. Passages from anthracite into ordinary coal have been observed, and this variety usually occurs where coal-bearing strata have been upheaved and contorted; but there are exceptions to this rule, and the anthracite may be due in some cases to alteration of the original vegetable material before entombment. It occurs locally in many coalfields as South Wales, Scotland, and Pennsylvania. It is used where a smokeless fire is required.

BITUMEN.

Bitumens are essentially hydrocarbons of the paraffin series, C_nH_{2n+2}, and of the naphthine series, C_nH_{2n+6}. Different bitumens have different proportions of these two series, and also subordinate amounts of allied series. The bitumens, in the widest sense of the term, include members ranging from a very liquid, light-yellow oil, of specific gravity 0·771, through all gradations to solid bitumens, such as asphalt, and to waxy substances such as ozokerite.

Crude Petroleum: *Naphtha, Mineral Oil.*—Under the name of petroleum are included liquids of a brown or blackish colour, often with a greenish tinge, generally somewhat lighter than water, and usually possessing a powerful and disagreeable odour. By fractional distillation various oils, known as petroleum ether, petroleum spirit, and benzine, etc., are separated, which are extensively used in internal combustion engines. The intermediate fractions of distillation are used for illumination, and the heavy products provide lubricating and fuel oils.

Petroleum is usually found in sandstones and dolomites which are bent into gentle folds or domes, and the most important oil-bearing strata in the Old World are of a geologically recent date. The chief oil-fields of the world are Baku, near the Caspian Sea, Pennsylvania, Galicia, Mexico, Burma, and Ontario. The presence of petroleum is shown at the surface by seepages of oil, or by pitch or bitumen deposits, the latter due to the evaporation and oxidation of the volatile hydrocarbons.

Asphalt, Asphaltum, Mineral Pitch.—Asphalt is a mixture of different hydrocarbons, usually occurring under the form of a brown or black pitchy substance, soft, but occasionally solid, and may be with a conchoidal fracture. By the action of suitable solvents, carbon bisulphide, etc., asphalt may be resolved into, on the one hand, various hydrocarbons, and on the other, into a non-bituminous organic matter approximating to coal, with this latter being mixed any inorganic substances present in the crude material. Asphalt occurs in quantity in the celebrated pitch lake of Trinidad, in Venezuela, in Cuba, in Alberta; in these localities the asphalt deposits result from the oxidation of petroleum. In England asphalt has been found at Castleton, in Derbyshire, Pitchford, near Shrewsbury, and at Stanton Harold, in Leicestershire, where it encrusts crystals of galena and copper pyrites; these occurrences are of no commercial value whatever.

Porous sedimentary rocks, such as sandstones or dolomites, may become impregnated with up to 15 per cent. of asphalt, and are then worked for natural paving material, or for the extraction of asphalt. Such asphalt-rocks occur at Neufchâtel and Seyssel, Kentucky, Oklahoma, and near all asphalt deposits.

The various grades of asphalt are mixed with different quantities of rock-chips to form paving material, and the purer varieties are suitable for waterproofing masonry, as insulating material, etc.

Elaterite: *Elastic Bitumen, Mineral Caoutchouc.*—Elaterite is a soft and elastic brownish solid bitumen, much like indiarubber in its physical properties. It has been reported from Castleton in Derbyshire, Neufchâtel, and elsewhere.

Albertite: *Grahamite, Uintaite, Wurtzillite.*—All these substances are varieties of solid bitumen, differing slightly in their chemical and physical properties.

Ozokerite.—Ozokerite resembles beeswax in appearance, and is a dark yellow or brownish colour, often with a greenish opalescence. It is found associated with petroleum in Utah, Moldavia, and in Galicia, where it is mined. In Galicia, ozokerite occurs squeezed up into fractures, so as to form a vein-like body; when these "veins" have been worked out, they are slowly filled by the rising of fresh material from below.

Ozokerite is purified to form ceresine, which is used for candles.

Hatchettine.—Hatchettine is a colourless or yellowish, soft waxy substance, resembling ozokerite, and has been found in the cracks of ironstone nodules at Merthyr Tydvil.

Amber.—Amber is a fossil resin much used for the mouthpieces of pipes, beads, etc. Its composition may be given as: carbon, 78·96 per cent.; hydrogen, 10·51 per cent.; and oxygen, 10·52 per cent. Amber varies in colour from deep orange-yellow to very pale yellowish tints, and even white; it is frequently clouded, and sometimes contains fossil insects. It has a hardness from 2 to 2·5, and a conchoidal fracture. When heated, amber leaves a black residue used in the manufacture of the finest black varnishes. Amber occurs as irregular nodular fragments in strata of recent geological age, deposited under estuarine conditions, and is extensively worked on the Prussian coast of the Baltic.

Copalite: *Highgate Resin.*—Copalite is a pale yellow or brownish waxy substance, found in small films or fragments in the London Clay, at Highgate Hill, London. It burns easily with a yellow smoky flame, and leaves little ash.

Gum Copal.—Gum Copal is resin found buried in modern sands, as in New Zealand, and is an inferior kind of amber.

BORON (B).

Boron does not occur native, but may be procured as a grey amorphous powder by reduction of boric acid.

Boron occurs in combination in several silicates: tourmaline is a boro-silicate of aluminium; datolite, a boro-silicate of calcium. The principal forms in which boron occurs in nature are, however, the borates. The chief borates are—

Sassoline (boric acid), H_3BO_3, or $3H_2O.B_2O_3$.

Borax (hydrated sodium borate), $Na_2B_4O_7.10H_2O$, or $Na_2O.2B_2O_3.10H_2O$.

Colemanite (hydrated calcium borate), $Ca_2B_6O_{11}.5H_2O$, or $2CaO.3B_2O_3.5H_2O$.

Ulexite (hydrated sodium calcium borate), $NaCaB_5O_9 8H_2O$, or $Na_2O2CaO.5B_2O_3.16H_2O$.

Boracite (magnesium borate and chloride), $6MgO.MgCl_2.8B_2O_3$.

These borates occur in two ways : (1) As deposits from hot springs (sassoline); (2) as the result of the drying up of salt lakes—that is, as *saline residues* (borax, colemanite, ulexite, boracite).

Other minerals of the saline residues are enumerated on p. 137, and their descriptions should be consulted.

Tests.—See pp. 22 and 25.

Boric acid, borax, and other borates are used as fluxes for the manufacture of artificial gems, glasses, and enamels, especially in the pottery and enamelled iron trades. Also largely employed as preservatives, antiseptics, and in paint-driers. The chief sources are the borates, ulexite and colemanite, of Chili and the United States respectively. The crude material is boiled with sodium carbonate to produce sodium borate (borax), or treated with sulphuric acid to produce boric acid.

SASSOLINE : Native Boric Acid. (Sasso, near Sienna.)

Comp.—Boric acid, $B(OH)_3$, or $3H_2O. B_2O_3$.

Cryst. Syst.—Triclinic.

Com. Form.—Sometimes in prismatic crystals ; usually as small glistening scales associated with sulphur.

Cleav.—Basal.

Colour.—White, greyish ; sometimes yellow, from the presence of sulphur.

Lustre.—Pearly, translucent to transparent. Feels smooth and unctuous. Sextile and flexible. Taste, acidulous, slightly saline and bitter.

H.—1. *Sp. Gr.*—1·48.

Tests.—Fuses easily in blowpipe flame, tingeing flame green. Soluble in water and in alcohol. Dissolved in alcohol, colours flame green by presence of boron.

Occurrence.—Sassoline occurs with sulphur in the crater of Vulcano, Lipari; also around fumaroles (small vents or outlets of sulphureous emanations), and in the steam or vapours which rise from the bottom of the small hot lakes or lagoons of Tuscany. It is condensed in the water, and afterwards separates out in large flakes, which contain about 50 per cent. of boric acid. Also occurs in natural waters of Clear Lake, California.

BORAX : **Tincal.** (Arabic, *buraq.*)

Comp.—Hydrated borate of sodium, $Na_2B_4O_7.10H_2O$, or $Na_2O.2B_2O_3.10H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Occurs in prismatic crystals, resembling in shape the crystals of augite; also in lumps and masses.

Cleav.—Parallel to the orthopinacoid (100) and to the prism (110).

Colour.—White, sometimes with tinges of blue, green, or grey.

Streak.—White.

Lustre.—Vitreous, sometimes earthy. Taste, sweetish alkaline.

Fract.—Conchoidal. Soft and brittle.

H.—2–2·5. *Sp. Gr.*—1·7.

Tests.—Before the blowpipe, bubbles up, and fuses to a clear glassy bead. Soluble in water, producing an alkaline solution. Colours the flame yellow, due to sodium; with sulphuric acid gives green flame, due to boron.

Occurrence.—Borax, together with the other borates, ulexite and colemanite, occurs in hot springs and lakes in the neighbourhood of recent volcanoes, as in California, where it occurs associated with sodium carbonate and chloride. The drying-up of these lakes produces "alkaline flats" or "borax marshes," where the borax forms dazzling white deposits. These Californian deposits of borax have been leached out from bedded colemanite deposits of Tertiary age. Borax also occurs in Tibet, on the shores and in the waters of lakes, and is there called "tincal."

COLEMANITE.

Comp.—Hydrated borate of calcium, $Ca_2B_6O_{11}.5H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Short prismatic crystals usually projecting into cavities; also massive crystalline, and granular.

Cleav.—Good, parallel to clinopinacoid (010); also to basal plane (001).

Colour.—Colourless, white, also greyish.

Streak.—White.

Lustre.—Vitreous to adamantine; transparent to translucent.

Fract.—Hackly.

H.—4–4·5. *Sp. Gr.*—2·42.

Tests.—Colemanite resembles felspar, calcite, and some other spars in appearance, but may be distinguished from these by blowpipe tests. Yields water on heating; yellow-green flame of boron. Heated on charcoal, becomes white; on heating again with cobalt nitrate, turns blue. Soluble in hydrochloric acid, with separation of boric acid on cooling.

Occurrence.—Colemanite occurs in deposits of Tertiary age in San Bernardino, Los Angeles, Kern, and Ingo Counties, California. The colemanite is present as nodules in clays, and also in 10 to 50 feet beds, resting upon rhyolitic tuffs. From these deposits have been derived the lake deposit of borax and ulexite, to which reference has already been made.

Priceite and Pandermite.

Priceite and pandermite are hydrated calcium borates related to colemanite. Priceite is a soft, white, earthy mineral, and pandermite is a somewhat harder mineral.

ULEXITE: Boronatrocalcite, Natroborocalcite.

Comp.—Hydrated borate of calcium and sodium, $NaCaB_5O_9.8H_2O$.

Com. Form.—Globular or reniform masses, which, when broken open, exhibit a fibrous structure.

Colour.—White, opaque.

Lustre.—Silky internally. Tasteless.

H.—1. *Sp. Gr.*—1·65.

Tests.—Gives water on heating; fuses to a clear glass. Moistened with sulphuric acid, colours flame deep green.

Occurrence.—Ulexite occurs associated with borax in the lake deposits of California mentioned above. Also in Chili, as white or reniform masses, in lagoon deposits associated with gypsum and rock salt.

BORACITE: Stassfurtite.

Comp.—Borate and chloride of magnesium, $6MgO.MgCl_2 8B_2O_3$.

Cryst. Syst.—Cubic, tetrahedral.

Com. Form.—Crystals cubic or octahedral in shape; also massive crystalline and columnar; also granular.

Cleav.—Very imperfect, parallel to tetrahedra.

Colour.—Colourless, white, yellow, greenish, greyish.

Streak.—White.

Lustre.—Vitreous; subtransparent to subtranslucent.

Fract.—Uneven, conchoidal; brittle.

H.—7. *Sp. Gr.*—2·95.

Tests.—On charcoal fuses, forming a bead, which solidifies on cooling to a crystalline mass. Green flame of boron. Heated on charcoal, moistened with cobalt nitrate, reheated, pink mass due to magnesia. Chloride given by copper oxide test (see p. 23). Insoluble in water; soluble in hot hydrochloric acid.

Occurrence.—Boracite occurs in the Stassfurt salt deposit in Germany, associated with rock salt, gypsum, and anhydrite. These deposits are the result of the evaporation of sea-water, and in them the boracite occurs as small crystals or concretions. Also at Panderma in Asia Minor, and at Kalkburg and Schildstein in Hanover, Luneville and La Meurthe in France, where it is associated with the same set of minerals as at Stassfurt.

SULPHUR (S).

Sulphur occurs both native and in combination. Sulphur is capable of assuming three distinct forms—(1) orthorhombic crystals, native and artificial; (2) monoclinic crystals, artificial and (3) amorphous, artificial. Both the naturally and artificially formed crystals dissolve easily in carbon bisulphide, but the amorphous form does not. Sulphur is insoluble in water and alcohol.

Native sulphur and metallic sulphides (mainly iron pyrites) form practically the sole source of the sulphuric acid of commerce, and may be regarded as the most important minerals in connection with chemical industry.

Native sulphur is purified from the associated gangue by melting in ovens, etc., or by distilling in closed vessels with the production of cast-stick sulphur, or of flowers of sulphur condensed in flues. In America, sulphur, over 99 per cent. pure, is now largely obtained from deep-seated deposits in Louisiana, U.S.A., by the Frasch process, the average annual output from this source being over 250,000 tons. A double tube is driven down to the sulphur bed, and superheated steam or hot air is forced down. The sulphur thus melted is forced up the inner tube to the surface and run into vats.

For the manufacture of sulphuric acid, iron pyrites, which theoretically contains 53·46 per cent. of sulphur, and which is commonly sold on a guarantee of 45 to 50 per cent., is more used than any other mineral, or than native sulphur itself. The oxide of iron, which is formed during the roasting, is saleable for its iron content; and if containing copper, gold, or silver, even in small quantities, is paid for at a higher rate.

The value of sulphides when smelting oxidized ores is well known, and the calorific value of burning sulphur is utilised in pyritic smelting. Enormous quantities of sulphur dioxide are lost in furnace gases, but many large smelters now recover it as sulphuric acid.

The common association of arsenic with sulphur in mineral sulphides, and especially in iron pyrites, necessitates special care in the manufacture of sulphuric acid; but native sulphur, although seldom containing arsenic, is more liable to be contaminated with selenium, which is also objectionable.

The world's production of pyrites amounts to about 2,000,000 tons annually.

Sulphur forms with hydrogen an acid sulphuretted hydrogen, H_2S. This gas, being readily absorbed in water, is found in certain mineral springs, as at Harrogate. By the replacement of the hydrogen of sulphuretted hydrogen by a metal a *sulphide* is formed. Sulphides occurring as common minerals are—galena, PbS; blende, ZnS; cinnabar, HgS; iron pyrites, FeS_2.

With oxygen and hydrogen, sulphur forms many compounds, only one of which is important as an acid in mineralogy; this is sulphuric acid, H_2SO_4. *Sulphates* are formed by the substitution of a metal for the hydrogen of this acid; mineral examples of sulphates are—

gypsum, $CaSO_42H_2O$; anglesite, $PbSO_4$, etc. The sulphides and sulphates are described under the headings of their metallic constituents.

Tests.—Sulphur may be recognised when present in a mineral by the silver coin test. The powdered mineral is first fused with sodium carbonate on charcoal; the fused mass placed on a silver coin and moistened produces a black stain. Sulphides give, on roasting in the open tube or on charcoal, a sharp pungent odour of sulphur dioxide, SO_2. Sulphates give a dense white precipitate of barium sulphate on the addition of barium chloride to the solution; also after reduction by heating to the sulphide give the silver coin test as above.

NATIVE SULPHUR.

Comp.—Pure sulphur (S), but often contaminated with other substances, such as clay, bitumen, etc.

Crys. Syst.—Orthorhombic.

Comp. Form.—Crystals bounded by acute pyramids. Also massive and in encrustations.

Cleav.—Imperfect, parallel to the prism (110) and to the pyramid (111).

Colour. — Sulphur-yellow, often with a reddish or greenish tinge.

Streak.—Sulphur-yellow.

Lustre.—Resinous; transparent to subtranslucent.

Fract.—Conchoidal; sectile.

H.—1·5–2·5. *Sp. Gr.*—2·07.

Tests.—Sulphur may be recognised by its burning with a blue flame, during which suffocating sulphurous fumes of sulphur dioxide are formed. Sulphur is insoluble, and not acted upon by acids, but is dissolved by carbon bisulphide.

Varieties.—Crude and impure forms of sulphur are purified by heating, the pure material being collected on cool surfaces. This fine sulphur is usually melted and cast into sticks, and is then known as brimstone or roll sulphur.

Occurrence.—Sulphur is found in the craters and crevices of extinct volcanoes, and has been deposited by gases, as in Japan, where it is mined from an old crater lake. Another mode of origin is by the action of hot springs, by which sulphur is deposited with tufa, etc., as in Wyoming, California, and Utah. The most important occurrences of sulphur, from a commercial aspect, are those in which the element is bedded with gypsum, and in this case a common association of minerals is sulphur, gypsum, calcite, aragonite, celestine, and often petroleum. Examples of this mode of occurrence are provided by the famous Sicily and by the Louisiana deposits. Opinion is divided as to whether these bedded deposits have been formed by true sedimentation or by alteration from gypsum (see p. 152).

Uses.—Sulphur is used for the manufacture of sulphuric acid, in making matches, gunpowder, fireworks, and insecticides, for vulcanising india-rubber and in bleaching processes involving the use of sulphur dioxide.

SELENIUM (Se).

Selenium belongs to the same group as sulphur and tellurium. It occurs in native sulphur and in all pyritic ores, although often in negligible traces. It is found native and as salts of the acid H_2Se, which is analogous to sulphuretted hydrogen, H_2S. Clausthalite is a lead selenide, $PbSe$; berzelianite a copper selenide, Cu_2Se. The principal sources of selenium are the deposits in sulphuric acid chambers and the anode mud or slime obtained in the electrolytic refining of copper and matte. Its industrial uses are small, but there is a steady demand for what is produced. It is mainly employed in the production of red glass, enamels, and glazes, and for spectro-photometric work.

Native Selenium.

Native selenium occurs in cavities in the lavas of Vesuvius, as well as in the interior of the solid mass. Also in greyish and black encrustations. It is translucent, and is red, in thin splinters, by transmitted light; its hardness is 2 and its specific gravity 4·3.

AMMONIUM (NH_4).

The ammonium radicle NH_4 occurs as the metallic portion of several salts—for example:

Sal ammoniac (ammonium chloride), NH_4Cl.
Mascagnite (ammonium sulphate), $(NH_4)_2SO_4$.

All the ammonium salts are more or less soluble in water, and are entirely and easily volatilised before the blowpipe; this character alone suffices to distinguish them from other minerals. They also give off the characteristic ammonia odour when heated with quicklime, or when triturated with lime and moistened at the same time with water.

SAL AMMONIAC (Latin, *sal*, salt; Arabic, *hama nija*, camel's dung).

Comp.—Ammonium chloride, NH_4Cl.

Cryst. Syst.—Cubic.

Com. Form.—Octahedron, but generally efflorescent or encrusting.

Colour.—White when pure, often yellowish or grey.

Lustre.—Internally vitreous, externally dull, translucent to opaque.

Taste.—Pungent, cool, and saline.

H.—1·5–2. *Sp. Gr.*—1·52.

Tests.—When ground in a mortar with soda-lime gives an ammoniacal odour.

Occurrence.—Occurs as a white efflorescence in volcanic districts. All sal ammoniac of commerce is an artificial product.

Uses.—Sal ammoniac is used in medicine, in dyeing, in soldering, in various metallurgical operations, as a chemical reagent, and also in electric batteries.

Mascagnite.

Natural ammonium sulphate $(NH_4)_2SO_4$. Occurs as yellowish-grey, pulverulent, mealy crusts in the neighbourhood of volcanoes. It is vitreous, and easily soluble in water.

SODIUM (Na; Latin, *natrium*).

Sodium does not occur native. Metallic sodium may be prepared by the reduction of sodium hydroxide (NaOH) by carbon, or by the decomposition of a melt of the hydroxide by an electric current. Sodium is a soft, silver-white metal, easily tarnishing in the air, and decomposing water, forming sodium hydroxide and hydrogen. Sodium compounds are of common occurrence in many rocks. Sodium enters into the composition of many rock-forming silicates, such as albite, $Na_2O.Al_2O_3.6SiO_2$, etc.

Sodium chloride (NaCl) is the compound of most frequent occurrence in nature, and is procured either as rock salt or by the evaporation of sea-water. Compared with these vast supplies, other sodium compounds, with the possible exception of the nitrate, are insignificant, although considerable quantities of the carbonate are met with in some countries. These, and other soluble salts of sodium, occur as saline residues. The most important sodium minerals are—

Chloride.—Rock salt, $NaCl$.
Nitrate.—Soda nitre, $NaNO_3$.
Sulphates Mirabilite, $Na_2SO_4.10H_2O$.
Glauberite, $Na_2SO_4.CaSO_4$.
Thenardite, Na_2SO_4.
Carbonates Natron, $Na_2CO_3.10H_2O$.
Trona, $3Na_2O.4CO_2.5H_2O$.
Thermonatrite, $Na_2CO_3.H_2O$.
Gaylussite, $Na_2CO_3.CaCO_3.5H_2O$.
Borates Borax, $Na_2B_4O_7.10H_2O$ (see p. 127).
Ulexite, $NaCaB_5O_9.8H_2O$ (see p. 126).
Fluoride.—Cryolite, $3NaF.AlF_3$ (see p. 174).

Tests.—See also Part I. Sodium compounds colour the blowpipe flame intense yellow. After heating before the blowpipe, sodium compounds give an alkaline reaction with litmus. (Also given by K, Ca, Mg, Ba, Sr.)

ROCK SALT: Common Salt, Halite.

Comp.—Sodium chloride, $NaCl$. Calcium sulphate, calcium chloride, and magnesium chloride are usually present; sometimes also magnesium sulphate. The presence of magnesium compounds causes the mineral to become wet and lumpy.

Cryst. Syst.—Cubic; galena type.

Com. Form.—Common crystals in cubes, rarely octahedra; cubes often with hollow faces, giving hopper crystals, as shown in Fig. 45. Also occurs massive and granular, rarely fibrous.

Cleav.—Perfect parallel to the cube.

Colour.—Colourless, or white when pure; often with yellow or red; sometimes blue amethystine or purple tints.

Lustre.—Vitreous. Transparent to translucent.

Taste.—Saline; soluble.

Fract.—Conchoidal; brittle.

H.—2–2·5. *Sp. Gr.*—2·2.

Tests.—Taste quite distinctive. Colours flame deep yellow, due to sodium; crackles and decrepitates when heated; gives the usual blue chlorine flame with copper oxide in microcosmic salt bead, and a white precipitate of silver chloride with silver nitrate solution.

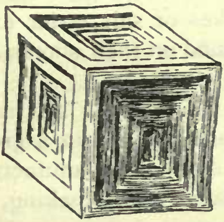


FIG. 45.—HOPPER CRYSTAL OF ROCK SALT.

Occurrence.—Deposits of rock salt occur as extensive geological beds, and are the result of the evaporation of sea-water. During the concentration and drying up of enclosed bodies of sea-water, the contained salts separate out in definite order, and at the great German deposits at Stassfurt this order is—

1. Dolomite and calcite—calcium and magnesium carbonates.
2. Gypsum and anhydrite—calcium sulphates.
3. Rock salt—sodium chloride.
4. Polyhalite—calcium magnesium potassium sulphate.
5. Kieserite—magnesium sulphate.
6. Carnallite—potassium magnesium chloride.

Hence there is a regular sequence in the deposits from bottom to top in the order named. In most cases of the drying up of saline waters, however, the process has not been carried so far, although in most salt deposits local variations of formation have given rise to patchy beds of differing nature, and the usual associates of rock salt may be found. Salt beds occur at various geological horizons—in the Silurian and Carboniferous of Michigan, New York State, and Ontario; in the Trias of Cheshire, England; Vic, France; Wurtemberg, Germany; Salzburg, Austria; and in the Tertiary of Wieliczka, Poland.

The salt is extracted either by ordinary mining by shafts and galleries, or by pumping the brine from the salt bed to the surface, and there recovering the salt by evaporation.

Salt is present in the waters of the ocean; also vast lakes of salt water exist, and deposits of rock salt are found on their shores, as the Dead Sea, Great Salt Lake of Utah, etc.

Uses.—Rock salt is used for culinary and preserving purposes, and in a great number of manufacturing processes—the manufacture of sodium carbonate for glass-making, soap-making, etc.

NITRATINE: Soda-Nitre, Nitrate of Soda.

Comp.—Sodium nitrate, $NaNO_3$.

Cryst. Syst.—Hexagonal-rhombohedral.

Com. Form.—Crystals not common, of calcite shape. As efflorescence in crusts, and also massive granular.

Cleav.—Perfect parallel to the rhombohedron.

Colour.—White, grey, yellow, greenish, purple, and reddish-brown.

Lustre.—Vitreous, transparent.

Fract.—Imperfectly conchoidal; rather sectile; cooling taste.

H.—1·5–2. *Sp. Gr.*—2·29.

Tests.—Deflagrates less violently than nitre (*q.v.*) when heated, and colours the flame yellow, by which and by its deliquescence it may be distinguished from that mineral.

Occurrence.—Economically important deposits of soda-nitre are found in the Atacama Desert of Northern Chili, where the mineral occurs, mixed with much common salt and clayey or sandy material, in beds up to 6 feet thick. These beds probably occupy the site of a salt lake near a volcanic centre. This caliche, as the material is termed, may contain 1 per cent. of sodium iodate, and forms the source of iodine.

MIRABILITE: Glauber Salt.

Comp.—Hydrated sodium sulphate, $Na_2SO_4.10H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals like those of augite in shape. Also in efflorescent crystals and in solution in mineral waters.

Cleav.—Perfect; parallel to the orthopinacoid (100).

Colour.—White or yellow.

Lustre.—Vitreous; translucent to opaque.

Taste.—Cooling, saline, and bitter; soluble in water.

H.—1·5–2. *Sp. Gr.*—1·48.

Tests.—Gives water on heating in closed tube. Yellow flame of sodium. Black stain on moistening with water on a silver coin, the residue obtained by heating on charcoal.

Occurrence.—Mirabilite occurs mixed with common salt, sodium carbonate, epsomite, etc., in the residues of saline lakes, as at the Great Salt Lake of Utah and the alkaline lakes of Wyoming.

GLAUBERITE.

A sulphate of sodium and calcium, $Na_2SO_4.CaSO_4$, occurring associated with rock salt, borax, etc., in saline residues. Occurs in monoclinic crystals, tabular parallel to the basal plane. Perfect basal cleavage.

Colour.—Yellow, red, grey, streak white.

H.—2·5–3. *Sp. Gr.*—2·8.

Lustre.—Vitreous.

Fract.—Conchoidal.

Occurrence.—Economically important deposits of glauberite occur in the valley of the Ebro, North Spain, and bear the characters of a saline residue.

Thenardite.

Comp.—Sodium sulphate, Na_2SO_4.

White orthorhombic prisms; soluble in water. Occurs in saline residues in California and Arizona.

NATRON.

Comp.—Hydrated sodium carbonate, $Na_2CO_3.10H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Usually in solution, but also as efflorescent crusts.

Colour.—White, grey, or yellowish.

Lustre.—Vitreous or earthy.

Taste.—Alkaline.

H.—1–1·5. *Sp. Gr.*—1·42.

Tests.—Effervesces with acid; gives water on heating in closed tube; yellow sodium flame.

Occurrence.—Found in solution in the soda lakes of Egypt, etc.

TRONA: Urao.

Comp.—Hydrated basic sodium carbonate, $3Na_2O.4CO_2.5H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Fibrous or columnar layers and masses.

Cleav.—Basal and perfect.

Colour.—Grey or yellowish-white.

Lustre.—Vitreous, translucent.

Taste.—Alkaline, soluble in water.

H.—2·5–3. *Sp. Gr.*—2·11.

Tests.—Effervesces with acid; gives water on heating in closed tube; yellow flame of sodium.

Occurrence.—In saline residues with other minerals formed in this way. California, Mexico, and Fezzan.

Thermonatrite.

Comp.—Hydrated sodium carbonate, $Na_2CO_3.H_2O$.

An orthorhombic mineral occurring as a saline residue.

Gaylussite.

Comp.—Hydrated sodium calcium carbonate, $Na_2CO_3.CaCO_3.5H_2O$.

A white monoclinic mineral with a vitreous lustre, occurring as a saline residue.

H.—2–3. *Sp. Gr.*—1·94.

POTASSIUM (K; Latin, *kalium*).

Potassium does not occur native. The metal is prepared in similar fashion to sodium, and its chemical and physical properties are very like those of that metal. Formerly, potassium salts were procured for the most part from vegetable matter, which was burnt, and the soluble portion of the ashes dissolved in water. The plants, however, have in the first instance procured their potassium from soils which have resulted more or less from the decomposition of igneous rocks containing orthoclase felspar, a mineral, presently to be described, consisting of potassium aluminium silicate, $K_2O.Al_2O_3.6SiO_2$. The extraction of potash from such minerals has been found too troublesome for industrial purposes. Nowadays the source of potassium compounds is from the great saline residues of Stassfurt, Germany and in a quite minor degree from India and Galicia. In the Stassfurt deposit, the most important potassium mineral is carnallite, $KCl.MgCl_2.6H_2O$; other potassium minerals occurring are kainite, $KCl.MgSO_4.3H_2O$, and sylvine, KCl.

The common potassium minerals are—

Chlorides
- Sylvine, KCl.
- Kainite, $KCl.MgSO_4.3H_2O$.
- Carnallite, $KCl.MgCl_2.6H_2O$.

Nitrate.—Nitre, KNO_3.

Tests. — Potassium compounds give a lilac flame coloration, which is, however, easily masked by sodium and other elements. The flame should be viewed through blue glass or an indigo prism, thereby eliminating colours produced by the elements other than potassium. Fused potassium compounds give an alkaline reaction with litmus. For the detection of small quantities of potassium compounds in solution, a few drops of platinic chloride produce in such a solution after prolonged stirring a precipitate of minute yellow crystals of potassium-platinichloride, K_2PtCl_6.

SYLVINE.

Comp.—Potassium chloride, KCl.

Cryst. Syst.—Cubic.

Com. Form.—Cube modified by octahedron; crystalline massive and granular.

Cleav.—Cubic.

Colour.—Colourless or white.

Lustre.—Vitreous; saline taste.

H.—2. *Sp. Gr.*—2.

Tests.—Lilac flame of potassium. Gives blue flame in the copper oxide-microcosmic salt bead test; soluble in water.

Occurrence.—Occurs as a saline residue in the Stassfurt salt deposits associated with rock salt and carnallite. Also around the fumaroles of Vesuvius.

CARNALLITE.

Comp.—Hydrated chloride of potassium and magnesium, $KCl.MgCl_2.6H_2O$. Chlorides of sodium and potassium often present.

Cryst. Syst.—Orthorhombic.

Com. Form. — Crystals rare; occurs massive and granular.

Colour.—White, but usually pink or reddish, from admixture with oxide of iron.

Lustre.—Shining and greasy; transparent to translucent; bitter taste.

Fract.—Conchoidal.

H.—1. *Sp. Gr.*—1·60.

Tests.—Gives water on heating in closed tube. Lilac flame of potassium; blue flame of chloride in copper oxide-microcosmic salt bead test. Pink mass due to magnesium by heating, with cobalt nitrate, the residue from roasting on charcoal.

Occurrence.—Occurs as a saline residue at Stassfurt, and represents the final stage in the drying up of the salt lake.

Uses.—In the natural state is used as a fertiliser; also as a source of potassium salts.

KAINITE.

A white hydrated magnesium potassium sulphate and chloride, $KCl.MgSO_4.3H_2O$, occurring in the Stassfurt salt deposits as an alteration of the carnallite zone (see above), due to the leaching out of magnesium chloride.

NITRE: Saltpetre, Nitrate of Potash.

Comp.—Potassium nitrate, KNO_3.

Cryst. Syst.—Orthorhombic.

Com. Form.—Acicular crystals; also in silky tufts and thin crusts.

Colour.—White.

Lustre.—Vitreous, subtransparent; brittle.

Taste.—Saline and cooling.

H.—2. *Sp. Gr.*—1·93.

Tests.—Lilac flame of potassium. Soluble in water. Deflagrates when heated on charcoal.

Occurrence.—Occurs in considerable quantities in the soils of certain districts—India, Egypt, Algeria, Persia, and Spain. Also in Kentucky, Tennessee, and the Mississippi Valley, in the loose earth forming the floors of natural caves; in France, Germany, etc. Nitre is artificially manufactured from refuse animal and vegetable matter, which is mixed with calcareous soil. Calcium nitrate is thus formed, and when treated with potassium carbonate yields nitre.

Uses.—Nitre is used in the manufacture of explosives, in metallurgy and chemistry, etc., and as a fertiliser.

CALCIUM (Ca).

Calcium does not occur in the free state in nature, but its compounds are extremely abundant. It may be procured from calcium chloride by decomposition by an electric current, or by heating calcium iodide with sodium. Although not occurring native, calcium nevertheless enters into the composition of a very considerable portion of the earth's crust; whole formations, such as the Chalk, and the Carboniferous Limestone, consist almost entirely of calcium carbonate, while thick and thin beds of limestone are more or less common throughout the entire series of stratified rocks. Calcium enters also into the composition of many igneous rock silicates, such as anorthite felspar, $CaO.Al_2O_3.2SiO_2$.

The following are the more important calcium minerals:

Carbonates	Calcite, $CaCO_3$ (hexagonal). Aragonite, $CaCO_3$ (orthorhombic). Dolomite, $CaCO_3.MgCO_3$.
Sulphates	Gypsum, $CaSO_4.2H_2O$. Anhydrite, $CaSO_4$. Polyhalite, $2CaSO_4.MgSO_4.2H_2O$.

Phosphate.—Apatite, $3Ca_3P_2O_8.Ca(Cl,F)_2$.

Fluoride.—Fluor-spar, CaF_2.

Borates	Ulexite, $NaCaP_5O_9.8H_2O$ (see p. 126).
	Colemanite, $Ca_2B_6O_{11}.5H_2O$ (see p. 128).

Tests.—Some calcium minerals give a brick-red flame coloration, which is enhanced by moistening the substance with hydrochloric acid. Fused calcium compounds give an alkaline reaction with litmus. On the addition of sulphuric acid to solutions containing calcium salts, a white precipitate of calcium sulphate, gypsum, is formed.

CALCITE : Calc Spar, Carbonate of Lime. (Latin, *calx*, lime.)

Comp.—Calcium carbonate, $CaCO_3$.

Cryst. Syst.—Hexagonal, rhombohedral, calcite type.

Com. Form.—Good crystals, common (see p. 74). Three main types: (1) Nail-head type—combination of flat rhombohedron and prism; (2) dog-tooth type—combination of scalenohedron and prism; (3) prismatic crystals. Two of these types are shown in Figs. 46 and 47. Also occurs fibrous, lamellar, stalactitic, nodular, granular, compact, and earthy.

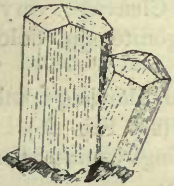


FIG. 46.—NAIL-HEAD SPAR.

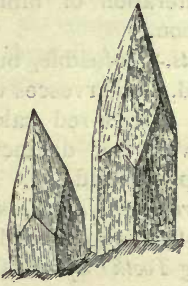


FIG. 47.—DOG-TOOTH SPAR.

Cleav.—Perfect parallel to the unit rhombohedron. Powdered calcite consists of minute cleavage rhombohedra (see p. 75).

Colour.—Colourless or white, sometimes with grey, yellow, blue, red, brown, and black tints.

Streak.—White.

Lustre.—Vitreous to earthy; transparent to opaque.

Fract.—Conchoidal, but difficult to observe owing to the perfect cleavage.

H.—3. Scratched by knife. *Sp. Gr.*—2·71.

Opt. Props.—In ordinary light appears usually as shapeless grains traversed by excellent rhombohedral cleavages, giving one, two, or three sets of intersecting lines. In polarised light "twinkles" when the nicol is rotated, due to the refractive index of the ordinary ray being much higher than that of balsam, whilst that of the extraordinary ray is lower. Between crossed nicols polarises in very high colours, giving a grey, interspersed with points of pink, blue, etc. Rarely occurs as a primary constituent of igneous rocks, but common as an alteration or infiltration product. Twinning very common.

Tests.—Infusible, but becomes highly luminous when heated. Effervesces with evolution of carbon dioxide in acids. Brick-red calcium flame. Cleavage very distinctive. For distinction from aragonite and dolomite see pp. 150 and 151.

Varieties—Nail-Head Spar.—Crystals showing combination of flat rhombohedron and prism (see Fig. 46).

Dog-Tooth Spar.—Crystals showing combination of scalenohedron and prism (see Fig. 47).

Iceland Spar.—A very pure transparent form of calcite first brought from Iceland. It cleaves into very perfect rhombohedra and exhibits double refraction in a marked degree; hence it is employed in the construction of the nicol prism (see p. 101). The less perfectly transparent crystals, although exhibiting a vast number of variously combined forms, are all included under the common name of calcite. Certain popular names for special types, such as dog-tooth spar, nail-head spar, have been explained.

Satin Spar.—A compact finely fibrous variety with a satin-like lustre, which it displays to great advantage when polished. It has mostly been formed in veins or crevices in rocks, the fibres stretching across the crevices. The term "satin-spar" is also applied to a fibrous form of gypsum (*q.v.*).

Aphrite and Argentine are unimportant lamellar varieties of calcite.

Stalactites.—Stalactites are pendent columns formed by the dripping of water charged with calcium carbonate from the roofs of caverns in limestone rocks and other favourable situations; successive layers of calcite are deposited one over another, so that a cross section of the stalactite displays concentric rings of growth. The surplus dripping of the water gives rise to a similar deposit which forms in crusts one above the other on the floors of caverns, and which has in contradistinction received the name "stalagmite." Beneath these stalagmitic crusts the remains of pre-historic cave-haunting men and animals have been found.

Oriental Alabaster, *Algerian Onyx.*—These are stalagmitic varieties of calcite characterised by well-marked banding, and were used by the ancients for making ointment-jars. Both names, however, are bad, since true alabaster is a sulphate of calcium, and onyx is a cryptocrystalline banded variety of silica.

Calcareous Tufa, *Travertine*, *Calc Tufa.*—More or less cellular deposits of calcium carbonate derived from waters charged with calcareous matter in solution. At Matlock, Knaresborough, and other places, where the water is thus highly charged, twigs, birds'-nests, and other objects, when immersed in the spring, become encrusted with a hard coating of tufa. Calcareous tufa sometimes forms very thick beds.

Agaric Mineral, Rock Milk, Rock Meal.—These are white earthy varieties of calcite, softer than chalk, deposited from solution in caverns, etc.

Chalk.—A well-known soft, white, earthy carbonate of lime, forming thick and extensive strata in various parts of the world. It has been deposited from the waters of an ancient sea, as shown by the marine character of the fossils which it contains, and often consists to a very great extent of the remains of microscopic organisms—foraminifera.

Limestone, Marble.—A general term for carbonate of lime when occurring in extensive beds. It may be crystalline, oolitic (*q.v.*), or earthy; and when impure, argillaceous, siliceous, bituminous, ferruginous, or dolomitic. All true marbles are limestones which have been crystallised by heat or pressure, and their different names are derived either from the locality where they are found, the formations in which they occur, the fossils which make up their substance, or from some peculiarity in structure, colour, etc. Examples are shell marble, ruin marble, crinoidal limestone, Carboniferous Limestone, etc.

Lithographic Stone.—A very fine-grained variety of limestone used in printing.

Pisolite and Oolite.—Calcium carbonate deposited in concentric layers around small nuclei. Pisolite differs from oolite in the larger size of the granules.

Anthraconite.—Stinkstone. A dark-coloured limestone containing bituminous matter, and emitting a fetid odour when struck.

Fontainebleau Sandstone.—A name given to calcite which contains a large admixture of sand; sometimes when concretionary 80 per cent., and even when crystallised in rhombohedra it has been known to envelop 65 per cent. of sand. It was formerly found at Fontainebleau, in France.

Thinolite.—Interlacing crystals of yellow or brown calcite, occurring as tufaceous deposits in Nevada, Australia, etc. It often occurs in skeleton crystals.

Occurrence.—The occurrence of calcite has been indicated above. Calcite may be either of an organic or of an inorganic, chemical, origin, and both varieties may be metamorphosed into crystalline marble.

Uses.—Carbonate of lime finds many different uses according to its purity and character. The varieties containing some clayey matter are burnt for cement, the purer varieties providing lime. Marbles and crystalline limestones are important building and ornamental stones. Calcium carbonate is also used as a flux in smelting, and certain varieties, as seen above, in printing. The perfectly crystallised form, Iceland spar, is used in the construction of optical apparatus.

ARAGONITE (Aragon, in Spain).

Comp.—Calcium carbonate, $CaCO_3$. Same as calcite. Sometimes contains 1 per cent. or 2 per cent. $SrCO_3$, or other impurity.

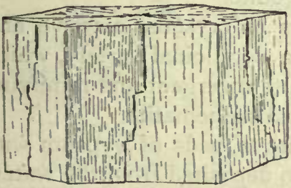


FIG. 48.—PSEUDO-HEXAGONAL TWIN OF ARAGONITE.

FIG. 49.—ARAGONITE.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, often terminated by acute domes. Very commonly twinned on the face of the prism (110); by repetition of this twinning, six-sided pseudo-hexagonal crystals are formed (see Fig. 48). These pseudo-hexagonal twins are distinguished from hexagonal crystals by re-entrant angles. Individual crystals often many times twinned, and with alternately reversed striation on faces of prism and cleavage planes. Also occurs in acicular crystals, often radiating, columnar, and in globular, reniform, stalactitic, coralloidal, and encrusting forms.

Cleav.—Poor, parallel to macropinacoid.

Colour.—White, grey, yellowish, sometimes green or violet.

Lustre.—Vitreous; transparent to translucent.

Fract.—Subconchoidal; brittle.

H.—3·5–4. *Sp. Gr.*—2·94.

Tests.—Before blowpipe, whitens and crumbles. With acid, gives carbon dioxide. Calcium flame. Distinguished from calcite by—(1) shape of the crystals; (2) cleavages; (3) aragonite is harder than calcite; (4) specific gravity higher; (5) *Meigen's Test.* Aragonite is stained with a solution of cobalt nitrate, whereas calcite is not. The mineral under observation is boiled with cobalt nitrate for a quarter of an hour and then washed. A pink staining indicates aragonite.

Varieties.—Aragonite occurs as crystals, massive and stalactitic. "Flos ferri" is a coralloidal variety, which consists of beautiful snow-white divergent and ramifying branches, in most cases encrusting hematite.

Occurrence.—Aragonite occurs in beds of gypsum with iron ore (flos ferri). It is also deposited from the waters of hot springs. The tests of reef-building corals, some algæ, etc., are composed of aragonite; this aragonite is changed into calcite by pressure, so that the upper parts of a coral island may be aragonite and the lower calcite.

DOLOMITE: Pearl Spar.

Comp.—Carbonate of magnesium and calcium, $CaCO_3$. $MgCO_3$. Not a mixture of the two carbonates: $CaCO_3$, 54·35 per cent.; $MgCO_3$, 45·65 per cent.

Carbonate of iron is sometimes present, sometimes to such an extent as to form a passage between dolomite and chalybite.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Occurs as rhombohedral crystals (*cf.* calcite), the faces of which are often curved (see Fig. 50).

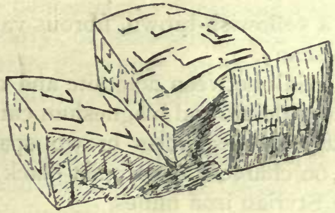


FIG. 50.—DOLOMITE WITH CURVED FACES.

Also occurs massive and granular, forming extensive geological beds. In this state has a saccharoidal texture.

Cleav.—Perfect parallel to the rhombohedron.

Colour.—White, often tinged with yellow and brown; sometimes with red, green, or black.

Lustre.—Of crystals, vitreous inclining to pearly; dull when massive; opaque when massive.

Fract.—Conchoidal or uneven; brittle.

H.—3·5–4. *Sp. Gr.*—2·8–2·9.

Tests.—Before blowpipe, behaves like calcite. Magnesium in sodium carbonate bead. Cold acid acts very slightly on fragments, but in warm acid the mineral is readily dissolved with effervescence.

Lemberg's Test.—If calcite is boiled for fifteen minutes with a solution of aluminium chloride and logwood, it will be stained pink. Dolomite undergoes no such staining. Ferric chloride may be used with equal advantage.

Varieties—Pearl Spar is a white, grey, pale yellowish or brownish variety, with a pearly lustre, occurring in small rhombohedra with curved faces. Frequently associated with galena and blende.

Brown Spar, Rhomb Spar, Bitter Spar.—Comprise the large, somewhat ferruginous varieties, which turn brown on exposure.

Miemite is a yellowish-brown, fibrous variety found at Mieme, in Tuscany.

Ankerite is a link between dolomite and chalybite, containing, besides calcium and magnesium carbonates, some iron carbonate. It resembles brown spar; but before the blowpipe, on charcoal, it becomes black and magnetic. Found in the Styrian iron mines.

Magnesian Limestone.—Crystalline granular dolomite, which occurs in massive and extensive geological beds.

Occurrence.—Dolomite occurs in extensive beds on many horizons, the Magnesian Limestone of England being of Permian age. Dolomite has probably been deposited directly from sea-water, and beds of dolomite may also be formed by the alteration of the limestone of coral reefs by sea-water.

Uses.—Dolomite is an extremely important building material. It is also used for making refractory furnace linings, and as a source of carbon dioxide.

GYPSUM. (*Gypsos*, the ancient name for the mineral; or from *ge*, earth, and *epseo*, to cook.)

Comp.—Hydrated calcium sulphate, $CaSO_4.2H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals common; combinations of the prism, clinopinacoid and the negative hemipyramid. Twins of two types: (1) Swallow tail—twin plane, the orthopinacoid (100) (see Fig. 16); (2) arrow head—twin plane, an orthodome. Crystals often in stellate interpenetrated groups. Also in laminated, granular, or compact masses, and in fibrous forms.

Cleav.—Perfect parallel to the clinopinacoid (010); giving very thin, flexible, non-elastic plates; sectile.

Colour.—Crystals colourless; massive varieties, colourless or white, sometimes grey, yellowish, or red.

Lustre.—Of clinopinacoid faces and cleavage planes, shining and pearly; of other faces, subvitreous. Massive varieties generally glistening, but sometimes dull and earthy. Fibrous forms, silky.

Pellucidly transparent, like glass, to translucent and even opaque, from admixture with impurities.

H.—1·5–2. May be scratched easily with the finger-nail. *Sp. Gr.*—2·3.

Tests.—Before the blowpipe, gives water in the closed tube. Gives red calcium flame, not readily. Fused with sodium carbonate, yields a mass, which blackens silver when moistened.

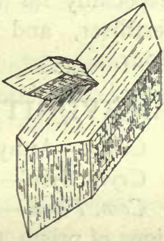


FIG. 51.—GYPSUM.

Varieties—Selenite.—Crystallised forms of gypsum.

Alabaster.—Very fine grained and compact, snow-white or light-coloured massive variety.

Satin Spar.—Fibrous variety, having a silky lustre.

Occurrence.—Gypsum occurs in three chief ways—

1. As a saline residue (see p. 137). By the evaporation of enclosed basins of sea-water, as at Stassfurt, in Germany, and in the United States, etc. These deposits are of great commercial value.

2. Accompanying the dolomitisation of limestone in the sea.

3. By the formation of calcium sulphate by the action of sulphuric acid (generated by the decomposition of pyrites) on shells, etc., in clays. Good crystals of

selenite are found in many clay formations, as in the London Clay, Oxford Clay, etc.

Uses.—Gypsum is extensively used in the manufacture of plaster of Paris. The mineral is heated to expel some of the water of crystallisation, and then ground up. In this condition it is used for stucco and plaster work. Alabaster in its natural state is used for vases and other ornamental works, and for much interior decoration, especially for mosques. Impure gypsum is used as a fertiliser, and the white varieties as adulterants of flour.

ANHYDRITE. (Greek, *a*, without, and *hudor*, water.)

Comp.—Anhydrous calcium sulphate, $CaSO_4$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals, prismatic or tabular; combinations of prism, the three pinacoids and the macrodome; also combinations of brachydome and macrodome. Also commonly fibrous, lamellar, granular, and compact; lamellar varieties sometimes contorted.

Cleav.—Parallel to the three pinacoids, giving rectangular fragments. Brachypinacoidal cleavage less perfect than the other two.

Colour.—White, often with a grey, bluish, or reddish tint.

Lustre.—Pearly, on cleavage planes; on the basal plane, vitreous. Transparent to subtranslucent.

Fract.—Uneven. Splintery in lamellar and fibrous varieties.

H.—3–3·5 (*cf.* gypsum). *Sp. Gr.*—2·8–2·9.

Tests.—Before the blowpipe, turns white, but does not exfoliate like gypsum; after a time yields an enamel-like bead. Fused with sodium carbonate and charcoal, it yields a mass, which blackens silver when moistened. Dissolved in hydrochloric acid, a white precipitate given on addition of barium chloride. Distinguished from gypsum by the hardness.

Varieties—Vulpinite.—A scaly granular variety. It is sometimes harder than common anhydrite, owing to the presence of silica. It is found at Vulpino, in Lombardy, and is occasionally cut and polished for ornaments.

Tripe Stone. — A contorted concretionary form of anhydrite.

Muriacite.—A name sometimes applied to some of the crystallised varieties.

Occurrence.—Occurs as a saline residue associated with gypsum and rock salt, as at Stassfurt, in Germany, and elsewhere. Sometimes occurs in cubes, pseudomorphous after rock salt.

APATITE. (Greek, *apatao*, to deceive; observers prior to Werner having referred the mineral to aquamarine, chrysolite, etc.)

Comp.—Phosphate and fluoride of calcium, or phosphate and chloride of calcium; the first being fluorapatite, $3Ca_3P_2O_8.CaF_2$, the second chlorapatite, $3Ca_3P_2O_8.CaCl_2$. Usually both chloride and fluoride are present together.

Fluorapatite:—phosphate, 92·26 per cent.; fluoride, 7·74 per cent. Chlorapatite: — phosphate, 89·35 per cent.; chloride, 10·65 per cent.

Cryst. Syst.—Hexagonal.

Com. Form.—Crystals common; combinations of prism and pyramid with or without the basal plane (Fig. 52). Also mammillated, concretionary and massive.

FIG. 52.—APATITE.

Cleav.—Very poor, parallel to the basal plane.

Colour.—Usually pale sea-green or bluish-green, yellowish-green or yellow; sometimes different shades of blue, grey, red, and brown; also white, and at times colourless and transparent.

Streak.—White.

Lustre.—Subresinous, or vitreous; transparent to opaque.

Fract.—Conchoidal and uneven; brittle.

H.—5. *Sp. Gr.*—3·17–3·23.

Opt. Props.—Occurs in igneous rocks as small prismatic crystals, giving lath-shaped longitudinal sections and hexagonal cross-sections. Refractive index high and polarisation colours low; basal sections isotropic, prismatic sections extinguish straight.

Tests. — Lustre rather distinctive. Blowpipe tests depend on the composition. Red flame of calcium. Heated with magnesium and moistened, phosphoretted hydrogen given off. With sulphuric acid, gives greasy bubbles of hydrofluoric acid. Chloride indicated by copper oxide-microcosmic bead test.

Varieties.—The two major divisions of natural phosphates are—(1) *Apatite*, which has a definite chemical composition; (2) *Rock phosphates*, such as phosphorite, phosphatic limestone, guano, and bone beds, which have no definite chemical composition.

Phosphorite.—A variety of natural phosphate resulting from the accumulation of organic remains and droppings upon desert islands, the calcite of the island rock being replaced by phosphates to form a mixture of calcium phosphate and unaltered calcite. Phosphorite may show traces of the original structure of the parent rock, or may be concretionary and mammillated, in which case it goes under the name of staffelite.

Coprolite.—This term applies more particularly to those masses of phosphate found in some sedimentary rock, which exhibits a corrugated or convoluted form corresponding with what is supposed to have been the form of the internal casts of the intestines of certain saurians, fishes, etc., and consequently regarded as the fossil excrement of those animals. The name coprolite has been loosely applied for phosphatic concretions which have formed round fossil shells or bones, and which have been worked at several geological horizons—for example, the Greensand, Gault, and the Crags of England.

Asparagus Stone.—A translucent, greenish-yellow variety of apatite.

Osteolite.—A massive impure altered phosphate. It usually has the appearance of lithographic stone.

Occurrence.—Natural phosphates occur as a primary constituent of igneous rocks (apatite) in veins of pneumatolytic origin (apatite), such vein deposits being worked in Canada and Norway; and also in the form of phosphorite in concretions, residual beds, and replacing limestone, as explained above. These phosphorite deposits are worked on a large scale on many of the Pacific Islands, in Florida and Utah, and up till recently in the Eastern Counties of England.

Uses.—Apatite is used as a fertiliser.

FLUORSPAR (Latin, *fluo*, to flow, being used as a flux) : **Blue John, Derbyshire Spar.**

Comp.—Calcium fluoride, CaF_2.

Cryst. Syst.—Cubic.

Com. Form.—Crystals of cubes very common (see Fig. 53); more rarely octahedra or tetrahexahedra. Also occurs compact and coarsely or finely granular.

Cleav.—Perfect parallel to the octahedron.

Colour.—Colourless, white, green, purple, amethyst, yellow, and blue.

Streak.—White.

Lustre.—Vitreous, transparent to translucent.

Fract.—Conchoidal to uneven; brittle.

H.—4. *Sp. Gr.*—3–3·25.

Tests.—Red flame of calcium. Heated with sulphuric acid, gives greasy bubbles of hydrofluoric acid gas, which cause a white film of silica to be deposited on a drop of water held at the mouth of the tube.

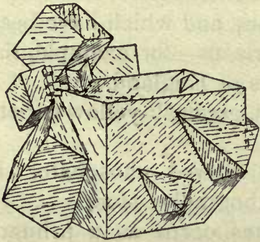


FIG. 53.—FLUOR.

Varieties — *Blue John.* — A purple or blue variety from Derbyshire, used for vases.

Occurrence.—Fluor-spar occurs as a common gangue of lead and tin lodes, associated with galena, barytes, calcite and zinc blende. Such lodes are worked in Southern Illinois and Kentucky, and recently in Weardale, Durham; Castleton, Derbyshire.

Uses.—The finest grade fluor-spar is used in enamelling, chemical and glass trades; the inferior grades are used as a flux in steel making and for foundry work. Increasing quantities of fluor are being used for the construction of lenses.

BARIUM (Ba; Greek, *barus*, heavy).

The metal barium has been procured in the form of powder by the decomposition of barium chloride by an electric current. It resembles calcium in its properties.

The chief minerals of barium are—

Sulphate ...	Barytes, $BaSO_4$.
Carbonates ...	Witherite, $BaCO_3$. Barytocalcite, $BaCO_3.CaCO_3$.

Barium occurs also in small amounts in many of the rock-forming silicates. The rare felspar, celsian, is a barium aluminium silicate, $BaO.Al_2O_3.2SiO_2$, corresponding to anorthite ($CaO.Al_2O_3.2SiO_2$). Commercially, the most important salt is the sulphate, which is used as an adulterant for white lead; the carbonate is used in pottery manufacture.

Tests.—Barium compounds colour the blowpipe flame yellowish-green. Fused barium salts give an alkaline reaction with litmus. With dilute sulphuric acid, solutions of barium salts give a white precipitate of barium sulphate, $BaSO_4$. Barium minerals are whitish minerals, with a high specific gravity.

BARYTES: Heavy Spar. (Greek, *barus*, heavy.)

Comp.—Barium sulphate, $BaSO_4$. Strontium and calcium sulphates often present as impurities.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals common, combination of prism, basal plane, and macrodome (see Fig. 54). Also occurs massive, coarsely lamellar, granular, compact, columnar, and rarely stalactitic, with a radiating fibrous structure resembling wood.

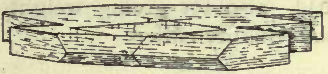


FIG. 54. — BARYTES, SHOWING PRISM, BASAL PLANE, AND MACRODOME.

Cleav.—Perfect parallel to the basal plane, also perfect parallel to the prism (110).

Colour.—Colourless or white, often tinged with yellow, red, and brown, sometimes bluish.

Streak.—White.

Lustre.—Vitreous, approaching resinous, and sometimes pearly; transparent to opaque.

Fract.—Uneven; brittle.

H.—2·5–3·5. *Sp. Gr.*—4·5.

Tests.—Before the blowpipe, decrepitates and fuses with difficulty, colouring the flame yellowish-green. Is absorbed by charcoal when fused with sodium carbonate; the saturated charcoal, when placed on a silver coin and moistened, leaves a black stain. The high specific gravity is distinctive.

Varieties — Cockscomb Barytes. — Tabular crystals arranged nearly parallel to one another.

Calk.—The barytes occurring in the Derbyshire lead mines.

Bologna Stone.—A nodular and concretionary form of barytes.

Occurrence.—Barytes is a very common vein stone in lead veins, where it is associated with galena, calcite, fluor, and quartz, deposits of this nature being worked. It also occurs as residual nodules, resulting from the decay of barytes-bearing clays or limestones, as in Virginia. The cement of some sandstones (*e.g.*, the Hemlock Stone of Nottingham) is barytes.

Uses.—Used as a pigment—as a substitute for white lead—also for giving weight to paper, and for dressing poor quality calico.

WITHERITE.

Comp.—Barium carbonate, $BaCO_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals are always repeatedly twinned, giving rise to six-sided prisms and pyramids, which much resemble those of quartz; but re-entrant angles are sometimes observed. See Fig 55. Twin plane, prism. Also massive, often with a columnar or granular structure, tuberose and botryoidal.

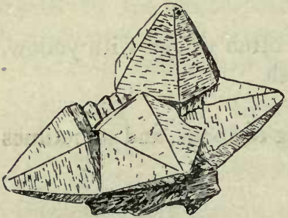


FIG. 55.—WITHERITE.

Cleav.—Poor, parallel to the brachypinacoid.

Colour.—White, yellowish, or greyish.

Streak.—White.

Lustre.—Vitreous, resinous on fracture surfaces; subtransparent to translucent.

Fract.—Uneven; brittle.

H.—3–3·75. *Sp. Gr.*—4·29–4·35.

Tests.—Effervesces with hydrochloric acid, solution giving a dense white precipitate on addition of sulphuric acid; colours the flame yellowish-green; weight noticeable.

Occurrence.—Occurs as a gangue material in lead veins, associated with galena and barytes, as at Alston Moor, Fallowfield in Northumberland, St. Asaph, and Kentucky.

Uses.—Used in beet-sugar refining and for pottery.

Bromlite: Alstonite.

Bromlite is a double carbonate of calcium and barium, calcium replacing barium in varying proportions. Similar to witherite in properties and occurrence.

BARYTOCALCITE.

Comp.—Double carbonate of calcium and barium, $CaCO_3.BaCO_3$.

Cryst. Syst.—Monoclinic.

Com. Form.—In prismatic crystals; also massive.

Cleav.—Prismatic and perfect.

Colour.—White, greyish, or yellowish.

Lustre.—Vitreous or slightly resinous; transparent to translucent.

Fract.—Uneven.

H.—4. *Sp. Gr.*—3·6.

Tests.—Yellowish-green flame of barium; sometimes also the brick-red flame of calcium. Effervesces in hydrochloric acid. Heated on charcoal, the barium carbonate fuses and sinks into the charcoal, leaving the calcium carbonate as an infusible residue.

Occurrence.—Occurs in lead veins at Alston Moor and Fallowfield.

STRONTIUM (Sr; Strontian, in Argyllshire).

Strontium does not occur in a free state in nature, but it may be prepared by passing an electric current through strontium chloride. It much resembles calcium in its properties.

The chief minerals of strontium are—

Sulphate	Celestine, $SrSO_4$.
Carbonate	Strontianite, $SrCO_3$.

Tests.—Strontium compounds colour the blowpipe flame crimson. Fused strontium compounds give an alkaline reaction with litmus. With dilute sulphuric acid, solutions of strontium salts give a white precipitate of strontium sulphate, $SrSO_4$.

CELESTINE. (Latin, *cœlestis*, celestial, in allusion to its blue tint.)

Comp.—Strontium sulphate, $SrSO_4$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Tabular crystals resembling those of barytes—combinations of prism, basal plane, macrodome and brachydome; also fibrous, granular, and massive.

Cleav.—Perfect parallel to the basal plane, and good parallel to the prism.

Colour.—White, usually with a pale blue tint.

Lustre.—Vitreous, inclined to pearly at times; transparent to subtranslucent.

Fract.—Imperfectly conchoidal; very brittle.

H.—3–3·5. *Sp. Gr.*—3·96.

Tests.—Gives a crimson flame of strontium. Fuses to a milk-white globule; insoluble in acids. Fused with sodium carbonate, gives a mass which blackens silver when moistened. Distinguished from barytes by the flame coloration and by its granular character.

Occurrence.—Occurs in beds of rock salt, gypsum, and clay, as near Bristol (Yate); also in the sulphur deposits of Sicily (*q.v.*, p. 133); also as lumps and nodules in limestones.

Uses.—Used in the manufacture of fireworks and in refining beet sugar.

STRONTIANITE.

Comp.—Strontium carbonate, $SrCO_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, often acicular and divergent; frequently twinned like aragonite; also fibrous and granular.

Cleav.—Nearly perfect, parallel to the prism.

Colour.—Pale green, yellow, grey, and white.

Lustre.—Vitreous to resinous on fracture surfaces; transparent to translucent.

Fract.—Uneven, brittle.

H.—3·5–4. *Sp. Gr.*—3·6–3·7.

Tests.—Gives the crimson flame of strontium. Effervesces with hydrochloric acid.

Occurrence.—Occurs in veins with galena and barytes, etc., as at Strontian, in Argyllshire. Also as nodules, nests, and geodes in limestones, as at Clinton, U.S.A., etc.

MAGNESIUM (Mg).

Magnesium is not found free native, but is prepared artificially by electrolysis of a mixture of anhydrous magnesium and potassium or sodium chlorides. It is a silver white metal, easily tarnishing to the oxide magnesia, MgO. The salts are employed in medicine.

Magnesium is of very common occurrence in rock-forming silicates, namely, the ferromagnesian silicates; examples are biotite, pyroxene, amphibole, olivine, etc. The chief nonsilicate magnesian minerals are—

Oxides	Periclase, MgO. Brucite, $MgO.H_2O$.
Carbonates	Magnesite, $MgCO_3$. Dolomite, $MgCO_3.CaCO_3$.
Sulphates	Epsomite, $MgSO_4.7H_2O$. Kieserite, $MgSO_4.H_2O$.
Chloride and Sulphate ...	Kainite, $KCl.MgSO_4.3H_2O$ (see p. 143).
Chloride	Carnallite, $KCl.MgCl_2.6H_2O$ (see p. 142).
Borate and Chloride ...	Boracite, $6MgO.MgCl_2.8B_2O_3$ (see p. 129).
Aluminate	Spinel, $MgO.Al_2O_3$ (see p. 171).

Tests.—The tests for magnesium are very unsatisfactory. Some magnesium compounds, heated on charcoal, moistened with cobalt nitrate and strongly reheated, give a pink residue. On the addition of sodium phosphate to an alkaline solution of a magnesium salt, a white precipitate of ammonium magnesium phosphate is thrown down.

PERICLASE: Native Magnesia. (*Peri*, around, and *clasis*, cleavage.)

Comp.—Magnesium oxide, MgO.

Cryst. Syst.—Cubic.

Occurs as minute dark green grains and octahedra, with a perfect cubic cleavage, disseminated in masses of limestone from Monte Somma, Vesuvius. It is not found in sufficient quantity to be of any commercial value.

BRUCITE.

Comp.—Hydrated oxide of magnesia, $MgO.H_2O$.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Hexagonal prisms and broad tabular crystals. Usually found massive and foliated, sometimes fibrous. Laminæ easily separable and flexible, but not elastic. Fibres separable and elastic

Cleav.—Perfect ; parallel to the basal plane.

Colour.—White, often bluish, greyish, and greenish.

Lustre.—On cleavage planes, pearly, elsewhere between waxy and vitreous; fibrous kinds silky; translucent to subtranslucent.

H.—2·5. *Sp. Gr.*—2·39.

Tests.—Heated in a closed tube, gives off water, and becomes opaque and friable. Before the blowpipe, becomes brilliantly incandescent, and yields a pink mass when moistened with cobalt nitrate and strongly reheated. Soluble in acids, which distinguishes it from talc and gypsum. Distinguished from heulandite and stilbite by its infusibility.

Occurrence.—Occurs in metamorphosed impure limestones (pencatites). Also occurs in veins traversing serpentine.

MAGNESITE.

Comp.—Magnesium carbonate, $MgCO_3$.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Crystals very rare; resemble dolomite. Commonly massive or fibrous ; sometimes very compact; sometimes granular.

Cleav.—Perfectly rhombohedral in crystals.

Colour.—White, greyish-white, yellowish, or brown ; commonly chalk-like.

Lustre.—Vitreous ; fibrous varieties sometimes silky ; compact varieties, earthy and dull ; transparent to opaque.

Fract.—Flat, conchoidal.

H.—3·5–4·5. *Sp. Gr.*—Of crystals 3; of earthy varieties, from 2·8 to over 3.

Tests.—The compact chalk-like variety, quite distinctive. Effervesces with hot acids. Heated on charcoal, gives an incandescent mass, which, when moistened with cobalt nitrate and strongly reheated, turns pink.

Occurrence.—Magnesite results from the alteration of rocks rich in magnesium silicates (olivine, etc.), and is therefore associated with serpentine and talc. It occurs in irregular veins and in fracture zones, and workable deposits are found in California, Styria, Greece, and India. The Styrian deposits are the most important, and are different from the other deposits, in that they replace a dolomite and are associated with chalybite.

Uses.—Used in the production of carbon dioxide and magnesium salts; also for refractory bricks, crucibles, and in the paper and sugar industries.

EPSOMITE : Epsom Salts.

Comp.—Hydrated magnesium sulphate, $MgSO_4.7H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals rare, prismatic; commonly in fibrous crusts or botryoidal.

Colour.—White.

Lustre.—Vitreous; transparent to translucent.

Taste.—Bitter and saline.

H.—2–2·5. *Sp. Gr.*—1·75.

Tests.—In closed tube, gives water. Magnesium reaction with cobalt nitrate on charcoal. Sulphate given by silver coin test.

Occurrence.—Epsomite occurs in solution in sea-water, and in mineral waters; also as efflorescent crusts and masses, as in the limestone caves of Kentucky, and encrusting serpentine and other rocks rich in magnesium.

Uses.—In medicine.

KIESERITE.

Comp.—Hydrated magnesium sulphate, $MgSO_4.H_2O$.

A white mineral, massive, granular, or compact, occurring as a saline residue in the Stassfurt salt deposits.

ALUMINIUM (Al).

Aluminium is not found in a free state, but in combination constitutes 8·16 per cent. of the earth's crust, and is the most abundant of metals. It is an essential constituent of clays, micas, and felspars, and occurs in smaller amounts in many rocks. The chief industrial sources of aluminium and its compounds are bauxite, cryolite, alunite, and shales. Such articles of commerce as potter's clay, slates, china clay (kaolin), fuller's earth, etc., are silicates, while oxides occur as bauxite, corundum, and emery.

The metal aluminium is produced in the electric furnace by the reduction of alumina obtained from bauxite. It is a silver-white, durable metal, capable of taking a high polish. Owing to its low specific gravity (2·58), it is of great value in the manufacture of many articles where lightness is of importance. It melts at 657° C., and alloys with most metals and some non-metals. The light alloys of chief importance are those with zinc and containing a small proportion of magnesium. Aluminium is produced in Scotland, United States, France, and Switzerland, localities where hydro-electrical installations are practicable.

The energetic action of finely divided aluminium on a metallic oxide, when heated together, is taken advantage of in the "Thermit" process for the production of metallic chromium, manganese, molybdenum, tungsten, uranium, etc. The aluminium combines directly with the oxygen of the oxide, and the heat evolved by the reaction is sufficient to promote the fusion of the reduced metal.

The world's production was probably about 40,000 tons in 1912.

Bauxite: There are, commercially speaking, two kinds of bauxite, red and white. While the principal use of bauxite is for the manufacture of aluminium, considerable quantities of the mineral are used as abrasives and in the manufacture of aluminium compounds. Lower grades of bauxite are used as refractories—*i.e.*, for the manufacture of bricks and for furnace and converter linings. For chemical purposes the white bauxite containing only a trace of iron is used, but for the manufacture of metallic aluminium, iron is not harmful, although the presence of more than 3 per cent. of silica or of titanium oxide is objectionable. The world's production of bauxite in 1912 amounted to over 1,100,000 tons.

Alunite has been suggested as a source of aluminium and potash, and when this mineral is calcined and leached, potassium sulphate can be recovered together with pure alumina, which is eminently suited to the manufacture of aluminium.

Corundum is, with the exception of diamond, the hardest mineral known, and is used as an abrasive. Grinding "wheels" are made by the incorporation of a binding medium, such as shellac, with crushed corundum. The mining and preparation of corundum is costly, but there is a steady demand for the article. Emery is an impure and less hard form of corundum. In 1912 Canada produced nearly 2,000 tons of grain corundum. India and Madagascar each produced about 500 tons. Turkey is the largest producer of emery (about 30,000 tons in 1912). Greece and the

United States follow with 10,000 and 900 tons respectively.

Artificial corundums, marketed under the names of "Alundum" and "Aloxite," are made by fusing bauxite in the electric furnace.

CORUNDUM. (Indian, *korund.*)

Comp.—Aluminium oxide, Al_2O_3.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Occurs mostly in barrel-shaped or pyramidal crystals (see Fig. 56), due to the presence of many rhombohedra and scalenohedra; also in steep hexagonal bipyramids (see Fig. 56). The crystals from alluvial deposits are usually much water-worn and rounded. Also occurs massive and granular.

Cleav.—None, but separation planes parallel to the basal plane common.

FIG. 56.—CORUNDUM.

Colour.—Of common varieties, grey, greenish or reddish, and dull; sometimes colourless. The well-known red colour of the *ruby* and the blue colour of the *sapphire* serve to distinguish, and, in fact, to constitute, these varieties. Oriental amethyst, oriental emerald, and oriental topaz, are purplish, green, and yellow respectively.

Lustre.—Vitreous; crystal faces frequently dull.

Fract.—Conchoidal or uneven.

H.—9 (next to diamond). *Sp. Gr.*—3·9–4·1.

Opt. Props.—Occurs in crystals somewhat elongated and irregular, showing the basal parting in suitable sections. Usually clear; if coloured, the colour is patchy. The refractive index is very high, and the polarisation colours very low.

Tests.—Not acted on by acids. The hardness and physical properties usually distinctive. Finely powdered and heated with cobalt nitrate on charcoal, corundum gives a blue colour.

Varieties—(1) *Corundum Gem-Stones.*—The ruby, sapphire, oriental amethyst, oriental emerald, and oriental topaz, are varieties of corundum coloured red, blue, purple, green, and yellow respectively, and are used as gem-stones.

(2) *Emery.*—Emery is a greyish-black variety of corundum containing much admixed magnetite or hematite. Crushed, ground, and sifted, its powder is used for polishing hard surfaces.

Occurrence.—Corundum occurs as contact veins and segregations associated with peridotites in the Appalachian Belt, in the Eastern United States. Also original in syenite of Ontario and in anorthosite of India. Also occurs as the result of the contact metamorphism of limestones, as in Burma.

Emery occurs as segregations from igneous rocks, and as masses in granular limestone and gneiss, as at Naxos.

The corundum gem-stones occur either as isolated crystals in limestone, etc., or as rounded pebbles in alluvial deposits.

Uses.—Emery is used as an abrasive, and the coloured varieties of corundum as gem stones.

Bauxite.—An amorphous earthy granular or pisolitic mineral of dirty-white, greyish, brown, yellow, or reddish-brown colour. Essentially hydrated aluminium oxide, $Al_2O_3.2H_2O$, generally with impurities of Fe_2O_3,P_2O_3, etc. It is now the chief source of aluminium. Occurs at Beaux near Arles in France, Antrim, and is extensively mined in the United States. Bauxite probably results from the weathering of igneous rocks under tropical conditions, and may be residual or transported.

Diaspore.—A hydrated aluminium oxide, $Al_2O_3.H_2O$, occurring in orthorhombic prismatic crystals, foliated and scaly forms, of a white colour, and hardness nearly 7; specific gravity, 3·5. Found with corundum and emery.

Gibbsite, Hydragillite.—A hydrated aluminium oxide, $Al_2O_3.3H_2O$, occurring usually as concretions, rarely as monoclinic crystals. White in colour; hardness, 3; specific gravity, 2·35; argillaceous odour.

SPINEL.

Comp.—Magnesium aluminate, $MgO.Al_2O_3$, but iron oxide, manganese oxide, and chromium oxide, may replace magnesia.

Cryst. Syst.—Cubic.

Com. Form.—Crystals commonly octahedra or rhombdodecahedra, often twinned on a face of the octahedron.

Colour.—Red, brown, and black; sometimes green and blue.

Lustre.—Vitreous; dark-coloured crystals, usually opaque.

Fract.—Conchoidal.

H.—8. *Sp. Gr.*—3·5–3·6.

Opt. Props.—Gives four- or six-sided sections, also irregular grains; colourless, green (pleonaste), red, and brown (picotite); refractive index high; between crossed nicols isotropic.

Tests.—Infusible. When black, resembles magnetite, but is not magnetic. Resembles garnet, but is not fusible. Resembles zircon, but is harder. Therefore, form, hardness, and infusibility characteristic.

Varieties—Ruby Spinel.—Clear red variety. Spinel ruby, balas-ruby, rubicelle, are deep red, rose-red, and yellow varieties.

Pleonaste.—Dark green spinel, containing iron.

Picotite.—Brown spinel, containing iron and chromium.

Hercynite.—An iron spinel, $FeO.Al_2O_3$, black in colour.

Gahnite.—A zinc spinel, $ZnO.Al_2O_3$, dark green.

Occurrence.—Occurs as an original constituent in igneous rocks, especially basic rocks; also in metamorphosed crystalline limestones, gneisses, and serpentines. Also in alluvial deposits, resulting from the degradation of the parent rock. Used as a gem-stone.

CHRYSOBERYL: Alexandrite.

Comp.—Beryllium aluminate, $BeO.Al_2O_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Occurs in prismatic crystals, often twinned to produce stellate and six-sided forms.

Cleav.—Distinct parallel to brachydome.

Colour.—Shades of green.

Lustre.—Vitreous; translucent to transparent.

Fract.—Conchoidal and uneven.

H.—8·5. *Sp. Gr.*—3·5–3·8.

Tests.—Recognised by its physical properties.

Varieties—Alexandrite.—A greenish variety, which is reddish by transmitted light.

Occurrence.—Occurs in alluvial deposits and in place in gneiss, granite, and mica schist. Used as a gem-stone.

ALUNITE: Alumstone.

Comp.—Hydrated sulphate of aluminium and potassium, $K_2O.3Al_2O_3.4SO_3\ 6H_2O$.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Crystals uncommon; small rhombohedra with basal plane. Usually found massive, granular, fibrous, and sometimes earthy.

Cleav.—Parallel to basal plane, nearly perfect.

Colour.—White, greyish, or reddish.

Lustre.—Of crystals, vitreous; of massive kinds, frequently dull.

Fract.—Of crystals, flat, conchoidal, or uneven; of massive varieties, splintery, and sometimes earthy; brittle.

H.—3·5–4. *Sp. Gr.*—2·58–2·75.

Tests.—In closed tube, gives water; blue colour when heated with cobalt nitrate. Sulphur test by silver coin. Insoluble, therefore no taste.

Occurrence. — Occurs as an alteration product of trachytes or rhyolites, in which it forms seams, as in Hungary and Malta.

ALUNOGENE.

Comp. — Hydrated aluminium sulphate, $Al_2(SO_4)_3.18H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals uncommon. Usually occurs in masses composed of delicate and closely packed fibres; also massive and in crusts.

Colour.—White, sometimes yellowish or reddish.

Lustre.—Vitreous and silky, subtransparent to subtranslucent.

Taste.—Of common alum; soluble in water.

H.—1·5–2. *Sp. Gr.*—1·6–1·8.

Tests.—Gives water in closed tube. Blue mass when heated with cobalt nitrate on charcoal. Soluble in water.

Occurrence.—Occurs in the neighbourhood of volcanoes, also in coal districts; and in beds of alum shale where pyrites is decomposing.

WEBSTERITE: Aluminite.

Comp.—Hydrated aluminium sulphate, $Al_2O_3.SO_3.9H_2O$.

Com. Form.—An earthy material occurring in veins and in reniform or tuberose masses.

Colour.—White and yellowish.

Lustre.—Dull and opaque.

Fract.—Earthy; adheres to the tongue, and yields to the finger-nail.

H.—1–2. *Sp. Gr.*—1·66.

Tests.—In closed tube, gives water. Blue mass with cobalt nitrate on charcoal. Sulphur by silver coin test. Physical properties distinctive.

Occurrence.—Usually found in clays of Tertiary age; frequently in clay-filled pipes or pot-holes in the surface of chalk, as at Newhaven, etc.

ALUM: Potash Alum, Kalinite.

Comp.—Hydrated sulphate of potassium and aluminium, $KAl(SO_4)_2.12H_2O$.

Crystallises in the cubic system, generally in small octahedra on shales, as at Whitby, Yorkshire, and elsewhere. It does not occur in sufficient quantity to be of any use. It is readily soluble in water, and has a characteristic taste. Hardness, 2–2·5; specific gravity, 1·75. Also occurs in the neighbourhood of volcanoes.

CRYOLITE.

Comp.—Fluoride of aluminium and sodium, $AlF_3.3NaF$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals not common. Usually found massive and cleavable, with a lamellar structure.

Cleav.—Perfect parallel to basal pinacoid; less perfect parallel to prism and orthodome.

Colour.—Colourless, snow-white, reddish, brownish, brick red, and even black.

Lustre.—Vitreous; subtransparent to subtranslucent.

Fract.—Uneven; brittle.

H.—2·5. *Sp. Gr.*—2·95–3.

Tests.—Cryolite becomes practically invisible when immersed in water, since its refractive index equals that of water. Alone before the blowpipe, fuses easily, colouring the flame intense yellow from sodium. The residue, from heating on charcoal, when moistened with cobalt nitrate and strongly reheated, gives a blue mass from aluminium. Heated with sulphuric acid, greasy bubbles of hydrofluoric acid evolved.

Occurrence.—Cryolite occurs as a pegmatitic vein in granite at Evigtuk, in West Greenland, associated with galena, blende, chalybite, fluor, etc. The cryolite has been proved to a depth of 150 feet, and is shipped to Europe and the United States.

Uses.—Cryolite is used for the manufacture of aluminium, for making sodium and aluminium salts, and in the manufacture of a white porcellanous glass.

TURQUOISE.

Comp.—Hydrous phosphate of aluminium, with a small percentage of copper oxide.

Com. Form.—Amorphous, reniform, stalactitic, and encrusting.

Fract.—Conchoidal, brittle.

Colour.—Turquoise blue or bluish-green; colour probably due to copper.

Lustre.—Rather waxy, internally dull. Feebly translucent to opaque.

H.—6. *Sp. Gr.*—2·6–2·8.

Tests.—Gives water when heated in closed tube; gives copper reactions. Soluble in hydrochloric acid.

Occurrence.—Turquoise occurs in patchy deposits and seams in a trachyte in Persia and New Mexico.

Uses.—Turquoise is much used in jewellery; but fossil bones and teeth, coloured by phosphate of iron, and termed odontolite, or bone turquoise, are frequently cut and polished for the same purpose.

WAVELLITE.

Comp.—Hydrated phosphate of aluminium, $4AlPO_4.2Al(OH)_3.9H_2O$. Some analyses show the presence of a little fluorine and of iron oxide.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals rare; usually occurs in small spheres (see Fig. 57) having a radiating structure, which is well displayed when they are broken across. The spheres usually range from half an inch in diameter to less.

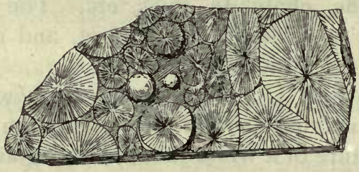


FIG. 57.—WAVELLITE.

Colour.—White, yellowish, and brownish.

Lustre.—Vitreous, inclining to pearly or resinous; translucent.

H.—3·5–4. *Sp. Gr.*—2·33.

Tests.—Structure quite characteristic. Yields water when heated in closed tube; blue mass when heated with cobalt nitrate on charcoal; also usually gives reactions for fluorine.

Occurrence.—Occurs in the residual deposits formed from igneous rocks, as at St. Austell; also occurs as nodular masses associated with manganese ores and limonite, as at Holly Springs, Pennsylvania.

SILICON (Si; Latin, *silex*, flint).

Silicon does not occur in a free state in nature, but in the form of the oxide, silica, SiO_2, it constitutes a very considerable portion of the crust of the earth.

Silica, SiO_2, is the only oxide of silicon. It occurs in nature in the form of quartz, chalcedony, agate, flint, etc. Opal is a hydrated form of silica. Sand is usually quartz, sometimes flint, in a finely divided state, and in this form constitutes the sandstones.

Silicon enters into combination with oxygen and hydrogen to form various acids, and from these are derived an enormous number of mineral salts called silicates. The chief of these acids, and examples of representative silicates, are given below:

1. *Disilicic Acid.*—$H_2Si_2O_5$, or $H_2O.2SiO_2$. Oxygen ratio, 4 : 1.
   Petalite, $Li_2O.Al_2O_3.8SiO_2$. that is, $R''O.2SiO_2$.
2. *Polysilicic Acid.*—$H_4Si_3O_8$, or $2H_2O.3SiO_2$. Oxygen ratio, 3 : 1.
   Orthoclase, $KAlSi_3O_8$, or $K_2O.Al_2O_3.6SiO_2$.
3. *Metasilicic Acid.*—H_2SiO_3, or $H_2O.SiO_2$. Oxygen ratio, 2 : 1.
   Leucite, $KAl(SiO_3)_2$, or $K_2O.2Al_2O_3.4SiO_2$.
4. *Orthosilicic Acid.*—H_4SiO_4, or $2H_2O.SiO_2$. Oxygen ratio, 1 : 1.
   Zircon, $ZrSiO_4$, or $2ZrO.SiO_2$.
5. *Basic Silicates.*—Oxygen ratio, less than 1 : 1.
   Hemimorphite, $(ZnOH)_2SiO_3$, or $H_2O.2ZnO.SiO_2$.
6. *Hydrated Silicates.*
   Stilbite. $(Na_2Ca)O.Al_2O_3.6SiO_2.6H_2O$.

Silicon minerals of economic value are—

(*a*) Quartz for sands for glass-making, also for optical work, etc.

(*b*) Opal, zircon, sphene, moonstone, topaz, tourmaline, peridot, amethyst, garnet, etc., as gem-stones.

(*c*) Tripoli, as an abrasive.

(*d*) Felspars, in the manufacture of porcelain.

(*e*) Clays, kaolin, used in brickmaking and pottery manufacture.

(*f*) Slates, sandstones, as building materials.

(*g*) Mica, for electric work.

(*h*) Asbestiform minerals, for non-combustible materials.

Tests.—Some silicates gelatinise when boiled with hydrochloric acid; the mineral should first be roasted with sodium carbonate on charcoal. In some cases the silica separates in the form of indistinct flakes. Silica is insoluble in the microcosmic bead, and after the fusion of silicates in that bead, the silica remains behind as a whitish framework or ghost.

Crystalline Silica: Quartz and Tridymite.

QUARTZ.

Comp.—Silicon dioxide, SiO_2.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Hexagonal prism, terminated by positive and negative rhombohedra, giving a form like a hexagonal pyramid when equally developed. For a fuller discussion of the crystallography of quartz, see p. 78. See Figs. 58 and 59. Crystals, sometimes with the faces very irregularly developed; occasionally crystals contain small cavities partially or wholly filled with liquid; not infrequently acicular crystals of rutile, etc., and scales and grains of chlorite and mica are enveloped.

Also occurs massive, granular, and sometimes stalactitic.

Colour.—When pure, colourless; often coloured by impurities, giving rise to some varieties mentioned below.

Lustre.—Vitreous, occasionally resinous, transparent to opaque.

Fract.—Conchoidal.

H. — 7. Cannot be scratched with the knife. *Sp. Gr.*—2·65.

Opt. Props.—In ordinary light, appears either as grains, or as well-formed crystals, the mode of occurrence depending upon the rock. Quartz is colourless, transparent, and unaltered; shows no cleavage, and an irregular fracture. The refractive index of quartz is nearly equal to that of balsam, hence the borders of the grains are not well marked. The polarisation colours are low; twinning never shown.

FIGS. 58, 59.—QUARTZ.

Tests.—Alone, before the blowpipe, unaltered. Soluble in the borax and sodium carbonate beads; insoluble in the microcosmic salt bead. Physical properties, distinctive.

Varieties—Rock Crystal.—Rock crystal is the purest and most transparent form of quartz. It is sometimes employed in jewellery and for making spectacle glasses.

Amethyst.—A purple or violet coloured transparent form of quartz, owing its colour probably to manganese. Used in jewellery.

Rose Quartz is a pale pink or rose-coloured variety of quartz; the colour fades on exposure, but may be restored by moistening.

Cairngorm, *Smoky Quartz.*—These are varieties of quartz of a fine smoky yellow or brown colour.

Morion is a nearly black variety. These types are used in Scotch jewellery.

Milky Quartz is a common variety, of a milk-white colour. The milkiness is sometimes merely superficial, and such crystals are called by the French "Quartz en chemise." The milkiness is due to the presence of a multitude of very small air-cavities.

Cat's Eye is quartz with a minutely fibrous structure, which causes it when suitably cut to exhibit a peculiar opalescent play of light, bearing some fanciful resemblance to a cat's eye.

Aventurine is quartz containing spangles of mica, hematite, etc.

Ferruginous Quartz contains iron oxides, which impart a reddish or brownish colour to the mineral.

Occurrence.—Quartz occurs as an original constituent of the more acid igneous rocks—granite, quartz-felsite, rhyolite, etc. It also forms the bulk of the sandstones which result from the breaking up of igneous rocks containing quartz, and therefore the sandstones consist of small, usually angular, fragments of the mineral bound together by, may be, silica, as in the quartzites; by limonite, ferruginous sandstone; by calcite, calcareous sandstone, and so on. It occurs also as a very prominent vein stone in many mineral veins, and in geodes.

TRIDYMITE.

Tridymite is a form of silica which occurs in small plates in trachyte, from the Drachenfels and Tardree, etc. The small plates overlap and produce the appearance of fish scales. Specific gravity, 2·28–2·33.

Cryptocrystalline Silica : Chalcedony, Jasper, etc.

CHALCEDONY.

Not crystallised, but having an obscure or minutely crystalline (cryptocrystalline) structure. It may be regarded as a mixture of crystalline and amorphous silica—*i.e.*, of quartz with opal. Usually occurs filling cavities in amygdaloidal rocks and in flint nodules. Surface generally mammillated or botryoidal, sometimes stalactitic.

Colour. — White, grey, pale blue, bluish - white, brownish, etc.

Lustre.—Rather waxy.

Opt. Props.—The cryptocrystalline varieties of silica give under the microscope characteristic polarisation between crossed nicols. Chalcedony gives a black cross, the arms of which are parallel to the nicol planes, owing to the straight extinction of the chalcedonic fibres.

Carnelian or Sard.—This is a well-known translucent variety of chalcedony of various shades of red, and brownish-red. It is used for signet-rings, etc.

Prase.—A translucent, dull, leek-green variety of chalcedony, and also of quartz.

Plasma. — A subtranslucent, leek green variety, speckled with white.

Blood Stone, or Heliotrope. — Blood stone is similar to plasma, but is speckled with red; used for signet-rings.

Chrysoprase.—Chrysoprase is an apple green chalcedony, probably coloured by nickel oxide.

Agate.—Agate is a variegated chalcedony, composed of different coloured bands, sometimes with sharp lines of demarcation, sometimes shading off imperceptibly one into another, and affording various patterns according to the direction in which the stone is cut.

Moss Agate, or Mocha Stone.—This is chalcedony containing small dendrites, which consist of oxide of iron or of a ferruginous chlorite (delessite). The agates are cut and polished for brooches, snuff-boxes, and similar articles. They mostly come from Saxony, Bavaria, Arabia, India, and Perthshire ("Scotch pebbles"), and are found embedded in amygdaloidal rocks.

Onyx and Sardonyx. — These are flat banded varieties of chalcedony, the latter stone being composed of red and white, or bluish-white layers.

FLINT.

Flint is compact cryptocrystalline silica of a black colour, or various shades of grey, and occurs in bands, or more usually in irregularly shaped nodules, arranged in layers in the Upper Chalk. It breaks with a well-marked conchoidal fracture, and affords sharp cutting edges. This substance was extensively used by prehistoric man for the fabrication of weapons, chisels, hatchets, etc., and before the invention of percussion locks and matches, was employed for gun-flints and for igniting tinder, these uses being based upon the well-known fact of flint generating sparks when struck with steel, small particles of steel being raised to a state of incandescence by the heat produced by the blow. Flint is much used in Kent, Sussex, etc., for road-making and building.

Hornstone and Chert.—These are names given to impure kinds of flint which do not break with a conchoidal, but with a more or less flat fracture.

JASPER.

An impure opaque form of cryptocrystalline silica, usually of red, brown, and yellow colours, rarely green; opaque even on the thinnest edges. Some varieties, such as Egyptian or ribbon jasper, are beautifully banded with different shades of brown.

Porcelain Jasper.—This is merely clay or shale altered or baked by contact with hot igneous rock. It may be distinguished from true jasper by being fusible on the edges before the blowpipe.

Amorphous Silica: Opal.

OPAL.

Comp.—Hydrated silica, $SiO_2.nH_2O$.

Com. Form.—Compact, amorphous, reniform, stalactitic.

Colour.—White, grey, yellow, red, brown, etc., the colours often blending and changing according to the direction in which the stone is viewed, and displaying beautiful internal reflections and opalescence.

Lustre.—Subvitreous.

H.—5·5–6·5; softer than quartz. *Sp. Gr.*—2·2; lighter than quartz.

Opt. Props.—Being amorphous, opal is isotropic under the microscope—*i.e.*, it remains black in all positions when rotated between crossed nicols.

Occurrence.—Opal occurs filling cracks and cavities in igneous rocks, and also embedded in flint-like nodules in limestone, etc.

Varieties — Precious Opal.—Exhibits opalescence and a brilliant play of colours.

Hydrophane.—An opaque white, or yellowish variety, which, when immersed in water, becomes translucent and opalescent.

Hyalite. — A transparent, colourless, glassy variety, occurring in small botryoidal or stalactitic forms.

Menilite, or Liver Opal. — An opaque liver-coloured variety, found in flattened or rounded concretions, with a pale exterior at Menil Montant, near Paris.

Wood Opal is wood in which the cavities have been filled and the tissues replaced by opal.

Siliceous Sinter. — Sometimes consists of hydrous, sometimes of anhydrous, silica. It has a loose porous texture, and is deposited from the waters of hot springs. It occurs on a grand scale around the hot springs of Taupo, in New Zealand, and is common in the geysers of Iceland and of the United States. From its mode of occurrence, it is named *geyserite.* It lines the bores or tubes of the geysers, and is deposited in cauliflower-like encrustations on the surface of the neighbouring ground.

Float Stone.—A porous form of silica which floats on water. It is found in the chalk at Menil Montant, Paris.

Diatomaceous Earth is a deposit of the tests and skeletons of siliceous organisms, such as diatoms, and consists of opal. It is used as a polishing powder, and as an absorbent for nitro-glycerine.

The Silicates.

Classification of Silicates.—The classification of the silicates cannot follow the method elsewhere employed, on account of their number and complexity, nor can a purely crystallographical classification be adopted, since then closely related minerals, such as the felspars, would be separated into different groups. As, however, most silicates are rock-forming minerals, a method of classification based on their optical properties when examined in thin sections under the microscope in the usual way offers a convenient basis for identification. The silicates of the heavy metals, such as copper, nickel, zinc, are, however, placed in the metallic section under their respective metals. The remaining silicates are separated into four divisions:

1. Biaxial minerals.
2. Uniaxial minerals.
3. Isotropic minerals.
4. Non-crystalline minerals.

The members of these groups are described under the headings of their families, as below:

1. *Biaxial Minerals.*—Felspars, pyroxenes, amphiboles, micas, chlorites, talc-serpentine group, olivine, epidote, aluminous silicate group, topaz, staurolite, cordierite, axinite, sphene, and the biaxial zeolites.

2. *Uniaxial Minerals.* — Nepheline, scapolite group, zircon, tourmaline, beryl, and the uniaxial zeolites.

3. *Isotropic Minerals.*—Garnets, leucite, sodalite group, and the isotropic zeolites.

4. *Non-Crystalline Silicates.*

Biaxial Silicates.

General Optical Properties of Biaxial Minerals.—Biaxial minerals belong to the orthorhombic, monoclinic, and triclinic systems. Their shape in thin sections depends not only on their crystal form, but also on the direction of section. No sections are isotropic. Sections of orthorhombic minerals all give straight extinction. Transverse and orthopinacoidal sections of monoclinic minerals extinguish straight, whereas clinopinacoidal sections extinguish obliquely. All sections of triclinic minerals give oblique extinction. When coloured, biaxial minerals generally show pleochroism.

THE FELSPARS.

Introduction.—The felspars are minerals consisting essentially of silicates of aluminium, with varying amounts of silicates of potassium, sodium, calcium, and barium. They may be considered as isomorphous mixtures of four molecules, namely:

1. The *orthoclase* molecule: potassium aluminium silicate, $K_2O.Al_2O_3.6SiO_2$.

2. The *albite* molecule: sodium aluminium silicate, $Na_2O.Al_2O_3.6SiO_2$.

3. The *anorthite* molecule: calcium aluminium silicate, $CaO.Al_2O_3.2SiO_2$.

4. The *celsian* molecule: barium aluminium silicate, $BaO.Al_2O_3.2SiO_2$.

For example, soda-orthoclase is intermediate in composition between orthoclase and albite, hyalophane between celsian and orthoclase, and a perfect gradation exists between albite and anorthite, giving the plagioclase group of felspars. The felspars may therefore be divided for the purposes of description into the following groups:

Celsian—Hyalophane—Orthoclase, Microcline.
|
Anorthoclase.
|
Soda-orthoclase.
|
Anorthite—Labradorite—Andesine—Oligoclase—Albite.

Orthoclase, hyalophane, and soda-orthoclase crystallise in the monoclinic system. Microcline and the albite-anorthite felspars are triclinic.

The felspars have a hardness of about 6, except when decomposing, and their specific gravity ranges from 2–3.

Felspars have two principal cleavages, in the monoclinic system parallel to the basal plane and the clinopinacoid, and in the triclinic system parallel to the basal plane and the brachypinacoid; that is, there are two cleavages at right angles, or nearly at right angles.

Twinning in felspars is in general simple in orthoclase, and repeated in the albite-anorthite series (the plagioclases).

The felspars enter largely into the composition of igneous rocks, orthoclase and the soda-felspars characterising the more acid rocks, the lime-felspars the more basic rocks.

Felspars alter commonly into micas, but by the action of gases are converted into kaolin (*q.v.*, p. 221).

Celsian.—Celsian is a triclinic felspar, similar in physical properties to anorthite (*q.v.* below), but containing barium in place of the calcium of anorthite. Its chemical composition is barium aluminium silicate, $BaO.Al_2O_3.2SiO_2$. Hardness, 6–6·5; specific gravity, 3·37. Usually colourless.

Hyalophane.—Hyalophane is intermediate in composition between celsian and orthoclase, it being a silicate of aluminium, barium, and potassium, $K_2O.BaO.2Al_2O_3.8SiO_2$. Like orthoclase, and especially the adularia variety, in physical properties.

ORTHOCLASE.

Comp.—Silicate of aluminium and potassium, $K_2O.Al_2O_3.6SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals common, prismatic, made up of the prism, clinopinacoid, basal plane, and, may be, some orthodomes. An orthoclase crystal has been described on p. 63. Crystals sometimes flattened parallel to the clinopinacoid. Twinning very common on three laws: (1) Carlsbad, (2) Manebach, (3) Baveno. These twins are shown in Fig. 19 on p. 64, where they are discussed. Crystals may sometimes lack the clinopinacoid, as in the variety adularia. Also occurs massive, and with a roughly lamellar or granular structure.

Cleav.—Perfect parallel to the basal plane and to the clinopinacoid, therefore giving in section two sets of cleavage lines at right angles; the basal cleavage more perfect.

Colour.—White, reddish-white, red, flesh-coloured, various shades of grey and greenish-grey; also colourless.

Lustre.—Vitreous to pearly on cleavage; semi-transparent to translucent, or opaque.

Fract.—Conchoidal to uneven and splintery.

H.—6. *Sp. Gr.*—2·57.

Opt. Props. — Orthoclase occurs in rectangular sections, and also in shapeless masses in rock slices. Usually colourless; often cloudy by alteration. Refractive index near that of Canada balsam. Cleavages, two at right angles, not often seen. Polarisation colours, slightly lower than those of quartz, greys. Twinning always simple; Carlsbad twins commonest; shape of the two twinned halves depends on the law of twinning followed.

Tests.—Distinguished from plagioclase by its absence of striations, due to lamellar twinning, which are seen in plagioclase on the basal plane. Fuses only on the edges of thin splinters. With borax, forms a transparent glass; insoluble in microcosmic head. Unaffected by acids; gives the potassium flame with difficulty.

Varieties—Common Orthoclase.—Subtranslucent or dull varieties.

Adularia.—Colourless variety of orthoclase, occurring in crystals made up of the prism and basal plane only.

Moonstone.—An opalescent to pearly variety. The name is also applied to some varieties of albite.

Sanidine.—Transparent, glassy crystals of orthoclase, occurring in the more acid volcanic rocks.

Sunstone, *Aventurine Felspar.*—Adularia, spangled with minute crystals and plates of hematite, ilmenite, limonite, etc.

Murchisonite.—A red felspar, with peculiar yellowish-golden lustre.

Occurrence.—Orthoclase occurs as an essential constituent of the more acid rocks, such as granite, syenite, quartz felsite, rhyolite, and trachyte. It is found in large crystals in some pegmatite veins, and is worked in an occurrence of this nature at Topsham, Maine. Orthoclase also occurs as grains in some felspathic sandstones, resulting from the incomplete alteration and sorting of weathered granites.

Uses.—Felspar in general is used for pottery, and as an abrasive.

MICROCLINE.

Comp.—Like orthoclase, silicate of aluminium and potassium, $K_2O.Al_2O_3.6SiO_2$.

Cryst. Syst.—Triclinic. The angle between the vertical and brachy-axes is nearly 90°, being 89° 30″.

Com. Form.—Crystals common, like those of orthoclase in habit. Combinations of prism, brachypinacoid, basal pinacoid common. Twins like those of orthoclase, also repeated twinning on two laws—(1) The Albite law, (2) The Pericline law; the directions of these two twinnings are nearly at right angles to one another, and show on the basal plane as two sets of fine striations, and cause "cross hatched" appearance between crossed nicols (see below); also massive and granular.

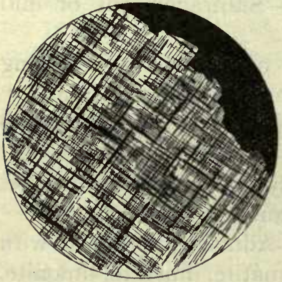


FIG. 60.—MICROCLINE. Between crossed nicols.

Cleav. — The usual felspar cleavage; perfect parallel to the basal plane, slightly less-perfect parallel to brachypinacoid.

Colour. — Greyish - white, pinkish, or flesh red, also bright green, as in Amazon stone.

Lustre. — Vitreous; transparent to translucent.

H.—6–6·5. *Sp. Gr.*—2·55.

Opt. Props.—Occurs in rock slices as small shapeless grains and plates. Like orthoclase in ordinary light, but between crossed nicols shows the characteristic "cross-hatched" appearance due to the repeated wedge-shaped twins on two laws (see Fig. 60).

Tests.—Distinguished from orthoclase by the presence of striations on basal plane, due to twinning.

Occurrence.—Microcline occurs in acid igneous rocks, especially granites.

Soda-Orthoclase.—A link between orthoclase and albite, and therefore consisting of aluminium silicate, with varying amount of potassium and sodium silicates, $(K,Na)_2O.Al_2O_3.6SiO_2$; like orthoclase.

Anorthoclase.—A sodium potassium felspar consisting of aluminium silicate, with varying amounts of sodium and potassium silicates; triclinic. Twinning on Carlsbad, Albite and Pericline laws common; like albite.

Perthite.—Perthite consists of an intergrowth of orthoclase and albite, the albite being arranged in wisps parallel to the orthopinacoid.

PLAGIOCLASE FELSPARS: The Albite-Anorthite Series.

Introduction.—The plagioclases are isomorphous mixtures of two molecules; the *albite molecule*—$Na_2O.Al_2O_3.6SiO_2$; and the *anorthite molecule*, $CaO.Al_2O_3.6SiO_2$. If Ab stands for the albite molecule and An for the anorthite molecule, the limits of the various members of the albite-anorthite series may be be defined as below:

Albite ...	... Ab_1An_0 to Ab_6An_1.
Oligoclase ...	... Ab_6An_1 to Ab_3An_1.
Andesine ...	... Ab_3An_1 to Ab_1An_1.
Labradorite	... Ab_1An_1 to Ab_1An_3.
Bytownite ...	... Ab_1An_3 to Ab_1An_6.
Anorthite ...	... Ab_1An_6 to Ab_0An_1.

The plagioclases show a continuous gradation in their physical properties—specific gravity, refractive index, crystal form, etc.—from albite to anorthite, as shown in the table on p. 192.

	Specific Gravity.	Refractive Index.	Angle between Cleavages.	Extinction on (001).
Albite	2·62	1·535	86° 24′	+ 5°
Oligoclase ...	2·65	1·542	86° 32′	+ 2°
Andesine ...	2·69	1·557	86° 14′	− 5°
Labradorite ...	2·72	1·570	86° 4′	− 17°
Bytownite ...	2·74	1·577	—	− 24°
Anorthite ...	2·77	1·585	85° 50′	− 37°

A characteristic feature of the plagioclases is their repeated or lamellar twinning, which is shown by the presence of a set of fine striations on the basal plane. This serves to distinguish them from orthoclase. These repeated twinnings are on two laws: (1) The albite law, twin plane, brachypinacoid; (2) pericline law, twin axis, the macro-axis. These two types of twins are sometimes seen in the same crystal.

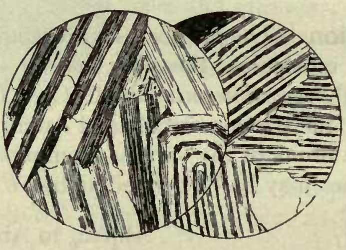


FIG. 61.—LAMELLAR TWINNING IN PLAGIOCLASE.
Between crossed nicols.

Optical Properties of Plagioclase Felspars.—Plagioclase felspars occur as four-sided, usually elongated, sections, giving low polarisation colours. They are distinguished from orthoclase by their lamellar twinning. It is difficult accurately to differentiate between the several varieties of plagioclase under the microscope, but several working rules are worthy of consideration.

Albite shows fine lamellar twinning, labradorite broad lamellar twinning. If a section which, when parallel to the cross-wires, shows very little signs of twinning, is taken and the extinction angle of one set of twins observed, the variety may be obtained by knowing that albite twins, under these conditions, extinguish at low angles, and labradorite twins at angles up to 50° ; therefore intermediate varieties may be recognised by interpolation.

ALBITE.

Comp.—Silicate of aluminium and sodium, $Na_2O.Al_2O_3.6SiO_2$.

Cryst. Syst.—Triclinic. Angle between *b* and *c* axes 86° 24′.

Com. Form.—Often in crystals, tabular parallel to the brachypinacoid, being combination of the prism, brachypinacoid, basal plane. Often with lamellar twinning on the albite law; Carlsbad twinning also. Also twinned on the pericline law, giving, with the albite twinning, two sets at right angles. Also occurs massive, with a granular or lamellar structure.

Cleav.—Perfect parallel to basal plane, almost as perfect parallel to the brachypinacoid.

Colour.—White, sometimes with a bluish, greyish, reddish, or greenish tinge ; also colourless.

Lustre.—Vitreous ; pearly on basal cleavage plane ; transparent to translucent.

Fract.—Uneven.

H.—6–6·5. *Sp. Gr.*—2·62–2·64.

Opt. Props.—Under the microscope albite occurs either as rectangular, sometimes lath-like, sections, or as shapeless plates. Colourless, often cloudy through alteration. Cleavage usually not well shown. Refractive index just below that of Canada balsam. Polarisation colours slightly lower than those of quartz, low greys. Between crossed nicols, twinning shows as two sets of fine lamellæ that extinguish at different instants.

Tests.—Before the blowpipe, fuses with difficulty, colouring the flame yellow.

Varieties—Aventurine} These two varieties occur as in
Moonstone} orthoclase.

Pericline.—A white semi-opaque variety occurring in somewhat large crystals, elongated along the *b* axis.

Peristerite.—A variety with play of colours like labradorite (*q.v.*), and which often contains disseminated grains of quartz.

Clevelandite.—A lamellar variety of white albite.

Occurrence.—Albite occurs in the acid and intermediate igneous rocks—granite, syenite, and diorite, and their hypabyssal and volcanic representatives. Sometimes secondary in lavas, etc. Also as fragments in arkoses and felspathic sandstones.

OLIGOCLASE.

Comp.—Ab_6An_1 to Ab_3An_1, where $Ab = Na_2O.Al_2O_3.6SiO_2$, and $An = CaO.Al_2O_3.2SiO_2$.

Cryst. Syst.—Triclinic.

Com. Form.—Crystals not common. Angle between basal pinacoid and brachypinacoid 86° 32′. Usually occurs massive and cleavable. Twinning shown as a series of fine striations on the basal cleavage plane.

Cleav.—Perfect parallel to the basal pinacoid (001), slightly less perfect parallel to the brachypinacoid (010).

Colour.—Greyish, greenish, yellowish, white, occasionally with a reddish tinge.

Lustre.—Resinous on cleavage planes, vitreous or pearly; translucent on edges. When weathered, dull.

Fract.—Conchoidal, uneven.

H.—6–6·5. *Sp. Gr.*—2·65.

Opt. Props.—As for albite (*q.v.*). Refractive index = 1·542. Extinction on the basal pinacoid (001) is 2°.

Tests.—Fuses more easily than orthoclase and albite, and forms a clear glass; insoluble in acids.

Occurrence.—Oligoclase occurs as an original mineral in intermediate igneous rocks—syenites, diorites, and their dyke and volcanic representatives. Accompanies orthoclase in many granites.

ANDESINE.

Comp.—Ab_3An_1 to Ab_1An_1, where Ab = albite molecule, $Na_2O.Al_2O_3.6SiO_2$, and An = anorthite molecule, $CaO.Al_2O_3.2SiO_2$.

Cryst. Syst.—Triclinic.

Com. Form.—Crystals not common. The angle between the clinopinacoid and the basal plane is 86° 14′. Usually occurs massive and cleavable.

Cleav.—Usual felspar cleavage; perfect basal and rather less perfect brachypinacoidal cleavages.

Colour.—White or grey.

Lustre.—Subvitreous to pearly.

H.—5–6. *Sp. Gr.*—2·69.

Opt. Props.—As for albite (*q.v.*). Refractive index = 1·557, nearly that of balsam. Extinguishes on the basal pinacoid (001) at −5°. Shows fine twin lamellæ between crossed nicols.

Occurrence.—Occurs as a primary mineral in intermediate igneous rocks, diorites and andesites.

LABRADORITE.

Comp.—Ab_1An_1 to Ab_1An_3, where Ab = albite molecule, $Na_2O.Al_2O_3.6SiO_2$, and An = anorthite molecule, $CaO.Al_2O_3.2SiO_2$.

Cryst. Syst.—Triclinic.

Com. Form.—Crystals uncommon; usually thin tabular crystals flattened parallel to the brachypinacoid. Angle between basal plane and brachypinacoid 86° 4′. Usually occurs massive, crystalline, and cleavable.

Cleav.—Usual felspar cleavage; perfect parallel to basal plane, less perfect parallel to brachypinacoid.

Colour.—Grey, dark ashy, brown, green, reddish, rarely colourless. Usually shows a rich play of colours, blue and green generally predominating. This show of colour is not always seen.

Lustre.—Vitreous, inclining to pearly on the most perfect cleavage; subvitreous or subresinous on other surfaces. Translucent, but only on fine edges.

Fract.—Imperfectly conchoidal, uneven, splintery, and brittle.

H.—6. *Sp. Gr.*—2·67–2·76.

Opt. Props.—Like those of albite (*q.v.*). Twins usually in broad lamellæ. Refractive index, 1·57; extinction, – 17° on basal pinacoid.

Tests.—Fuses rather more easily than orthoclase or oligoclase to a colourless glass. Powdered labradorite is soluble in hot hydrochloric acid.

Occurrence.—Occurs as a primary constituent of basic igneous rocks—gabbro, dolerite, and basalt.

BYTOWNITE.

A plagioclase whose composition is represented by Ab_1An_3 to Ab_1An_6. Specific gravity is 2·733; refractive index, 1·577; and extinction angle, – 24° on basal pinacoid.

ANORTHITE.

Comp.—Ab_1An_6 to Ab_0An_1, where Ab = albite molecule, $Na_2O.Al_2O_3.6SiO_2$ and An = anorthite molecule, $CaO.Al_2O_3.2SiO_2$.

Cryst. Syst.—Triclinic.

Com. Form.—Prismatic crystals, having the angle between the basal plane and the brachypinacoid 85° 50′. Usually massive and cleavable.

Cleav.—Usual felspar cleavage; perfect parallel to the basal plane, less perfect parallel to the brachypinacoid.

Colour.—Colourless or white.

Lustre.—Vitreous, pearly on cleavage planes; transparent to translucent.

Fract.—Conchoidal.

H.—6–6·5. *Sp. Gr.*—2·765.

Opt. Props.—As for albite. Refractive index, 1·585. Has higher polarisation colours and higher refractive index than albite. Extinction angle, – 37° on basal plane.

Tests.—Fuses to a glass. With hydrochloric acid, soluble, with some separation of gelatinous silica.

Occurrence.—Occurs as a primary constituent of basic igneous rocks—gabbro, anorthosite, etc.

THE PYROXENES.

Introduction.—The Pyroxenes are a group of allied minerals which have certain physical and chemical characters in common.

In chemical composition they are silicates of iron, magnesium, and calcium, sometimes sodium and potassium, and with or without silicate of aluminium. The mutual replacements of the various constituents do not affect the crystalline form.

The pyroxenes crystallise in the orthorhombic, monoclinic, and triclinic systems, the prismatic angle of the crystal being nearly a right angle. They are characterised by a good prismatic cleavage.

The chief, or most typical, pyroxene is augite, and the name augite and pyroxene are often applied to the same mineral. The difference between augite and hornblende is indicated in the introduction to the Amphiboles, p. 205.

The Pyroxenes may be divided into the following groups:

1. Orthorhombic Pyroxenes.

Enstatite, $MgO.SiO_2$.
Bronzite, $(Mg,Fe)O.SiO_2$.
Hypersthene $(Fe,Mg)O.SiO_2$.

2. Monoclinic Pyroxenes.

(*a*) Non-Aluminous:

Diopside, $CaMg(SiO_3)_2.Ca(Mg,Fe)(SiO_3)_2$.
Malacolite, *Sahlite*, *Hedenburgite*, *Schefferite*, *Jeffersonite*.
Diallage (in part).

(*b*) Aluminous:

Augite, $Ca(Mg,Fe)(SiO_2)_3$, with $(Mg,Fe)(Al,Fe)_2SiO_6$.
Diallage (in part).
Acmite, *Ægerine*, $NaFe(SiO_3)_2$.
Spodumene, $LiAl(SiO_3)_2$.
Jadeite, $NaAl(SiO_3)_2$.
Wollastonite, $CaO.SiO_2$.

3. Triclinic Pyroxenes.

Hiortdahlite, *Babingtonite*.

ORTHORHOMBIC-PYROXENES.

Introduction. — The orthorhombic pyroxenes are characterised by three chief minerals: enstatite, bronzite, and hypersthene, the properties of which show gradations from one to another. Enstatite contains no iron oxide, bronzite up to 15 per cent., hypersthene up to 30 per cent. The pleochroism, body colour, refractive index, and polarisation colours all increase from enstatite to hypersthene.

ENSTATITE.

Comp.—Silicate of magnesium, $MgO.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Stout prismatic crystals, showing prism and macro- and brachypinacoids. Usually occurs massive and lamellar.

Cleav.—Rather perfect parallel to the prism, giving two sets of cleavage lines, which intersect at nearly 90°.

Colour.—Grey, green, brown, yellow, and often colourless.

Lustre.—Vitreous, pearly, sometimes fibrous-looking on cleavage; subtranslucent to opaque.

H.—5·5. *Sp. Gr.*—3·1–3·3.

Opt. Props.—Occurs as light-coloured grains and crystal sections in rock slices; colourless to pale green. Transverse sections of crystals show two sets of cleavages at 90°; longitudinal sections show one set only. All sections give straight extinction; polarisation colours, low, about those of quartz. Pleochroism weak; alters into serpentine.

Occurrence.—Enstatite occurs as a primary constituent of the intermediate and basic igneous rocks, as in the Cheviot andesite, Whinsill dolerite; and in serpentine and peridotites, as in the Kimberley blue ground.

BRONZITE.

Bronzite is an iron-bearing variety of enstatite, containing up to 15 per cent. of iron oxide, and is therefore $(Mg,Fe)O.SiO_2$. It usually has a bronze-like or pearly metallic lustre, and is foliated. It is very infusible, being the most infusible grade in Von Kobel's Scale of

Fusibility, 6, and can only be rounded on the edges of fine splinters in the blowpipe flame. Its optical properties are intermediate between those of enstatite and hypersthene.

HYPERSTHENE.

Comp.—Silicate of iron and magnesium, $(Fe,Mg)O.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Usually occurs foliated and massive.

Cleav.—Prismatic, and also parallel to the brachypinacoid (010), giving three sets of cleavage lines in transverse sections.

Colour.—Brownish-green, greyish or greenish-black, brown, sometimes almost black.

Lustre.—Rather metallic. Schillerisation is very characteristic of hypersthene, and is probably due to the presence of minute iron oxide scales arranged in parallel planes. Translucent to opaque.

Fract.—Uneven ; brittle.

H.—5–6. *Sp. Gr.*—3·5.

Opt. Props.—Hypersthene is recognised in thin sections by its well-marked pleochroism in greens to pinks. Polarisation colours and refractive index higher than those of enstatite.

Tests.—Before the blowpipe, fuses to a black enamel, and on charcoal to a magnetic mass.

Occurrence.—Occurs in norites and other basic rocks, and also in pyroxene granulites, charnockites, etc.

MONOCLINIC PYROXENES.

AUGITE.

Comp.—Silicate of calcium, magnesium, iron, and aluminium, $CaMg(SiO_2)_3$, with $(Mg,Fe).(Al,Fe)_2.SiO_6$. Composition variable.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals common; combinations of prism, clinopinacoid, orthopinacoid, and positive hemipyramid, as shown in Fig. 62. Crystals often twinned on the orthopinacoid, giving a re-entrant angle. Prism angle nearly 90°. Also occurs massive and coarsely lamellar, sometimes granular or fibrous.

Cleav.—Prismatic, giving two sets of cleavage lines, meeting at an angle of nearly 90°.

Colour.—Black and greenish-black.

Lustre.—Vitreous, inclining to resinous; opaque.

H.—5–6. *Sp. Gr.*—3·2–3·5.

Opt. Props.—Occurs as eight-sided cross-sections or four-sided longitudinal sections, the former showing the prismatic cleavage, two sets at right angles, the latter one set of cracks only (see Fig. 63). The colour in thin section is colourless to yellowish-brown; some titaniferous varieties are purplish. Augite is non-pleochroic. Polarisation colours, nice bright colours; refractive index much higher than that of Canada balsam. Extinction angle on the clinopinacoid, about 45°.

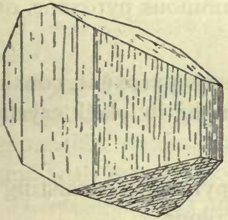


FIG. 62.—AUGITE.

FIG. 63.—AUGITE: TRANSVERSE SECTION.

Occurrence.—Augite occurs in short prismatic crystals in many volcanic rocks, andesites, basalts, etc.; also as crystals or plates in plutonic rocks, especially the basic members, such as diorite and gabbro ; also as grains in the pyroxene granulites.

Diopside.—A non-aluminous pyroxene, occurring in white or green prismatic crystals and granular masses ; a calcium magnesium silicate with a little iron. In thin section ; colourless.

Malacolite.—A non-aluminous variety of pyroxene ; white and various shades of yellow and pale green ; sometimes transparent and colourless.

Sahlite.—A non-aluminous pyroxene, of a more dingy green colour, less lustre and coarser structure than diopside.

Coccolite.—A granular, non-aluminous pyroxene, of a white or green colour.

Hedenburgite.—A non-aluminous pyroxene, consisting of a calcium iron silicate, occurring in black crystals and also in lamellæ.

Schefferite.—A non-aluminous pyroxene, consisting of iron manganese silicate ; black in colour.

Jeffersonite. — A non-aluminous manganese zinc pyroxene.

Diallage.—A form of diopside or augite, which occurs in lamellæ or in foliated masses, sometimes with a metallic or brassy lustre ; sometimes fibrous. Colour, grass-green, brown, or grey. It has a parting parallel to the basal plane, is brittle and translucent. It is characteristic of gabbros, and can be recognised under the microscope by the foliation parallel to the basal plane, showing as fine parallel lines. Its optical properties are those of augite.

ACMITE, ÆGERINE.

Comp.—Silicate of iron and sodium, $Na_2O.Fe_2O_3.4SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Long prismatic crystals, with sharp terminations.

Cleav.—Prismatic.

Colour.—Usually brown, sometimes green.

Lustre.—Vitreous; subtransparent to opaque.

H.—6–6·5. *Sp. Gr.*—3·5–3·55.

Opt. Props.—As for augite, but showing pleochroism in greens and browns.

Occurrence.—Occurs in soda-rich igneous rocks, such as nepheline-syenite, phonolite, etc.

SPODUMENE.

Comp.—Silicate of lithium and aluminium, $Li_2O.Al_2O_3.4SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Sometimes in large crystals made up of pinacoids, domes, and the prism; also found massive and with broad cleavage surfaces.

Cleav.—Perfect parallel to prism, also to the orthopinacoid.

Colour.—Greyish or greenish.

Lustre.—Pearly, but vitreous on fractured surfaces. Translucent to subtranslucent.

H.—6·5–7. *Sp. Gr.*—3·13–3·2.

Tests.—Before the blowpipe, swells up and becomes opaque. Colours the flame red, due to lithium, if not heated too much. Not acted upon by acids.

Variety—Hiddenite.—An emerald green variety.

Occurrence.—Occurs as large crystals in granite, as at Peterhead, Killiney, Huntington Maine.

JADEITE.

A silicate of sodium and aluminium, corresponding to spodumene; usually massive, of a green colour. Hardness, 6·5–7; specific gravity, 3·3–3·35.

WOLLASTONITE: Tabular Spar.

Comp.—Calcium silicate. $CaO.SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals usually tabular; combinations of pinacoids, domes, and prisms. Also found massive and cleavable, with a long fibrous or columnar structure, the fibres being either parallel or interlaced.

Cleav.—Perfect parallel to the orthopinacoid.

Colour.—White, grey, sometimes yellowish, reddish, or brownish.

Lustre.—Vitreous; rather pearly on cleavage surfaces; subtransparent to translucent.

H.—4·5–5. *Sp. Gr.*—2·8.

Tests.—Before the blowpipe, fuses easily on the edges; gelatinises with hydrochloric acid.

Occurrence.—Occurs in granite near the junctions, also as the product of metamorphism of impure limestones, in which it is associated with grossular, diopside, etc; also in basalts.

TRICLINIC PYROXENES.

Hiortdahlite.—A silicate of sodium, calcium, and zirconium. Occurs in yellow triclinic crystals.

Babingtonite.—A silicate of calcium, iron, and manganese. Occurs in black triclinic crystals.

Rhodonite.—A manganese silicate, sometimes classed with the pyroxenes (see p. 279).

THE AMPHIBOLES.

Introduction.—The Amphibole group, like the pyroxenes, includes several minerals, whose physical and chemical characters serve to link them together in one family.

In chemical composition they are analogous to the pyroxenes, and are silicates of iron, magnesium, calcium, sometimes potassium and sodium, with or without silicate of aluminium.

The amphiboles crystallise in the orthorhombic, monoclinic, and triclinic systems, but differ from the pyroxenes in the forms and angles of the crystals. The cleavage is parallel to the prism.

The distinction between pyroxenes and amphiboles is given in the following table:

	Amphiboles.	*Pyroxenes.*
1.	Prism angle nearly 120°.	Prism angle nearly 90°.
2.	Cleavages at 120°.	Cleavages at 90°.
3.	Bladed forms common.	Bladed forms uncommon.
4.	Pleochroic.	Non-pleochroic.
5.	Crystals terminated by three faces.	Crystals terminated by two faces.
6.	Twins, with no re-entrant angle.	Twins with re-entrant angle.
7.	Cross sections, six-sided.	Cross sections, eight-sided.
8.	Clinopinacoid only present.	Orthopinacoid and clinopinacoid both present.
9.	Extinction angle on the clinopinacoid, 16°.	Extinction angle on the clinopinacoid, 48°.
10.	Common in more acid rocks.	Common in more basic rocks.

The Amphiboles may be divided into—

1. **Orthorhombic.**

Anthophyllite $(Mg,Fe)O.SiO_2$.

2. **Monoclinic.**

(*a*) Non-Aluminous.

Tremolite, $CaO.3MgO.4SiO_2$.
Actinolite, $CaO.3(Mg,Fe)O.4SiO_2$.
Asbestos, *Nephrite*, *Smaragdite*.

(*b*) Aluminous.

Hornblende, $CaO.3(Mg,Fe)O.4SiO_2$, with $Na_2O.Al_2O_3.4SiO_2$ and $2(Mg,Fe)O.2(Al,Fe)_2O_3.2SiO_2$.

Glaucophane, $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$.

Riebeckite, $2NaFe(SiO_3)_2.FeSiO_3$.

Crocidolite.

Arfvedsonite.

3. **Triclinic.**

Cossyrite. Silicate of Na,Fe,Ti.

ORTHORHOMBIC AMPHIBOLES.

Anthophyllite.—An orthorhombic amphibole corresponding to enstatite-hypersthene among the pyroxenes, and being a silicate of magnesium and iron, $(Mg,Fe)O.SiO_2$. Colour, shades of brown. Often in aggregates of prismatic needles and in radiating fibres. Specific gravity, 3–3·2; hardness, 5·5–6. Occurs as a mineral of metamorphic origin in gneisses and schists.

MONOCLINIC AMPHIBOLES.

HORNBLENDE.

Comp.—Variable. Silicate of calcium, magnesium and iron, together with silicate of aluminium; sodium and potassium also present. The following is a rough typical analysis: SiO_2, 40 per cent.; CaO, 10 per cent.; Al_2O_3, 12 per cent.; MgO, 13 per cent.; Fe_2O_3, 7 per cent.; FeO, 14 per cent.; K_2O and Na_2O, 4 per cent.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals common. Prismatic, combination of prism, clinopinacoid, clinodome, and hemiorthodome (see Fig. 64). Angle of prism nearly 120°. Twinned on the orthopinacoid, causing the four clinodome faces to come to the top, and the two orthodome faces to be at the bottom of the crystal, and hence these twins are easily recognised. Also occurs in long blade-like forms, and massive and granular.

Cleav.—Parallel to the prism, producing two sets of cleavage lines, meeting at nearly 120° (see Fig. 65), and seen in a transverse section.

Colour.—Black, or greenish-black.

Lustre.—Vitreous; transparent rarely; translucent to opaque.

Fract.—Uneven.

H.—5–6. *Sp. Gr.*—3–3·47.

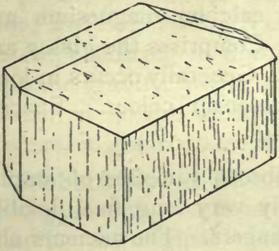


FIG. 64.—HORNBLENDE.
(*Clinopinacoid on the right.*)

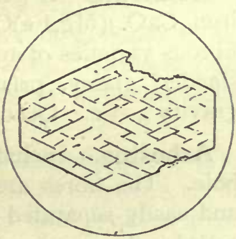


FIG. 65.—HORNBLENDE: TRANSVERSE SECTION.

Opt. Props.—Colour in thin section, green, or brown (basaltic hornblende). Transverse sections six-sided, with two sets of cleavages. Longitudinal sections with one set of cleavage lines. These latter sections extinguish at a small angle, up to 16°, to this cleavage (*cf.* Augite). Pleochroic in shades of brown and green.

Tests.—Physical properties distinctive. Before the blowpipe, fuses easily, forming a magnetic globule.

Varieties—Edenite.—Light-coloured hornblende.

Pargasite.—Dark-coloured hornblende.

Occurrence.—As a primary mineral in acid and intermediate igneous rocks—granites, syenites, diorites, etc.;

more rarely in basic rocks, picrite, etc. Also as a mineral of metamorphic origin in gneisses and schists; in some cases the hornblende forms practically the whole of the rock, which is then called *hornblende rock*.

Tremolite—*Comp.*—Silicate of calcium and magnesium, $CaO.3MgO.4SiO_2$. Occurs in white or dark grey crystals, often long blade-like; also columnar, fibrous, compact, and granular; sometimes transparent and colourless. Hardness, 5–6; specific gravity, 2·9–3·1. Found in schists at Tremola, in Switzerland, and elsewhere.

Actinolite.—A silicate of calcium magnesium and iron, $CaO.3(Mg,Fe)O.4SiO_2$. Comprises the glassy and fibrous varieties of amphibole. Generally occurs in long, slender, glassy, prisms of greenish colour. Specific gravity 3–3·2. Occurs in schists.

Asbestos.—Includes the fibrous varieties of amphibole. The fibres are generally very long, fine, flexible, and easily separated by the fingers. The ancients also called it "amianthus" (undefiled), in allusion to the ease with which cloth, woven from it, was cleaned by throwing it into the fire. The name amianthus is now restricted to the more silky kinds. The term asbestos, in the strictest sense, is confined to the fibrous forms of actinolite; but commercial asbestos includes also fibrous forms of serpentine, an example being the Canadian asbestos (*q.v.*, p. 220).

Commercial Asbestos. — Under the term "commercial asbestos" are included three mineral groups:

1. Anthophyllite group.
2. Hornblende group—tremolite, asbestos, mountain leather, crocidolite, etc.
3. Serpentine group—picrolite, chrysotile, talc.

All these minerals occur in long fibrous crystals. The commercial value of the mineral depends almost wholly on its property of being spun, and therefore good asbestos yields long silky fibres when rubbed between the fingers. The heat-resisting property of all the mineral varieties of asbestos is about the same.

Mountain Cork, Mountain Leather, Mountain Wood.—These are varieties of asbestos which vary in compactness and in the matting of their fibres.

Nephrite, Jade.—A compact form of actinolite.

Glaucophane.—A silicate of sodium, aluminium, iron, and magnesium, $NaAlSi_2O_6.(Fe,Mg)SiO_3$. Blue in colour, occurring in fibrous, massive, or granular forms. Specific gravity, 3–3·1; hardness, 6–6·5. Strongly pleochroic in shades of blue. Occurs as a metamorphic mineral in glaucophane schists.

Riebeckite.—A silicate of iron and sodium, $2NaFe(SiO_3)_2.FeSiO_3$. A blue or nearly black pyroxene, occurring as an original constituent of acid igneous rocks (granophyre, quartz-felsite, etc.), where it usually appears as small, rather shapeless, blue, pleochroic aggregates.

Arfvedsonite.—A black sodium amphibole. Specific gravity, 3·45; hardness, 6. Occurs in soda-rich igneous rocks.

Crocidolite.—An indigo-blue variety of amphibole, found in Griqualand, South Africa. By alteration it assumes a golden-yellowish, brown colour, and, when infiltrated with silica, constitutes the cat's eye used for ornaments.

TRICLINIC AMPHIBOLE.

Cossyrite.—A silicate and titanite of iron, sodium, aluminium, etc. Occurs as black, triclinic crystals in the soda-rich trachytes of Pantellaria (pantellarites), and under the microscope appears as small brown sections intensely pleochroic.

THE MICAS.

Introduction.—Micas are distinguished by a perfect basal cleavage, which causes them to split up into thin elastic plates, and by their splendent pearly, somewhat metallic, lustre. They all crystallise in the monoclinic system, but the forms approximate to those of the hexagonal system.

In composition they are silicates of aluminium, potassium, and hydrogen, together with iron, magnesium, sodium, and lithium.

When a blunt steel punch is placed on a cleaved plate of mica, and lightly struck, a small six-rayed star is produced. The three cracks which constitute these stars have a constant relation to the form of the crystal from which the plate is cleaved, and one of the cracks is always in the direction of the plane of symmetry. Micas give a biaxial interference figure in convergent polarised light, and, by the orientation of this figure with regard to the plane of symmetry, as revealed by the percussion figure, they are divided up into two groups. In the first of these groups, the "Muscovites," the line joining the eyes of the interference figure is normal to the plane of symmetry, and in the second group, the "Biotites," this line is in the plane of symmetry.

Hence the following classification is possible:

(*a*) The "**Muscovites.**"

Muscovite—potassium mica, white mica.
Paragonite—sodium mica.
Lepidolite—lithium potassium mica.

(*b*) The **"Biotites."**

Biotite—iron magnesium mica, black mica.
Zinnwaldite—lithium biotite.
Phlogopite—magnesium mica.

The specific gravity of the micas ranges from 2·7 to 3·1, and the average hardness is 2·5.

The micas differ from the chlorites and other micaceous minerals, in the alkalies which they contain, and in the elasticity of their cleavage flakes.

MUSCOVITE: Muscovy Glass, Common Mica, Potash Mica.

Comp.—Silicate of aluminium, potassium, and hydrogen, $2H_2O.K_2O.3Al_2O_3.6SiO_2$.

Cryst. Syst.—Monoclinic, pseudo-hexagonal.

Com. Form.—Usually in six-sided tabular crystals. Also in large plates; also massive, and in disseminated scales.

Cleav.—Extremely perfect parallel to the basal pinacoid, large and very thin laminæ being easily separated. These laminæ are flexible and elastic (*cf.* Chlorite, p. 215). When held up to a bright light these laminæ often exhibit asterism, star-like rays of light being transmitted.

Colour.—White, black, brown, yellow, and green.

Lustre.—More or less pearly. Transparent to translucent.

H.—2–2·5. *Sp. Gr.*—2·85.

Opt. Props.—Occurs as shapeless, colourless flakes, the vertical sections showing the perfect basal cleavage. Refractive index higher than that of balsam. Polarisation colours very high, delicate pinks and greens.

Tests.—Before the blowpipe, whitens and fuses only on thin edges. Not decomposed by acids. Yields water in the closed tube.

Varieties — *Sericite, Damourite, Gilbertite.* — Secondary micas, resulting from the alteration of numerous rock-forming minerals.

Occurrence.—Muscovite occurs as an original constituent of acid igneous rocks, granites. Workable quantities of muscovite occur in pegmatites, as at Nellore, India, and the Eastern United States, Canada, etc. Muscovite is a common constituent of metamorphic rocks, gneisses, and mica schists. The secondary micas occur as the alteration products of felspar, topaz, etc. Muscovite is a very common constituent of detrital sedimentary rocks, micaceous sandstones, clays, etc.

Uses.—Muscovite is used to cover lanthorns, and for lamp-chimneys, etc., and in some countries for windows. Mica in general is extensively used for insulating purposes in the construction of electrical instruments. Powdered mica is used in the manufacture of wall-paper and for giving the "frost" effect on Christmas cards, as a lubricant and as a paint.

Paragonite.—A sodium mica ($Al_3NaH_2Si_3O_{12}$) corresponding to muscovite in composition. Specific gravity, 2·9; hardness, 2·5–3. Colour like muscovite. Occurs in schists, associated with garnet and staurolite.

LEPIDOLITE: Lithium Mica.

Comp.—A silicate of potassium, lithium and aluminium, with varying amounts of hydroxyl, fluorine, etc.

Cryst. Syst.—Monoclinic.

Com. Form.—Occurs in forms like those of muscovite, but mostly in masses, composed of small scales or granules.

Cleav.—As in muscovite.

Colour.—Rose red, lilac, violet-grey, sometimes white.

Lustre.—Pearly, translucent.

H.—2·5–4. *Sp. Gr.*—2·8–2·9.

Tests.—Before the blowpipe gives red lithium flame. Usually gives reaction for fluorine.

Occurrence.—Occurs in pegmatites, associated with tourmaline, topaz, and other minerals of pneumatolytic origin, as in the Eastern United States, Elba, etc. It occurs as a gangue mineral of tin veins at Zinnwald, Saxony.

BIOTITE.

Comp.—Variable. Silicate of magnesium, aluminium, potassium, and hydrogen, together with iron salts in varying proportions $(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$.

Cryst. Syst.—Monoclinic. Pseudo-hexagonal.

Com. Form.—Occurs in six-sided prisms usually broad and tabular; also in small scales.

Cleav.—Very perfect parallel to the basal plane, affording extremely thin flexible and elastic laminæ.

Colour.—Black or dark green, in thick crystals, while by transmitted light thin laminæ appear brown, green, or blood red.

Lustre.—Splendent; and, on cleavage, more or less pearly. Transparent to opaque.

H.—2·5–3. *Sp. Gr.*—2·7–3·1.

Opt. Props.—Occurs as brown flakes showing the perfect basal cleavage. Very pleochroic, and the polarisation colours are usually masked by the deep body colour of the mineral. Alters into green chlorite. Figure nearly uniaxial.

Tests.—Heated with fluxes, gives a strong iron reaction. Decomposes in strong sulphuric acid, leaving a residue of siliceous scales.

Occurrence.—Occurs chiefly as an original constituent of igneous rocks of all kinds—granites, diorites, gabbros, etc., and their volcanic representatives. It occurs as a mineral of metamorphic origin in biotite gneisses and schists.

PHLOGOPITE.

Comp.—Variable. Silicate of aluminium, magnesium, potassium and hydrogen, with some iron, $AlMg_3KH_2Si_3O_{12}$.

Cryst. Syst.—Monoclinic.

Com. Form.—Six-sided prismatic crystals common; also in scales.

Cleav.—Perfect parallel to the basal plane. Thin laminæ, tough and elastic. Asterism often shown.

Colour.—White, colourless, brown, copper red.

Lustre.—Pearly, often submetallic on cleavage planes.

H.—2·5–3. *Sp. Gr.*—2·75.

Occurrence.—Phlogopite is a mineral resulting from the dedolomitisation of an impure dolomite, and is therefore found embedded in crystalline limestones associated with forsterite, grossular, etc. It is worked in Ontario from pockety deposits occurring in an Archæan crystalline limestone which has been baked by intrusions of pyroxenite.

ZINNWALDITE.

A mica whose composition is like that of biotite, but which contains, in addition, lithium. Pale yellow or brown in colour. Occurs in modifications of the Zinnwald granite, associated with tinstone, etc.

THE CHLORITES.

Introduction.—Under the general name of "chlorite" are included many allied minerals which are related in composition to the micas, but which are hydrated, more basic, and contain no alkalies. In general, they may be considered as hydrated silicates of aluminium, iron, and magnesium.

The chlorites are monoclinic, and some members are pseudo-hexagonal. They are green in colour, from which fact they derive their name. The chlorites have a perfect basal cleavage, giving flakes which are flexible, but not elastic (*cf.* Mica).

The chlorites are very soft, their hardness being 1·5.

Varieties.—Numerous species of chlorites have been described, but very few are sufficiently well defined to merit description. Among these varieties are—

Clinochlore. A chlorite occurring in monoclinic tabular crystals.

Penninite. Occurs in pseudo-hexagonal crystals, but is really monoclinic.

Vermiculite and *Ripidolite Types.* Chlorite occurring in tubular, radiating, and granular forms.

CHLORITE IN GENERAL.

Comp.—Hydrated silicate of aluminium, iron, and magnesium.

Cryst. Syst.—Monoclinic. Forms pseudo-hexagonal at times.

Com. Form.—In tabular crystals; commonest in granular masses, disseminated scales and folia in metamorphic rocks. Frequently encrusting; also in forms with a compact radiating structure.

Cleav.—Perfect parallel to the basal pinacoid, giving flexible, but not elastic, flakes.

Colour.—Green of various shades.

Lustre.—Rather pearly. Feels very slightly greasy when granular or in scales. Subtranslucent to opaque.

H.—1·5. Scratched by finger-nail. *Sp. Gr.*—2·6–2·8.

Opt. Props.—In thin section, chlorite occurs either as radiating aggregates filling cavities, or as an alteration product of minerals such as biotite, hornblende, etc. Colour green; refractive index low; polarisation colours very low. Pleochroic in greens and greenish-yellows.

Tests.—Distinguished by colour and physical properties. Heated in closed tube gives water. Fuses with difficulty on thin edges.

Occurrence.—Never a primary mineral. In amygdules, and as an alteration product of biotite, hornblende, etc. Common as a mineral of metamorphic origin, as in the chlorite schists.

HYDRATED SILICATES OF MAGNESIUM.

This division includes talc, serpentine, and meerschaum, which are all hydrated silicates of magnesium. Talc and serpentine are monoclinic, meerschaum is amorphous, but is included here because of its similar composition.

Talc—$3MgO.H_2O.4SiO_2$.
Serpentine—$3MgO.2H_2O.2SiO2$.
Meerschaum—$2MgO.2H_2O.3SiO2$.

TALC (Arabic, *talq*).

Comp.—Hydrated silicate of magnesium, $3MgO.H_2O.4SiO2$.

Cryst. Syst.—Probably monoclinic.

Com. Form.—Crystals rare, tabular. Usually found massive with a foliated structure, which permits it to be split into thin plates, which are flexible, but not elastic (the latter character serving to distinguish the laminæ of talc from those of mica). It is also found granular-massive, compact, and crypto-crystalline.

Cleav.—Basal and highly perfect, giving thin plates.

Colour.—White, silvery white, apple green, greenish-grey, and dark green.

Lustre.—Pearly, subtransparent to translucent. Feels greasy.

H.—1 (softest grade in Moh's scale). Easily cuts with a knife, or scratched with the finger-nail. *Sp. Gr.*—2·7–2·8.

Opt. Props.—Usually occurs under the microscope as laths and wisps in schistose rocks, when it cannot be distinguished from muscovite. Refractive index slightly higher than that of balsam; double refraction high, giving bright colours.

Tests.—Heated alone before the blowpipe, whitens and exfoliates, fusing to an enamel on the edges only. Not decomposed by acids, except the variety rensselærite.

Varieties — Steatite, Soapstone. — Simply a massive variety of talc, slabs of which have been employed for firestones in furnaces and stoves. Steatite is also turned, and carved into various objects, useful and ornamental, especially in India and China, and is frequently used for tipping gas-burners. It is employed in the manufacture of porcelain, as a means of lessening friction in machinery, and for removing grease, etc., from cloth. In colour steatite is mostly white, and grey of various shades, sometimes greenish or reddish. It has a greasy or soapy feel. It occurs associated with serpentine.

Potstone.—An impure talc with a slaty structure, and greyish-green, dark-green, iron-grey, or brownish-black colour. In Italy it is made into vessels for cooking, as it stands the fire well. The stone is easily turned on a lathe.

Talcose Slate.—A very impure variety of talc occurring as a slate.

Rensselærite.—A variety of soapstone found at St. Lawrence in Jefferson County, New York. It takes a high polish, and is made into inkstands and ornamental articles. Colours: white, yellow, black. Hardness, 3–4. It occasionally passes into serpentine.

French Chalk.—A steatite used by tailors for marking cloth.

Indurated Talc.—An impure slaty variety, somewhat harder than French chalk.

Steatite and these other varieties are amorphous. They are never found crystallised, although pseudomorphs of steatite are found in cavities which have been occupied by other minerals.

Occurrence.—Talc occurs as a secondary mineral resulting from the hydration of magnesium-bearing rocks, such as gabbros, diorites, etc., as in New York and other localities in the Eastern United States. It also occurs as a talc schist, as in the Appalachian belt (North Carolina especially), Tyrol, etc. Steatite occurs as a pseudomorph, or as beds resulting from the metamorphism of decomposed magnesium-rich rocks.

Uses.—These have been indicated in the description of the varieties.

SERPENTINE.

Comp.—Hydrated silicate of magnesium, $2H_2O.3MgO.2SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals not known; crystal system proved by optical properties. Occurs massive, granular, and fibrous; sometimes foliated.

Cleav.—One distinct parting.

Colour.—Different shades of green to almost black, sometimes red, yellow, or brown; it is usually veined and spotted with white, green, red, etc. The white veins are mostly steatite, which in many cases envelop crushed fragments of the darker serpentine, thus producing very ornamental patches of breccia.

Lustre.—Subresinous, greasy. Translucent to opaque. Sometimes slightly soapy to the feel.

Fract.—Conchoidal; tough.

H.—3–4. Cut with the knife. Easily turned into vases, chimney pieces, etc., and is extensively used in architectural decoration. *Sp. Gr.*—2·5–2·6.

Opt. Props.—Under the microscope, serpentine appears as a complete or partial pseudomorph after an olivine, pyroxene, or amphibole rock (see Fig. 66). The alteration from olivine is most common. In this case serpentine occurs as rounded pseudomorphous crystals showing a network of black particles of magnetite, which has been thrown out of combination by the alteration of the olivine into serpentine. Colour, greenish yellow; refractive index, low. Polarisation colours are greys of a low order, and in some cases the mineral may appear practically isotropic.

Tests.—Heated, yields water. Fuses on the edges with difficulty. Recognised by colour and softness.

Varieties—Precious or Noble Serpentine.—A translucent variety, oil green in colour.

Antigorite.—A lamellar variety.

Chrysotile.—A fibrous variety occurring as small veins in massive serpentine. It is like asbestos, and forms part of the asbestos of commerce (Canadian asbestos). See also p. 208.

Picrolite.—A columnar variety.

Ophicalcite.—A rock made up of green serpentine in white calcite. Results from the dedolomitisation of a siliceous dolomite; olivine and calcite being first formed, and then the olivine altering into serpentine.

Occurrence.—Serpentine results from the alteration of rocks rich in magnesium, therefore from those rocks containing olivine, pyroxene, or amphibole—that is, peridodites, gabbros, picrites, etc., as at the Lizard, Portsoy in

Banffshire, Galway, Wicklow, Siberia, and Canada. The Canadian deposits are worked for asbestos, chrysotile forming veins (see above). Serpentine is also formed by dedolomitisation (see above under Ophicalcite).

Uses.—As a building stone, and for ornamental work in general, chiefly interior decoration. Fibrous varieties used as asbestos (see p. 208).

Bastite, or Schillerspar.—A serpentine resulting from the alteration of rhombic pyroxene, enstatite or bronzite. Olive green, blackish green, or pinchbeck brown in colour. Cleavage in two directions. Lustre of cleavage surfaces metallic to pearly. Hardness, 3·5–4; specific gravity, 2·5–2·7.

It is found in serpentine at Baste in the Hartz, in the Cornish serpentines and at several places in the United States, and tends to enhance the beauty of the stone.

MEERSCHAUM: Sepiolite. (German, *Meer*, sea, and *Schaum*, froth.)

Comp.—Hydrated silicate of magnesium, $2H_2O.2MgO.3SiO_2$.

Cryst. Syst.—Amorphous.

Com. Form.—In beds and in irregular masses in alluvial deposits. Fine and earthy in texture.

Colour.—White, greyish-white, sometimes with a faint yellowish or pink tint.

Lustre.—Dull and earthy. Opaque.

H.—2–2·5. Easily scratched with the finger-nail. *Sp. Gr.*—2. When dry, floats on water.

Tests.—Decomposed in hydrochloric acid with gelatinisation. Gives off water when heated. Heated on charcoal with cobalt nitrate gives a pink mass.

Occurrence.—In beds and as nodular masses in alluvial deposits (see below under Uses).

Uses.—Its chief use is for making pipes and pipe bowls, for which purpose it is admirably adapted by reason of its absorbent nature and its lightness; moreover, when well coloured by long smoking it displays additional beauty, in the eyes of connoisseurs. The meerschaum, before it is made into pipes, is first soaked in tallow and afterwards in wax, and it then takes a good polish. It is also used by the Algerians as a substitute for soap. It is procured chiefly from Asia Minor, Samos, and Negropont in the Grecian Archipelago, Morocco, and Spain; in the latter country, it is used as a building stone.

HYDRATED SILICATES OF ALUMINIUM.

This division includes several clay-like minerals resulting from the weathering and alteration in the main of igneous rocks. Such minerals include kaolin, bole, lithomarge, fuller's earth, and allophane.

KAOLIN: Kaolinite, China Clay. (Chinese, *Kau Ling*, high ridge: the name of a hill in China whence it was first procured.)

Comp.—Hydrated silicate of aluminium, $2H_2O.Al_2O_3.2SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Small pseudo-hexagonal plates—kaolinite. Usually a very soft, fine, clayey material, crumbling to powder when pressed between the fingers—kaolin, China clay.

Colour.—White when pure; grey and yellowish.

Lustre.—Dull and earthy. Greasy feel. Argillaceous smell.

H.—2–2·5 of crystals. *Sp. Gr.*—2·6.

Tests.—Heated on charcoal with cobalt nitrate gives a blue mass due to aluminium.

Varieties—Kaolinite.—Crystallised.

Kaolin, China clay.—Partly crystalline and partly amorphous material.

Occurrence.—Kaolinite occurs in the coal measures of South Wales and elsewhere.

Kaolin results from the alteration of the felspars of granites. This alteration may be caused by two processes: (1) Ordinary weathering of the felspar, first into sericite and thence into kaolin; (2) by the action of gases on the felspar (pneumatolysis). Since kaolin is associated with cassiterite, tourmaline, and other minerals of undoubted pneumatolytic origin, it appears that the second mode of formation holds at least for the Cornish occurrences. Both types of deposits occur, but the second is economically important in England (Cornwall). Other localities are Malay, France, China, and the United States.

Uses.—For the manufacture of fine porcelain and china.

Bole (Greek, *bolos*, a clod of earth).—Bole is a brownish-yellow, or red clay, which gives a shining streak when scratched with the nail. In composition it is a hydrated silicate of aluminium with much iron oxide. It breaks with a somewhat conchoidal fracture, and falls to pieces with a crackling noise when placed in water. Before the blowpipe fuses easily to a yellow or green enamel. Chiefly found in Italy, Silesia, and Asia Minor.

Lithomarge (Greek, *lithos*, stone, and *marga*, marl).—A white, yellow, or reddish clay, often speckled and mottled. It is a hydrated silicate of aluminium. It adheres strongly to the tongue, feels greasy, and yields to the finger-nail, affording a shining streak. Before the blowpipe, infusible. Found in Cornwall, Saxony, Bohemia, and elsewhere.

Fuller's Earth.—A greenish-brown, greenish-grey, bluish, or yellowish, soft, earthy, mineral, with a soapy feel, yielding to the nail with a shining streak, and adhering to the tongue. When placed in water it falls to powder, but does not form a paste. It is a hydrated silicate of aluminium. Before the blowpipe, fuses to a porous slag, and ultimately to a white, blebby glass. Found at Nutfield near Reigate, Detling near Maidstone, Bletchingly in Surrey, near Woburn in Bedfordshire, Bath, etc. It is used for "fulling" or cleansing woollen fabrics and cloth; its absorbent properties causing it to remove greasy and oily matters.

ALLOPHANE (Greek, *allos*, other, and *phaino*, to appear; from its change of appearance before the blowpipe).

Comp.—Hydrated silicate of aluminium, $Al_2O_3.SiO_2.5H_2O$.

Cryst. Syst.—Amorphous.

Com. Form.—As encrustations; sometimes reniform.

Colour.—Snow white, and honey or wax yellow; sometimes bluish, green, or brown.

Lustre.—Resinous, or waxy; translucent to opaque.

Fract.—Flat, conchoidal. Very brittle.

H.—3. *Sp. Gr.*—1·7–1·8.

Tests.—Before the blowpipe loses colour and becomes pulverulent. Soluble in dilute acids; in concentrated acids it forms a siliceous jelly.

Occurrence.—Usually occurs in encrustations on joint planes and fissures in chalk and sandstone; or lining cavities in clays and marls; Charlton near Woolwich in chalk; Northampton in sandstone. Also found at Saarfield in Thuringia, Beauvais, Vire, and at Richmond in Massachusetts.

OLIVINE GROUP.

The olivine group consists of minerals composed of varying amounts of magnesium silicate, and of iron silicate. Pure magnesium silicate is the mineral forsterite; pure iron silicate is the mineral fayalite. Intermediate between these two members is olivine, a magnesium iron silicate, which is the most important member of the group.

OLIVINE, Peridot, Chrysolite.

Comp.—Silicate of magnesium and iron, $2(Mg,Fe)O.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals usually modified with domes and pinacoids; also as grains, massive, and compact.

Colour.—Shades of green, pale green, olive green, greyish-green, brownish, rarely yellow.

Streak.—Colourless.

Lustre.—Vitreous. Transparent to translucent.

Fract.—Conchoidal.

H.—6–7. *Sp. Gr.*—Forsterite, 3·2; Fayalite, 4–4·2.

Opt. Props.—In rock slices, olivine occurs as somewhat rounded elongated sections, traversed by cracks along which the mineral is usually altered to greenish serpentine—the alteration being marked by a net-work of magnetite. See Fig. 66. There is no cleavage. Refractive index, very high, and polarisation colours, bright.

FIG. 66.—OLIVINE ALTERING INTO SERPENTINE.

Tests.—Most varieties are infusible before the blowpipe; recognised by colour and physical characteristics.

Varieties—Forsterite.—$2MgO.SiO_2$. In whitish or light green crystals in crystalline limestones.

Fayalite.—$2FeO.SiO_2$. Brown to black. *Sp. Gr.*—4–4·2. Before the blowpipe easily fusible. Occurs in the Mourne Mountains, Fayal in the Azores, etc. Also in slags.

Peridot.—A transparent, pale green variety of olivine used as a gem stone. Found in the Levant.

Occurrence.—Olivine is the essential constituent of the peridotites, dunite being a pure olivine rock. It also occurs in basic and ultra-basic rocks, such as basalt, dolerite, picrite, and in the olivine gabbros. Olivine is also formed by the dedolomitisation of an impure dolomite, the variety forsterite being formed, which by alteration produces serpentine, thereby giving rise to ophicalcite (see p. 219).

THE EPIDOTES.

Introduction.—The name "epidote" is derived from the Greek, *epidosis*, increase, the base of the prism having one side longer than the other. In chemical composition they are silicates of aluminium, iron, calcium, and hydrogen, with manganese, cerium, etc. They may be classified by means of their crystal system into—

Orthorhombic.

Zoisite, $HCa_2Al_3Si_3O_{13}$.

Monoclinic.

Epidote, $HCa_2(Al,Fe)_3Si_3O_{13}$.

Piedmontite. As for epidote, but with manganese.

Allanite or *Orthite*. As for epidote, but with cerium.

ZOISITE.

Comp.—Silicate of calcium and aluminium, with water, $4CaO.3Al_2O_3.6SiO_2.H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, often striated longitudinally. Commonly columnar.

Cleav.—Perfect parallel to the brachypinacoid.

Colour.—White, grey, greenish, sometimes red.

Lustre.—Vitreous; transparent to translucent.

H.—6–6·5. *Sp. Gr.*—3·25–3·37.

Opt. Props.—Refractive index high, polarisation colours low. The pink variety, thulite, is pleochroic in pinks.

Variety—Thulite.—A pink variety.

Occurrence.—Occurs in metamorphic rocks, especially those formed from igneous rocks rich in lime.

EPIDOTE: Pistacite.

Comp.—Silicate of aluminium, calcium and iron, with water, $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Occurs in crystals elongated along the ortho-axis; (see Fig. 67); also granular.

FIG. 67.—EPIDOTE.

Cleav.—Perfect, parallel to the basal plane.

Colour.—Shades of green, pistachio green, blackish green, and a dark oil green.

Lustre.—Vitreous; transparent to opaque.

Fract.—Uneven.

H.—6–7. *Sp. Gr.*—3·25–3·5.

Opt. Props.—The shapes of sections are either elongated or rounded. Rare sections parallel to the brachypinacoid are six sided, and show the basal cleavage. Refractive index high; polarisation colours, bright. Pleochroic in greens and yellowish greens.

Tests.—Before the blowpipe, gives an iron reaction.

Varieties—Pistacite.—Pistachio green-coloured variety.

Arendalite.—Found in very fine crystals, externally blackish-green, and of a dark oil green on fractured surfaces. From Arendal, in Norway.

Withamite.—Red variety, very pleochroic.

Occurrence.—Occurs in metamorphic rocks, gneisses and schists. Also results from the contact metamorphism of limestones, and as an alteration product of many ferro-magnesian rock-forming silicates.

Piedmontite.—An epidote, containing manganese, of a dark reddish colour. Before the blowpipe, fuses readily to a black glass, and may thus be distinguished from pistacite and zoisite, which fuse only on thin edges. Occurs in schists, etc.

Orthite, Allanite.—A cerium-bearing epidote, brown in colour. In thin sections, may show crystalline form, and is pleochroic in browns. Occurs as an accessory mineral in granites.

ALUMINIUM SILICATES.

These are silicates of aluminium of the composition $Al_2O_3.SiO_2$, and are characteristic of argillaceous rocks altered by contact metamorphism. The members are—

Andalusite—orthorhombic.
Sillimanite—orthorhombic.
Cyanite—triclinic.

ANDALUSITE (from Andalusia, in Spain).

Comp.—Aluminium silicate, $Al_2O_3.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals common, made up of the prism, with basal plane and sometimes a small macrodome (see Fig. 68); also massive.

Colour.—Pearl grey, purplish-red, flesh red. Often altered on the outside to silvery mica.

Lustre.—Vitreous; translucent to opaque.

Fract.—Uneven, tough.

H.—7·5. *Sp. Gr.*—3·1–3·3.

Opt. Props.—The characteristic inclusions of chiastolite serve to distinguish this mineral in thin sections. Primary andalusite occurs in rounded grains, which are pleochroic in pinks to colourless.

FIG. 68.—ANDALUSITE.

FIG. 69.—CHIASTOLITE.

Tests.—Before the blowpipe, infusible. Gives blue colour when heated with cobalt nitrate solution on charcoal. Not acted upon by acids.

Varieties—Chiastolite (Greek, *chiastos*, crossed). *Macle* (Latin *macula*, a spot; or from *mascle*, a term used in heraldry for an empty lozenge).—A variety of andalusite found in some metamorphic rocks, and in certain slates, such as the Skiddaw slate of Cumberland and the Killas of Cornwall, and which results from the contact metamorphism of argillaceous sediments. The crystals, when cut or broken across, exhibit definite cruciform lozenge-shape or tessellated markings, which are due to impurities taken up by, and arranged in, the crystals during their formation. The British examples are small, but crystals from foreign localities attain considerably larger dimensions. The corners of the crystals wear away, and produce a form simulating that of a twin crystal (see Fig. 69).

Occurrence.—Andalusite occurs in metamorphosed argillaceous rocks, andalusite slate, chiastolite slate, etc. Andalusite occurs also as a primary accessory mineral in some granites—Cornwall, etc.

SILLIMANITE: Fibrolite.

Comp.—Aluminium silicate, $Al_2O_3.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Usually occurs as long needle-shaped crystals, and in wisp-like aggregates.

Cleav.—Brachypinacoidal.

Colour.—Shades of brown, grey, and green.

Streak.—Colourless.

Lustre.—Vitreous.

Fract.—Uneven.

H.—6–7. *Sp. Gr.*—3·23.

Opt. Props.—Under the microscope occurs usually as aggregates of long, slender crystals in cordierite, garnet, etc. Double refraction strong.

Occurrence.—Present in felspathic gneisses, schists, and cordierite gneisses.

CYANITE: Disthene, Kyanite (Greek, *kuanos*, blue).

Comp.—Aluminium silicate, $Al_2O_3.SiO_2$.

Cryst. Syst.—Triclinic.

Com. Form.—Usually occurs in long, thin, blade-like crystals, embedded in mica schist and gneiss.

Cleav.—Parallel to the pinacoids.

Colour.—Light blue, sometimes white, sometimes with the middle of the crystal blue and the margins colourless; also grey-green, and rarely black.

Streak.—White.

Lustre.—Of cleavage faces, rather pearly; transparent to subtranslucent.

H.—Varies on different faces—4–7. *Sp. Gr.*—3·6–3·7.

Opt. Props.—In thin sections, colourless to blue. If coloured, pleochroic. Usually shows cleavages.

Tests.—As for andalusite. Gives aluminium reactions. Shape and colour of crystals distinctive.

Occurrence.—Occurs in gneiss, mica schists, and eclogites.

TOPAZ (Greek, *Topazios*, an island in the Red Sea, whence the ancients procured a stone, which, however, was not the topaz of the present day).

Comp.—Fluo-silicate of aluminium, $Al_2SiO_4F_2$. Part of the fluorine may be replaced by hydroxyl, OH.

Cryst. Syst.—Orthorhombic.

Com. Form. — Occurs in prismatic crystals, made up of the prism with brachypinacoid, brachydome, basal plane, and pyramid (see Fig. 70). Crystals sometimes apparently hemimorphic, the extremities being unlike. It is also found columnar and granular.

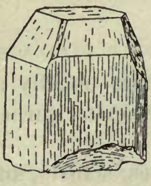


FIG. 70.—TOPAZ.

Cleav.—Perfect parallel to the basal plane.

Colour.—Wine yellow, straw yellow, white, greyish, and sometimes blue and pink. The pink colour of most of the topaz sold by jewellers is, however, produced by artificial heat, the stone being wrapped in amadou (a kind of tinder), which is ignited, and allowed to smoulder away.

Streak.—Colourless.

Lustre.—Vitreous; transparent to subtranslucent.

Fract.—Subconchoidal to uneven.

H.—8. *Sp. Gr.*—3·56.

Opt. Props.—Under the microscope, topaz in its general properties resembles quartz, but is distinguished from that mineral by its basal cleavage and by its much higher refractive index, which causes the borders of the grains to be well marked.

Tests.—Alone infusible. The powdered mineral, when heated, moistened with cobalt nitrate and reheated, assumes a blue colour, due to aluminium. Fused with microcosmic salt, gives off silicon fluoride, which etches the glass.

Occurrence.—Topaz occurs in igneous rocks, granites, rhyolites, etc., and good crystals are found projecting into the druses, as in the Mourne Mountain granite, and in the lithophysal cavities of rhyolites, as in Colorado. It is also a mineral which occurs in tin-bearing pegmatites and in tin veins generally, associated with other pneumatolytic minerals, fluor, cassiterite, and tourmaline.

STAUROLITE (Greek, *stauros*, a cross, and *lithos*, stone).

Comp.—Silicate of iron and aluminium, $H_2O.2FeO.5Al_2O_3.4SiO_2$. MgO and MnO_2 usually present.

Cryst. Syst.—Orthorhombic.

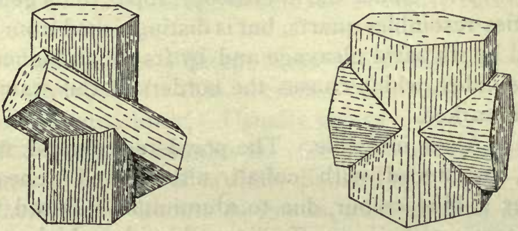
Com. Form.—Occurs in prismatic crystals made up of the prism, brachypinacoid, basal plane, and sometimes the macrodome. The crystals are commonly twinned. Twinning on two laws: the first on a pyramid (Fig. 71), the second on a brachydome (Fig. 72).

Cleav.—Parallel to the brachypinacoid.

Colour.—Reddish-brown, brownish-black, sometimes yellowish-brown.

Streak.—Colourless or greyish.

Lustre.—Subvitreous to resinous; translucent to opaque, usually opaque. Crystals usually have dull, rough surfaces.



FIGS. 71 AND 72.—STAUROLITE TWINS.

Fract.—Conchoidal.

H.—7–7·5. *Sp. Gr.*—3·7.

Tests.—The varieties containing manganese fuse easily to a black magnetic glass, but the other varieties are infusible.

Occurrence.—Staurolite occurs as a mineral of metamorphic origin in clay slates, mica schists, gneisses, etc.

CORDIERITE: Iolite, Dichroite.

Comp.—Silicate of aluminium, iron, magnesium, with water, $H_2O.4(Mg,Fe)O.4Al_2O_3.10SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Short pseudo-hexagonal crystals; usually massive.

Cleav.—Brachypinacoidal; crystals often divisible parallel to the basal plane.

Colour.—Blue of various shades; often deep blue when looked at in one direction, greyish-blue in another direction at right angles, and clear yellow in a third direction at right angles to the other two.

Streak.—Colourless.

Lustre.—Vitreous; transparent to translucent.

Fract.—Subconchoidal; brittle.

H.—7–7·5. *Sp. Gr.*—2·6–2·7.

Tests.—Heated before the blowpipe, loses transparency, and fuses with difficulty on the edges. The glassy appearance is very characteristic, and fusibility on the edges distinguishes it from coloured quartz. It is much softer than sapphire.

Variety—Pinite.—A pseudomorph of cordierite formed by the taking up of water.

Occurrence.—Cordierite occurs chiefly in metamorphic rocks, gneisses (cordierite gneisses), schists, etc. It also occurs as a primary mineral in igneous rocks, granite, basalt, etc.

AXINITE (Greek, *axine*, an axe).

Comp.—Boro-silicate of aluminium and calcium.

Cryst. Syst.—Triclinic.

Com. Form.—Usually in thin and very sharp-edged crystals (see Fig. 38); sometimes, but rarely, massive and lamellar.

Cleav.—Distinct, parallel to the brachypinacoid.

Colour.—Clove brown, plum blue, and pearly grey.

Streak.—Colourless.

Lustre.—Highly vitreous; transparent to subtranslucent.

Fract.—Conchoidal; brittle.

H.—6·5–7. *Sp. Gr.*—3·27.

Tests.—Before the blowpipe, fuses readily with intumescence, and colours the outer flame a pale green.

Not acted on by acids unless previously heated, when it gelatinises.

Occurrence.—Occurs as a mineral of pneumatolytic origin, as at Botallack, Lostwithiel, in Cornwall, etc.

SPHENE: Titanite (Greek, *sphen*, a wedge, in allusion to the form of the crystals).

Comp.—Titanate and silicate of calcium, $CaO.TiO_2.SiO_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals usually wedge or lozenge shape in habit; also massive. Crystals often twinned.

Cleav.—Prismatic.

Colour.—Brown, green, grey, yellow, and black.

Streak.—White.

Lustre.—Adamantine, or resinous; transparent to opaque.

Fract.—Imperfect, conchoidal; brittle.

H.—5–5·5. *Sp. Gr.*—3·54.

Opt. Props.—In rock sections occurs in four-sided lozenge-shape forms, Fig. 73, which are greyish-purple in soda-rich rocks, and brown in soda-poor rocks. Refractive index very high, polarisation colours high, but usually masked by the body colour. Distinctly pleochroic in deeply coloured varieties.

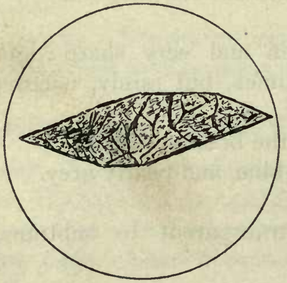


FIG. 73.—SPHENE.

Tests.—Heated before the blowpipe, the yellow varieties remain unaltered in colour, but the dark kinds become yellow. Partly soluble in hot hydrochloric acid; on the addition of tin, the solution will become violet if concentrated.

Varieties—Greenovite.—A sphene containing a little oxide of manganese, and is red or pinkish in colour.

Leucoxene.—A variety of sphene altering from ilmenite and other titaniferous minerals, the alteration taking place usually along three sets of lines making equal angles. Most sections of ilmenite show this alteration under the microscope especially well in reflected light.

Occurrence.—Occurs as an original mineral in acid igneous rocks, granite, syenite, etc. It also occurs in gneisses and metamorphic rocks rich in calcium, and in crystalline limestones. Leucoxene occurs as an alteration product of ilmenite, and other titaniferous minerals.

THE ZEOLITES.

In composition the Zeolites are hydrated silicates of calcium and aluminium, sometimes with sodium or potassium (*cf.* composition of the felspars). They result in general from the alteration of the felspars and aluminous minerals of igneous rocks, and, with the possible exception of analcime, occur only as secondary minerals, filling cavities, joint spaces, cracks and fissures, in such rocks as basalts, scoriaceous lavas, etc. Their formation may represent the final stages in the cooling down of an igneous intrusion, and they are therefore linked up in origin with many ore deposits.

Heated before the blowpipe, the zeolites froth or boil up; hence their name zeolite, from the Greek, *zein*, to boil, and *lithos*, stone. The zeolites are rather soft minerals, their hardness varying from 3·5 to 5·5. Their specific gravities vary from 2 to 2·4. The zeolites are readily recognised by their mode of occurrence.

In this book they are classified into—(1) biaxial, (2) uniaxial, (3) isotropic.

The biaxial zeolites only are considered here, and are divided up by their crystal systems:

1. *Orthorhombic.*—Natrolite, prehnite.
2. *Monoclinic.*—Stilbite, pectolite, laumonite, heulandite, and harmotome.
3. *Triclinic.*—Mesolite.

NATROLITE (Greek, *natron*, soda, and *lithos*, stone): Mesotype.

Comp.—Hydrated silicate of aluminium and sodium, $Na_2O.Al_2O_3.3SiO_2.2H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Small prismatic crystals known. Usually in slender acicular crystals; also massive, compact, granular, fibrous, and radiating.

Colour.—White, sometimes yellowish or reddish.

Streak.—White.

Lustre.—Vitreous or pearly; transparent to translucent.

H.—5–5·5. *Sp. Gr.*—2·2–2·25.

Tests.—Fusible in candle flame; gelatinises with acids.

Occurrence.—Found as a secondary mineral in the amygdules in the basalts of Antrim, Scotland, Bohemia, Auvergne, United States, etc.

PREHNITE.

Comp.—Hydrated silicate of calcium and aluminium, $2Ca_2O.Al_2O_3.3SiO_2.H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Usually found in botryoidal masses, with a radiating crystalline structure.

Colour.—Pale green; sometimes colourless.

Streak.—Colourless.

Lustre.—Vitreous; subtransparent to translucent.

Fract.—Uneven; rather brittle.

H.—6–6·5. *Sp. Gr.*—2·8–2 9.

Tests.—Heated in the closed tube, it gives off water.

Heated before the blowpipe, fuses, with intumescence to a bubbly enamel-like glass. Dissolves in hydrochloric acid without gelatinising.

Occurrence.—Zeolitic (see p. 235).

STILBITE (Greek, *stilbe*, lustre).

Comp.—Hydrated silicate of aluminium, sodium, and calcium, $(Na_2Ca)O.Al_2O_3.6SiO_2.6H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals usually thin, tabular parallel to the clinopinacoid, and compound, being twinned combinations of the unit prisms with clinopinacoid and basal plane. Extremely common in sheaf-like aggregates (see Fig. 74), and in divergent and radiating forms.

FIG. 74.—STILBITE.

Colour.—Usually white, sometimes red, yellow, or brown.

Streak.—Colourless.

Lustre. — On cleavage faces, pearly; elsewhere, vitreous; subtransparent to translucent.

H. 3·5–4. *Sp. Gr.*—2–2·2.

Tests.—Before the blowpipe, fuses with intumescence to a white enamel.

Occurrence.—Typically zeolitic; especially common filling the steam cavities of lavas, as in the basalts of Antrim, etc.

PECTOLITE—(Greek, *pektos*, put together, and *lithos*, stone.)

Comp.—Hydrated silicate of calcium and sodium, $Na_2O.4CaO.6SiO_2.H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Usually occurs in masses composed of divergent or parallel fibres closely compacted.

Colour.—White or greyish.

Lustre.—Silky or subvitreous when fibrous; dull when massive. Subtranslucent to opaque.

H.—5. *Sp. Gr.*—2·6–2·7.

Tests.—Heated in the closed tube, gives off water. Before the blowpipe fuses to a white enamel. Gelatinises with hydrochloric acid.

Occurrence.—Zeolitic (see p. 235); common in amygdules.

LAUMONITE.

Comp.—Hydrated silicate of aluminium and lime, $CaO.Al_2O_3.4SiO_2.4H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Common in prismatic crystals; also fibrous, columnar.

Colour.—White, greyish, or yellowish.

Streak.—Colourless.

Lustre.—Vitreous when unaltered, dull and pulverulent when altered. Transparent to translucent when unaltered, but becomes opaque and white on exposure.

H.—3·5–4. *Sp. Gr.*—2·2–2·3.

Tests.—Before the blowpipe, fuses with intumescence to a white enamel. Gelatinises with hydrochloric acid.

Occurrence.—Zeolitic (see p. 235).

HEULANDITE.

Comp.—Hydrated silicate of calcium and aluminium. $CaO.Al_2O_3.6SiO_2.5H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals with clinopinacoid, and orthodome largely developed; also globular.

Cleav.—Perfect, parallel to the clinopinacoid.

Colour.—White, brick-red, brown.

Streak.—White.

Lustre.—Vitreous; of clinopinacoid, pearly; transparent to subtranslucent.

Fract.—Subconchoidal or uneven; brittle.

H.—3·5–4. *Sp. Gr.*—2·2.

Tests.—Before the blowpipe, intumesces and fuses. Soluble in acids without gelatinisation.

Occurrence.—Zeolitic (see p. 235).

HARMOTOME (Greek, *armos*, a joint, and *temno*, to cut): **Cross-Stone.**

Comp.—Hydrated silicate of aluminium, potassium, and barium, $(K_2,Ba)O.Al_2O_3.5SiO_2.5H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—The crystals are always cruciform penetration twins, much resembling those of stilbite. These may be either simple twins, or they may occur as groups consisting of four individuals. These fourlings sometimes show re-entrant angles, whence the name, cross-stone, or they may present the aspect of a square prism combined with faces of a pyramid, which latter are really prism faces.

Colour.—White, or shades of yellow, grey, etc.

Streak.—White.

Lustre.—Vitreous; subtransparent to translucent.

Fract.—Uneven; brittle.

H.—4–4·5. *Sp. Gr.*—2·3–2·5.

Tests.—Before the blowpipe, whitens, crumbles, and fuses without intumescence to a white translucent glass. Dissolves in hydrochloric acid without gelatinising.

Occurrence.—Zeolitic (see p. 235).

MESOLITE (Greek, *mesos*, middle, and *lithos*, stone).

Comp.—Hydrated silicate of aluminium, lime and soda.

Cryst. Syst.—Triclinic.

Com. Form.—Usually occurs in tufts composed of very delicate acicular crystals; also sometimes massive.

Colour.—White or greyish.

Lustre.—Vitreous; when fibrous or massive, silky. Transparent to translucent; opaque when massive.

H.—5. *Sp. Gr.*—2·2–2·4.

Tests.—Gives off water when heated in the closed tube. With hydrochloric acid, it gelatinises. Before the blowpipe, it becomes opaque and fuses with worm-like intumescence to an enamel.

Occurrence.—Zeolitic (see p. 235).

Uniaxial Silicates.

General Optical Properties of Uniaxial Minerals.

Uniaxial minerals belong to the tetragonal and hexagonal crystal systems. Their form in thin section depends on the shape of the crystal and the direction of the section. Common sections are rectangular or six-sided. Between crossed nicols basal sections are isotropic, and longitudinal sections give straight extinction.

NEPHELINE (Greek, *nephele*, a cloud, because it assumes a clouded appearance when immersed in nitric acid).

Comp.—Silicate of aluminium, sodium, and potassium, $K_2O.3Na_2O.4Al_2O_3.9SiO_2$.

Cryst. Syst.—Hexagonal.

Com. Form.—Hexagonal prism with basal plane, often modified; also massive.

Cleav.—Prismatic, indistinct; basal, imperfect.

Colour.—Colourless, white, yellowish, dark green, brownish, etc.

Lustre.—Vitreous or greasy; transparent to opaque.

Fract.—Subconchoidal.

H.—5·5–6. *Sp. Gr.*—2·5–2·6.

Opt. Props.—In thin sections of rocks nepheline occurs either as hexagonal basal, or square longitudinal sections. The basal sections are isotropic, and the longitudinal sections polarise in low greys. Refractive index is low. Eleolite shows no crystal outline, but can be distinguished by its giving extinction parallel to the alteration cracks which are common in it.

Varieties—Ordinary Nepheline.—Small glassy crystals in lavas.

Eleolite.—A dark-coloured variety, with a greasy lustre; shows no definite crystalline form, but only rough cleavages. It occurs in some syenites.

Tests.—Before the blowpipe, fuses to a colourless glass. Gelatinises with acids.

Occurrence.—Nepheline occurs as an original constituent of volcanic rocks, such as the phonolites, nephelinites, nepheline basalts, etc. The term eleolite is restricted to the massive allotriomorphic varieties of nepheline, occurring as original constituents of plutonic igneous rocks, such as nepheline syenites, etc.

CANCRINITE.

A hydrated silicate of sodium, calcium, and aluminium, with carbon dioxide, occurring as yellow crystals in igneous rocks containing nepheline.

SCAPOLITE (Greek, *scapos*, a club, and *lithos*, stone): Wernerite.

Comp.—The term scapolite includes a number of minerals made up of varying amounts of the two molecules—

Meionite: calcium aluminium silicate, $4CaO.3Al_2O_3.6SiO_2$.

Marialite.—Silicate of sodium and aluminium with sodium chloride, $2NaCl.3Na_2O.3Al_2O._318SiO_2$).

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal and ditetragonal prism, terminated by pyramids; also occurs massive and granular and sometimes columnar.

Cleav.—Prismatic.

Colour.—White, or pale shades of blue, green, and red.

Streak.—Colourless.

Lustre.—Vitreous to pearly, or rather resinous; transparent to nearly opaque.

Fract.—Subconchoidal; brittle.

H.—5–6. *Sp. Gr.*—2·6–2·8.

Opt. Props.—In thin sections it is recognised by its prismatic cleavages, high polarisation colours, and the presence in it of swarms of minute inclusions.

Tests.—Before the blowpipe, fuses with intumescence to a white glass. Imperfectly decomposed in hydrochloric acid.

Occurrence.—Scapolite occurs either in impure limestones, as the result of metamorphism, or in igneous rocks, in which latter case it is usually an alteration product of a basic plagioclase felspar.

IDOCRASE (Greek, *edios*, like, and *crasis*, a mixture; the crystals displaying forms which have been mistaken for those of other minerals): **Vesuvianite.**

Comp.—A basic silicate of calcium and aluminium.

Cryst. Syst.—Tetragonal.

Com. Form.—Prismatic crystals, usually with pyramids and prisms of both orders, and basal plane (see Fig. 25); also massive.

Cleav.—Not very distinct, parallel to faces of the prism; basal cleavage more imperfect still.

Colour.—Brown, green, yellowish.

Streak.—White.

Lustre.—Vitreous or vitrio-resinous; subtransparent to subtranslucent.

Fract.—Subconchoidal or uneven.

H.—6·5. *Sp. Gr.*—3·35–3·45.

Opt. Props.—Thin sections, colour is a pale yellowish-brown; refractive index very high, and polarisation colours very low. Idocrase sometimes shows beautiful zoning.

Tests.—Before the blowpipe, fusible with intumescence, forming a greenish or brownish glass.

Occurrence.—Occurs in impure limestones which have been subjected to metamorphism, associated with grossular-garnet, wollastonite, scapolite, etc., as in the limestone blocks of Monte Somma, Vesuvius.

ZIRCON (Arabic, *zirk*, a precious stone).

Comp.—Silicate of zirconium, $ZrO_2.SiO_2$.

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal prism combined with tetragonal pyramid; forms much resembling those of idocrase (see p. 242), also in rounded grains.

Cleav.—Parallel to faces of the prism, indistinct; to pyramid, still less distinct.

Colour.—Colourless, grey, pale yellow, greenish, reddish-brown.

Streak.—Colourless.

Lustre.—Adamantine; transparent to opaque.

Fract.—Conchoidal.

H.—7·5. *Sp. Gr.*—4·7.

Opt. Props.—Occurs in small prismatic crystals, showing in thin section as square cross sections, or elongated longitudinal sections; the former being isotropic, and the latter polarising in very high colours The refractive index of zircon is very high, causing the mineral to have an intense black border.

Varieties—Hyacinth.—Transparent and red.

Jargoon.—Colourless and smoky tinted.

Zirconite.—Grey or brown.

Tests.—Before the blowpipe alone, infusible; but the coloured varieties become colourless and transparent when heated. When powdered and fused with sodium carbonate, and the product dissolved in dilute hydrochloric acid, the solution turns turmeric paper orange colour (presence of zirconium).

Occurrence.—Occurs as a primary mineral in igneous rock, especially the more acid, granite, nepheline syenite, etc. It is also found in crystalline limestones, gneisses, and schists. It is also found in alluvial deposits associated with precious stones and gold.

TOURMALINE (Cingalese, *turamali*).

Comp.—Boro-silicate of aluminium. Three types of composition may be given, as—(1) Alkali tourmaline, containing NaK or Li; (2) magnesium tourmaline, containing AlMg; (3) iron tourmaline (common tourmaline) containing Al and Fe. Intermediate varieties occur.

Cryst. Syst.—Hexagonal, rhombohedral (see p. 77).

Com. Form.—Hexagonal prism, with trigonal prism, terminated by rhombohedra (see Fig. 32). Sometimes occurs massive and compact, also columnar. Opposite terminations of crystals usually dissimilar.

Cleav.—Rhombohedral; difficult.

Colour.—Commonly black or bluish-black; more rarely blue, green, and red, and very rarely colourless; colours sometimes arranged in zones about the vertical axis of crystals.

Streak.—Colourless.

Lustre.—Vitreous; transparent to opaque.

Fract.—Subconchoidal or uneven; brittle.

H.—7–7·5. *Sp. Gr.*—2·98–3·2.

Opt. Props.—Under the microscope tourmaline occurs either as three- or six-sided cross-sections, or as badly terminated longitudinal sections, or else in groups of radiating needles. Colour usually dark brown, green, or yellow. Pleochroism very well marked. Pleochroic haloes, common. The refractive index is high, and the polarisation colours are fairly high, giving rather bright colours.

Tests.—Before the blowpipe, dark varieties intumesce and fuse with difficulty; red and green varieties only become milk-white and fuse slightly on the edges.

Varieties—Rubellite.—Red or pink, and transparent; sometimes cut as a gem.

Indicolite.—Indigo blue variety.

Brazilian Sapphire.—Berlin blue and transparent; cut as a gem.

Brazilian Emerald.—Green and transparent.

Peridot of Ceylon.—Honey yellow.

Schorl.—Black, opaque variety, occurring as aggregates of needle-like or columnar crystals, as in the granites of Cornwall.

Occurrence.—Occurs as an accessory mineral in many granites, syenites, and the more acid igneous rocks generally. It occurs also in pegmatite dykes, and as a product of pneumatolytic action. It may occur associated in veins with lead and cobalt minerals; also occurs in metamorphic rocks—such as mica schists, clay slates, and crystalline limestones; in detrital deposits also.

Uses.—Some varieties used as gem stones.

BERYL (Persian name *belur;* Latin, *beryllus*).

Comp.—Silicate of beryllium and aluminium, $3BeO.Al_2O_3.6SiO_2$.

Cryst. Syst.—Hexagonal.

Com. Form.—Crystals common, often of large size, one from Royalston, in Massachusetts, being said to weigh nearly two and a half tons, and to measure 45 by 24 inches in diameter and 1 foot in length. Crystals made up of hexagonal prism, pyramid, and basal plane (see Fig. 75 and p. 74). Also found massive, crystalline.

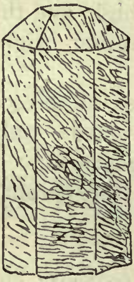


Fig. 75.—Beryl.

Cleav.—Parallel to the basal plane, indistinct.

Colour.—Emerald green and pale green (emerald), pale blue (aquamarine), yellow, white.

Streak.—White.

Lustre.—Vitreous or resinous; transparent to subtranslucent. Coarse kinds opaque.

Fract.—Conchoidal or uneven; brittle.

H.—7·5–8. *Sp. Gr.*—2·7.

Tests.—Before the blowpipe alone beryl and its varieties become clouded, otherwise remain unaltered, except that after protracted heating the edges of splinters become rounded.

Varieties—Emerald.—Emerald green and pale green.

Aquamarine.—Pale blue.

Beryl.—The coarse kinds which are, from their opacity, unfit for jewellery.

Occurrence.—Beryl occurs as an accessory mineral in acid igneous rocks, granites, and pegmatites, in the druses of which large crystals often project, as in the Mourne Mountain granite. It is also found in metamorphic rocks, schists, and crystalline limestones. The gem varieties come from Brazil, India, and Siberia.

UNIAXIAL ZEOLITES.

Introduction.—See p. 235.

UNIAXIAL ZEOLITES.

Apophyllite	... ...	Tetragonal.
Chabazite	... ...	Hexagonal.

APOPHYLLITE (Greek, *apophullizo*, to exfoliate; because it exfoliates before the blowpipe).

Comp.—Hydrated silicate of calcium and potassium, $8CaO.K_2O.16SiO_2.16H_2O$.

Cryst. Syst.—Tetragonal.

Com. Form.—Crystals of two habits: first, combinations of second order prism and basal plane, giving forms with a cube-like aspect; and, second, prismatic crystals made up of the second order prism, and first order pyramid, or of pyramid alone. Also occurs massive and foliated.

Cleav.—Basal and highly perfect.

Colour.—Milky white to colourless, greyish; sometimes greenish, yellowish, or reddish.

Streak.—Colourless.

Lustre.—Vitreous; that of basal plane, pearly. Transparent to translucent; rarely opaque.

Fract.—Uneven; brittle.

H.—4·5–5. *Sp. Gr.*—2·3–2·4.

Tests.—Heated in closed tube, gives off water, exfoliates, and whitens. Before the blowpipe, exfoliates and fuses to a white vesicular enamel; colours the flame violet (presence of potassium). Soluble in hydrochloric acid, with separation of silica.

Occurrence.—Typically zeolitic (see p. 235).

CHABAZITE (Greek, *chabazios*, the name of a stone mentioned in an old Greek poem).

Comp.—Hydrated silicate of aluminium, calcium, and potassium, $(Ca,Na_2)O.Al_2O_3.4SiO_2.6H_2O$.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Combinations of plus and minus rhombohedra; also massive.

Colour.—White, yellowish, reddish.

Lustre.—Vitreous; transparent to translucent.

H.—4–4·5. *Sp. Gr.*—2·06–2·17.

Tests.—Before the blowpipe, intumesces, whitens, and fuses to a glass. Gelatinises with acid.

Variety—Phacolite (Greek, *phacos*, a bean, and *lithos*, stone).—A variety of chabazite occurring in colourless, lenticular crystals.

Occurrence.—Typically zeolitic (see p. 235).

Isotropic Silicates.

General Optical Properties of Isotropic Minerals.—These minerals belong to the cubic system. Their form in thin sections depends upon their crystal form and the direction of section. They show no pleochroism, and between crossed nicols are normally isotropic, except, as in leucite and garnet, when polarisation colours are produced by strain in the mineral.

THE GARNETS.

Introduction.—The garnets (Latin, *granatus*, grain-like) are essentially silicates of various divalent and trivalent metals. Their general formula is—$3R''O,R'''_2O_3.3SiO_2$, where R'' is calcium, magnesium, iron, or manganese, and R''' is iron, aluminium, or chromium. The following are the principal members of this group:

1. *Grossular.*—Calcium aluminium garnet, $3CaO.Al_2O_3.3SiO_2$.
2. *Pyrope.* — Magnesium aluminium garnet, $3MgO.Al_2O_3.3SiO_2$.
3. *Almandine.*—Iron aluminium garnet, $3FeO.Al_2O_3.3SiO_2$.
4. *Spessartite.*—Manganese aluminium garnet, $3MnO.Al_2O_3.3SiO_2$.
5. *Andradite.* — Iron calcium garnet, $3CaO.Fe_2O_3.3SiO_2$.
6. *Uvarovite.*—Calcium chromium garnet, $3CaO.Cr_2O_3.3SiO_2$.

Crystallography of Garnets.—The garnets all crystallise in the cubic system, and occur as rhombohedra or trapezohedra, or as combinations of these forms (see Figs. 76 and 77). Garnets occur very rarely in one or two other cubic forms.

Optical Properties of Garnets.—In thin section garnet occurs in somewhat rounded crystals, traversed by branching cracks, and having no cleavage. The colour most usually seen is a slight tinge of pink. The refractive index is very high, giving the crystals well-marked borders and a pitted surface. Between crossed nicols the mineral is normally isotropic, though sometimes strain polarisation is shown.

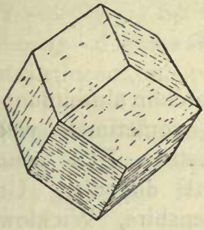


FIG. 76.—RHOMBDODECAHEDRON.

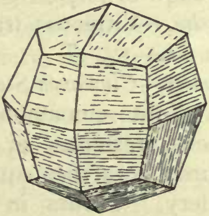


FIG. 77.—TRAPEZOHEDRON.

In hardness, the garnets range from 6·5–7·5, and in specific gravity from 3·5–4·2. Their streak is always white or whitish, and the fracture subconchoidal or uneven.

Occurrence.—Garnets occur in crystalline limestones and dolomites; in intrusive and especially in metamorphic rocks, such as mica schist, chlorite schist, gneiss, etc., and they are also met with in granite and syenite.

Uses.—Garnet is mined from metamorphic rocks in the United States and elsewhere, and is used as an abrasive. Some varieties are cut for gemstones.

VARIETIES OF GARNETS.

1. GROSSULAR (Latin, *grossula*, a gooseberry).

Comp. — Calcium aluminium silicate, $3CaO.Al_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron.

Colour.—Pale olive green, or greenish-white; occasionally yellow or pink.

Lustre.—Vitreous; translucent.

Sp. Gr.—3·5.

Variety—Cinnamon Stone.—A calcium aluminium garnet of a light cinnamon colour, sometimes yellowish. Vitreous, resinous, or dull lustre. Flat conchoidal fracture; scratches quartz with difficulty. Used in jewellery. Occurs in Aberdeenshire, Wicklow, and elsewhere.

Occurrence. — Grossular is characteristic of metamorphosed impure limestones, in which it occurs associated with other lime silicates, idocrase, scapolite, etc.

2. PYROPE (Greek, *puropos*, fiery).

Comp.—Magnesium aluminium silicate, $3MgO.Al_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Rarely crystallised; usually in rounded or angular fragments.

Colour.—Deep crimson or mulberry colour.

Lustre.—Vitreous; transparent to translucent.

Fract.—Conchoidal.

H.—7·5. *Sp. Gr.*—3·7.

Occurrence.—Pyrope occurs in basic igneous rocks associated with olivine, serpentine, etc., as in Saxony, Bohemia; also in detrital deposits, as in Ceylon.

3. ALMANDINE (precious garnet).

Comp.—Iron aluminium silicate, $3FeO.Al_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Combination of rhombdodecahedron and trapezohedron.

Colour.—Deep red.

Lustre.—Vitreous.

Fract.—Subconchoidal, or uneven.

H.—6·5–7·5. *Sp. Gr.*—3·9–4·2.

Variety—Common Garnet.—A brownish-red, translucent, subtranslucent, or opaque variety, similar in composition to the above.

Occurrence.—Common garnet is an extremely frequent mineral in metamorphic rocks, mica schists, and gneiss; also in granites. In detrital deposits, as in Ceylon.

4. SPESSARTITE.

Comp.—Manganese aluminium silicate, $3MnO.Al_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron.

Colour.—Deep hyacinth, or brownish-red.

Lustre.—Vitreous; slightly translucent on the edges.

Fract.—Imperfectly conchoidal.

H.—7–7·5. *Sp. Gr.*—4·2.

Tests.—Gives manganese reaction before blowpipe.

Occurrence.—A rather rare garnet occurring in granites, andesites, and some schists.

5. ANDRADITE (common garnet).

Comp.—Calcium iron silicate, $3CaO.Fe_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron and trapezohedron.

Colour.—Dark brown, yellowish-green, or brownish-green.

Lustre.—Vitreous; opaque.

H.—Over 7. *Sp. Gr.*—3·85.

Varieties — Colophonite. — A coarse granular variety, with a resinous lustre, and of a dark reddish or brownish colour. Named after Kolophon, a city in Ionia, whence resin was obtained.

Pyreneite. — A black or greyish-black variety. Generally occurs in small opaque rhombdodecahedra. Occurs in limestone in the Pyrenees, whence the name.

Melanite (Greek, *melas*, black). — A black variety, either dull or with a vitreous lustre.

Topazolite.—A transparent yellow or green iron-like variety.

Occurrence.—Andradite occurs in igneous and metamorphic rocks of all kinds.

6. UVAROVITE.

Comp. — Calcium chromium silicate, $3CaO.Cr_2O_3.3SiO_2$.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron.

Colour.—Emerald green.

Streak.—Greenish-white.

Lustre.—Vitreous; translucent at the edges.

H.—7·5. *Sp. Gr.*—3·5.

Tests.—Before the blowpipe, infusible alone. Gives a clear chrome green borax bead.

Occurrence.—In the Urals, in serpentines rich in chromium.

LEUCITE (Greek, *leukos*, white): **White garnet, Amphigene.**

Comp.—Silicate of aluminium and potassium, $K_2O.Al_2O_3.4SiO_2$.

Cryst. Syst.—Cubic at 500° C. When heated to that temperature, double refraction and other anomalous optical properties disappear. At ordinary temperatures it is double refracting, and the angles are approximately those of a tetragonal form.

Com. Form.—Crystals are in forms resembling that of the trapezohedron (see Fig. 77); also in disseminated grains.

Cleav.—Very imperfect.

Colour.—White or ashy grey.

Streak.—Colourless.

Lustre.—On fractured surfaces, vitreous; translucent to opaque.

Fract.—Conchoidal; brittle.

H.—5·5–6. *Sp. Gr.*—2·5.

Opt. Props. — Leucite shows rounded water-clear crystals, sometimes containing inclusions symmetrically arranged (see Fig. 78). Its refractive index is below that of Canada balsam, and, although usually isotropic, it may show polarisation colours due to strain (see above).

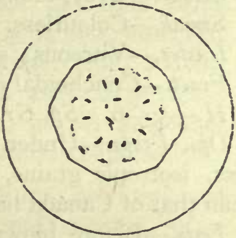


FIG. 78.—LEUCITE.

Tests.—Infusible before blowpipe; gives blue aluminium coloration when heated with cobalt nitrate in the oxidising flame. Soluble in hydrochloric acid without gelatinisation.

Occurrence.—Leucite occurs as a primary constituent of volcanic rocks, and usually in fresh or recent types, such as the Vesuvian lavas, and in leucite basalts, leucite phonolites, leucite tephrites, leucitophyres, and leucitites. Leucite and nepheline are the principal members of the felspathoid group, which differs from the felspars chemically by a lower percentage of silica. Free quartz and a felspathoid never occur therefore in a rock together.

SODALITE (soda; and Greek, *lithos*, stone.)

Comp.—Silicate and chloride of sodium and aluminium, $3NaAlSiO_4.NaCl$.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron; also occurs massive.

Cleav.—Rhombdodecahedra.

Colour.—Grey, bluish, lavender blue, yellowish.

Streak.—Colourless.

Lustre.—Vitreous; subtransparent to translucent.

Fract.—Conchoidal or uneven.

H.—5·5–6. *Sp. Gr.*—2·2.

Opt. Props.—Under the microscope occurs in colourless, isotropic grains, having a refractive index lower than that of Canada balsam.

Tests.—Before blowpipe, fuses with intumescence to a colourless glass. Decomposed by hydrochloric and nitric acids, with separation of gelatinous silica.

Occurrence.—Occurs in soda-rich igneous rocks, nepheline syenite, etc.

LAPIS LAZULI: Lazurite.

Comp.—Silicate of aluminium and sodium, with probably sodium sulphide.

Cryst. Syst.—Cubic.

Com. Form.—Cubes and rhombdodecahedra rare; usually massive and compact.

Cleav.—Imperfect rhombdodecahedral.

Colour.—Berlin blue or azure blue.

Lustre.—Vitreous; translucent to opaque.

Fract.—Uneven.

H.—5·5. *Sp. Gr.*—2·38–2·45.

Tests.—Fuses with intumescence to a white glass. Decomposed by hydrochloric acid with evolution of sulphuretted hydrogen, a gelatinous deposit of silica being left. The mineral is often spangled with iron pyrites.

Occurrence.—It is found in crystalline limestone, also in syenites, etc.

Uses.—It is cut and polished for ornamental purposes, but is too soft to be much used in jewellery. Ancient Egyptian amulets carved in this material are common. When powdered, lazurite constitutes the blue paint ultramarine. Most of the ultramarine is now, however, artificially prepared by heating together clay, sodium carbonate, and sulphur; and as the artificial pigment costs only about one-fiftieth the price of the powdered mineral, the latter has been almost entirely superseded.

Hauyne.—A silicate of aluminium, calcium, and sodium, with sulphate of sodium and calcium, of a bright blue or greenish-blue colour, with a colourless streak, and a vitreous or somewhat greasy lustre. It crystallises in the cubic system in small octahedra and rhombdodecahedra, but usually occurs in rounded or subangular grains embedded in lava, vesicular basalt, trachyte, etc., as at Vesuvius, etc. Optical properties, see below under Nosean.

Nosean.—Allied to hauyne, but consists only of silicate of aluminium and sodium with sodium sulphate.

It is usually of a greyish or brown colour. It occurs in some phonolites.

Under the microscope, nosean and hauyne are recognised by their well-marked borders due to inclusions. Hauyne is blue in thin section. Both minerals are, of course, isotropic.

ISOTROPIC ZEOLITES.

Introduction.—See p. 235.

ANALCIME (Greek, *analkis*, weak; in allusion to its weak electricity when heated or rubbed).

Comp. — Hydrated silicate of sodium, $Na_2O.Al_2O_3.4SiO_2.2H_2O$.

Cryst. Syst.—Cubic.

Com. Form.—Crystals, the trapezohedron very common (see Fig. 77); also occurs massive and granular.

Cleav.—Cubic; obscure.

Colour.—Milk white; often colourless, greyish, greenish, and reddish-white or pink.

Streak.—White.

Lustre.—Vitreous; transparent to nearly opaque.

Fract.—Subconchoidal and uneven; brittle.

H.—5–5·5. *Sp. Gr.*—2·22–2·29.

Opt. Props.—Recognised by its isotropism, and refractive index lower than that of Canada balsam. Strain polarisation may be shown.

Tests.—Heated in closed tube, yields water. Before blowpipe on charcoal, fuses to a clear, colourless globule. Gelatinises with hydrochloric acid.

Occurrence.—Typical zeolitic (see p. 235). Sometimes regarded as a primary mineral of some dolerites.

Amorphous Silicates.

Glauconite (Greek, *glaukos*, sea-green).—Amorphous, granular, or earthy. Occurs extensively disseminated in small grains in the chalk marl, chloritic marl, and greensands of England, and also in rocks much older than these (Comley sandstone, etc.).

In colour, olive-green, yellowish, greyish, and blackish-green. Lustre, dull or glistening; opaque. Hardness, 2; specific gravity, 2·2–2·4. In composition glauconite is essentially a hydrated silicate of iron and potassium, though aluminium, magnesium, and calcium are often present. Before the blowpipe, fuses easily to a dark magnetic glass, and gives off water when heated. Besides its occurrence in geological beds, it also occurs in oceanic sediments in actual process of formation.

Meerschaum (see p. 220).

II. METALLIC MINERALS.

The distinction between "metallic" and "non-metallic" minerals is not an ideal one, but as it is so universally met with, it is considered advisable here to retain the distinction, in spite of the fact that some element of doubt exists as to the group into which certain minerals more naturally fall.

High specific gravity and metallic lustre are sometimes stated to be characteristic of metallic minerals, but most of the minerals usually included do not show both these characters. Molybdenite, dialogite, realgar, blende, calamine and malachite, all fail to exhibit them, and the mere mention of the names is sufficient to demonstrate the fact that the distinction is unsatisfactory. But these minerals would be still less satisfactorily placed with those generally called non-metallic, and they are therefore described in their usual places with the metallic minerals. Again, such minerals as rock salt, fluor-spar, barytes and bauxite have a case for inclusion as metallic minerals, but they are so much at home in the non-metallic division that few mineralogists would attempt to evict them.

TITANIUM (Ti).

Titanium has not been found in a free state in nature. It is a greyish metal, and resembles tin in its chemical properties, and, like that metal, is capable of forming two oxides: TiO and TiO_2. Only the latter occurs in nature, and constitutes the three minerals:

Rutile, TiO_2	Tetragonal.
Anatase, TiO_2	Tetragonal.
Brookite, TiO_2	Orthorhombic.

Titanium occurs in some silicates, the chief of which is sphene, $CaO.TiO_2.SiO_2$ (see p. 234).

Titanium oxide occurs in some of the iron ores; for example, ilmenite is an oxide of iron and titanium, and many magnetites contain varying quantities of titanium, giving the titaniferous magnetites. These titaniferous iron ores will be described under the heading of Iron, since they are worked for that metal. Some small amount of titanium is used in the metallurgy of steel, the titaniferous iron ore being sometimes smelted in the electro-furnace direct for the production of ferro-titanium alloys.

The oxide of titanium rutile is not applied to any industrial purposes, except for imparting a pinkish colour to artificial teeth, and a yellow colour to porcelain; certain qualities fetch a high price on the market.

Titanium metal has a limited application in the manufacture of special steels and for electric lamps.

Tests.—Titanium minerals colour the microcosmic bead yellow when hot, colourless when cold, in the oxidising flame; and yellow hot, violet cold, in the reducing flame. Titanium minerals, when fused with sodium carbonate on charcoal, dissolved in hydrochloric acid, and a few grains of tin added, give a violet solution. The best test for titanium, however, is as follows: Heat the mineral with sodium carbonate on charcoal and dissolve the mass in sulphuric acid, to which has been added an equal quantity of water. Cool, dilute with water. On the addition of a drop of hydrogen peroxide, the solution becomes amber coloured.

TITANIUM OXIDES.

The minerals which consist of titanium oxide are three in number: Rutile (tetragonal), anatase (tetragonal), and brookite (orthorhombic).

RUTILE.

Comp.—Titanium oxide, TiO_2.

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal prisms terminated by pyramids. Di-tetragonal forms also developed. Crystals frequently acicular, and radiately grouped in the interior of other minerals, especially in quartz. Crystals at times twinned on the second order pyramid (101), giving forms bent at a sharp angle, called geniculate or knee-shaped twins. Twinning may be repeated until wheel-shaped multiple twins result. Crystals often striated longitudinally. Also compact and massive.

Cleav.—Poor parallel to the prisms (110) and (100).

Colour.—Reddish-brown, red, yellowish, and black. In thin section foxy red.

Streak.—Pale brown.

Lustre.—Metallic, adamantine, opaque, or subtransparent.

Fract.—Subconchoidal or uneven ; brittle.

H.—6–6·5. *Sp. Gr.*—4·2.

Tests.—Alone infusible. Microcosmic bead, in oxidising flame yellow hot, colourless cold ; in reducing flame, yellow hot, violet cold. Fused mass dissolved in sulphuric acid, then diluted with water, gives, with a drop of hydrogen peroxide, an amber-coloured solution.

Occurrence.—Rutile occurs as a primary mineral in acid igneous rocks ; also in metamorphic rocks—gneisses, mica-schists and phyllites (clay slate needles). As acicular crystals in quartz and felspar (sagenitic inclusions). As grains in alluvial deposits resulting from the destruction of acid igneous rocks. As an alteration product of other titaniferous minerals.

ANATASE : Octahedrite (Latin, *anatasis*, erection, in reference to the length of the principal axis).

Composed of titanium oxide, but though tetragonal, differs from rutile by crystallising in slender, nearly transparent tetragonal pyramids of a brown colour, passing into indigo blue and black ; also in tabular crystals with the basal plane prominent. Hardness, 5·5–6. Specific gravity, 3·82–3·95. Colourless streak. Never primary, but alters from titanium minerals. Occurs in granite, dolerite, schist, shales, sandstone, and limestone.

BROOKITE

Also consists of titanium oxide, but, unlike rutile and anatase, crystallises in the orthorhombic system. It occurs mostly in thin, platy, hair-brown, reddish, and iron-black crystals, tabular parallel to the macropinacoid. Hardness, 5·5–6. Specific gravity, 4. It is brittle, and has a colourless streak. Occurrence as for anatase ; for instance, it is common in rotten dolerites as at Tremadoc, in North Wales. It also occurs in Bavaria, Norway, and Brazil.

Other Titanium Minerals:

Ilmenite, $FeO.TiO_2$ (see p. 333).
Perofskite, $CaO.TiO_2$.
Sphene or Titanite, $CaO.TiO_2.SiO_2$ (see p. 234).

THORIUM (Th).

Thorium is a metal related to titanium, has the colour of nickel, and a specific gravity of 11. The metal has no industrial application, but the oxide is of great commercial importance. This is chiefly used in the manufacture of incandescent mantles; it also enters into the construction of Nernst lamps, and is used in medicine.

The most important mineral is monazite, which is essentially a phosphate of the cerium earths, but it invariably contains a certain proportion of thoria. The mineral was formerly obtained from the United States (chiefly from North Carolina), but since 1910 the market has been supplied from Brazil. The mineral occurs as a constituent of the seashore sand (monazite sands) near the town of Prado, in the south of the State of Bahia, and at various parts of the coasts of the States of Espirito Santo and Rio de Janeiro. The concentrate from such sands contains 5 to 7 per cent. thoria. Less important inland deposits yield monazite with 4 to 5·7 per cent. thoria. The exports for 1912 were 3,398 metric tons.

In recent years the State of Travancore (Madras) has become an important producer of monazite. In 1912 the exports were 1,135 tons. The mineral from this locality is richer in thoria than that of Brazil, the oxide rising to 14 per cent. in selected specimens.

The mineral is also recorded from Nigeria, Nyassaland, Ceylon, and Malaya, and these localities may become commercially important. In Nigeria and Malaya it forms a by-product in the final dressing of alluvial tin-ore.

Monazite sands usually consist of monazite naturally concentrated with other heavy minerals, such as magnetite, rutile, ilmenite, zircon, garnet, etc. Separation is effected by electro-magnetic separators, the magnets of which are adjusted to varying intensities. Magnetite and ilmenite are first removed, and monazite, usually the most feebly magnetic, last. Rutile, zircon, and siliceous matter pass into the reject. The manufacture of the thoria from the separated monazite is a complicated and purely chemical operation.

When found in quantity, thorianite is a valuable source of thoria, but only in Ceylon is it produced on a commercial scale.

THORIANITE.

Comp.—$ThO_2U_3O_8$.
Cryst. Syst.—Cubic.
Com. Form.—Cube.
Colour.—Black.
Streak.—Black.
Sp. Gr.—9·3.

THORITE.

Comp.—$ThSiO_4$.
Cryst. Syst.—Tetragonal.
Colour.—Black.
Streak.—Dark brown.
Lustre.—Vitreous on fresh surfaces.
Cleav.—Prismatic.
Fract.—Conchoidal.
H.—4·5. *Sp. Gr.*—4·5.

MONAZITE.

Comp.—Phosphate of the cerium metals with thorium silicate.

Cryst. Syst.—Monoclinic.

Com. Form.—Complex crystals, commonly flattened parallel to 100 or elongated along the ortho-axis. Twinned on 100. Both contact and penetration twins are known. Also occurs massive or as rolled grains.

Colour.—Pale yellow to dark reddish-brown.

Streak.—White.

Lustre.—Resinous.

Cleav.—Basal; usually imperfect.

Fract.—Conchoidal or uneven.

H.—5·5. *Sp. Gr.*—5.

Opt. Props.—Refractive index, 1·81. Double refraction positive, ·045; op. ax. pl. perpendicular to 010 and nearly parallel to 100.

It occurs in granites and pegmatites, but on a commercial scale it is obtained only from sands where a certain amount of natural concentration has gone on.

TUNGSTEN (W).

Tungsten is not found native, but is produced in the form of a greyish-black powder, which has a specific gravity of about 17.

The name tungsten was first used by Cronstedt, and signifies "heavy stone."

The chief ore is wolfram, which is usually associated with tinstone, and for a long time the separation of these minerals was a matter of some difficulty. It is effected both by electromagnetic separation, and by roasting the crushed ore with sodium carbonate, by which operation sodium tungstate is formed, and the tin ores can be removed. In the case of several tin-mining companies the presence of wolfram enables profits to be made, which but for the "mixed minerals" would be impossible.

Tungsten ores (chiefly wolfram) appear on the market in the form of concentrates, varying between 60 per cent.

and 70 per cent. tungstic acid (WO_3), and are purchased on the basis of their tungstic acid content. Seventy per cent. material is exceptionally good quality, and grades lower than 60 per cent. are saleable, but are subject to penalisation.

The world's production of tungsten ores in 1912 amounted to rather over 8,000 tons of concentrates, estimated, for the purposes of calculation, at an average of 60 per cent. WO_3. Burma and the Shan States produced about 1,800 tons, Portugal about 1,300 tons, and the United States about 1,200 tons. The 1912 production was the largest in any one year. There does not appear to be any slackening in the demand.

Uses, etc.—The chief use of tungsten (either as metallic tungsten, or in the form of ferro-tungsten alloys produced in the electric furnace) is for tool steels. Other uses are for the manufacture of electric filaments. Tungsten salts are used as mordants and for fire-proofing purposes.

Two oxides of tungsten are known—WO_2 and WO_3. WO_3 is known by the name of tungstic acid, and from it are formed various salts called tungstates, several of which occur as minerals. Tungstic acid, WO_3, occurs as the mineral tungstic ochre, found as an alteration product of the mineral tungstates. The tungsten minerals are—

Oxide ...	... Tungstic ochre, WO_4
Tungstates ...	Wolfram $(Fe,Mn),WO._3$
	Hubnerite, $MnWo_4$.
	Ferberite (Reinite), $FeWO_4$.
	Scheelite, $CaWO_4$.

Tests.—Tungsten salts colour the microcosmic bead blue in the reducing flame. Tungsten minerals, fused with sodium carbonate and dissolved in hydrochloric acid, give, on the addition of a small piece of tin or zinc, a blue solution when heated.

Tungstic Ochre, Tungstite, Wolframine.

This occurs in a pulverulent and earthy condition, and results from the alteration of ores of tungsten. It is of a bright yellow or yellowish-green colour, and is composed of pure tungstic oxide, WO_3. Before the blowpipe, infusible alone, but becomes black in the inner flame. In the oxidising flame, with microcosmic salt, it affords a colourless or yellowish bead, which in the reducing flame becomes violet when cold. Tungstic ochre is soluble in alkaline solutions, but not in acids.

WOLFRAM (Swedish, Wolfrig, Eating, from its admixture with tin ores, formerly diminishing the amount of tin in the smelting).

Comp.—Tungstate of iron and manganese, $(FeMn)WO_4$.

Cryst. Syst.—Monoclinic.

Com. Form.—Prismatic crystals, commonly tabular; also massive and bladed, the latter being very characteristic.

Cleav.—Perfect parallel to the clinopinacoid.

Colour.—Chocolate brown, dark greyish-black, reddish-brown.

Streak.—Chocolate brown.

Lustre.—Submetallic, brilliant shining on cleavage faces, dull on others and on fractures; subtransparent to opaque.

Fract.—Uneven.

H.—5–5·5. *Sp. Gr.*—7·1–7·9.

Tests.—Fusible. Microcosmic bead reddish, borax bead green. Heated with sodium carbonate and carbon, fused mass treated with hydrochloric acid and powdered tin, gives a blue solution. Characterised by streak, cleavage, and the two lustres.

Allied Species—Hubnerite, $MnWO_4$, usually contains some iron. Like wolfram in appearance.

Ferberite (Reinite), $FeWO_4$.

Occurrence.—Wolfram occurs in pneumatolytic veins surrounding granite masses, as in Cornwall (St. Austell), Zinnwald, Malay, Bolivia, etc. Associated minerals are tinstone and quartz. The disintegration of these tin-wolfram veins results in the formation of alluvial or placer tin and wolfram deposits; such deposits are worked in many of the localities mentioned above. Wolfram may also be found as a metasomatic deposit, replacing limestone.

SCHEELITE.

Comp.—Tungstate of calcium, $CaWO_4$.

Cryst. Syst.—Tetragonal.

Com. Form.—Crystals are tetragonal pyramids, variously modified by other and less symmetrical pyramidal faces. Usually occurs reniform, with a columnar structure; also massive and granular.

Cleav.—Perfect parallel to the pyramid.

Colour. — Yellowish - white or brownish, sometimes almost orange-yellow.

Streak.—White.

Lustre. — Vitreous, inclined to adamantine; transparent to translucent.

Fract.—Uneven, brittle.

H.—4·5–5. *Sp. Gr.*—5·9–6·1.

Test.—Tungsten reaction in borax bead, blue in reducing flame. The fused mass obtained by heating on charcoal with sodium carbonate and charcoal, when dissolved in hydrochloric acid and tin added, gives a blue solution.

Occurrence.—Scheelite occurs under the same circumstances as wolfram and hubnerite—that is, in veins associated with tinstone, quartz, topaz, and other minerals of pneumatolytic origin, as at Caldbeck Fell (Cumberland), Cornwall, Zinnwald, Harz, Saxony, Dragon Mountains (Arizona), and Trumbull (Connecticut).

TANTALUM (Ta).

Tantalum metal is produced by means of the electric furnace. It is a hard, white, ductile metal of great tensile strength, having a specific gravity of 16·8 and a melting-point of 2,250° to 2,300° C. Its industrial uses, which are small at present, include the manufacture of small laboratory crucibles, electric filaments, and for special steels, such as dental and surgical instruments. For the addition to steel it is more usual to employ ferro-tantalum alloys, which are made from tantalite in the electric furnace. The only source of any commercial importance is the mineral tantalite which is sold on a basis of 60 per cent. Ta_2O_5, and which is chiefly obtained from the neighbourhood of Greenbushes, in Western Australia, where it also occurs in association with tin-stone and wolfram. Probably not more than 100 tons in all have been exported, and since 1909 none has there been mined owing to the small demand.

A part of the tantalum in tantalite is almost invariably replaced by the closely allied metal *columbium* (niobium), and when the amount of the latter exceeds the former, the mineral is known under the name of columbite (niobite).

TANTALITE: Columbite.

Comp.—Niobate and tantalate of iron and manganese.

Cryst. Syst.—Orthorhombic.

Com. Form.—Occurs as elongated crystals with several prisms, macro and brachypinacoids, one or more pyramids, macro and brachydomes, and basal pinacoid. The most common twin plane is a face of the brachydome (021). Often massive.

Colour.—Black, grey, or brown. Sometimes iridescent.

Streak.—Dark red to black.

Lustre.—Submetallic to subresinous.
Cleav.—100 and 010. The former is the more perfect.
Fract.—Subconchoidal to uneven.
H.—6. *Sp. Gr.*—5·3–7·3.

MOLYBDENUM (Mo).

Molybdenum does not occur in a free state in nature, but may be prepared from its sulphide (molybdenite) direct in the electric furnace, or by the reduction of its oxide by means of carbon, or by the Thermit process (see under Aluminium). The metal has a specific gravity of about 9, melts at about 2,000° C., and is white or greyish, and brittle. Molybdic acid (MoO_3) is sometimes met with as the mineral molybdine or molybdic ochre, and results from the surface alteration of other molybdenum minerals. Molybdic acid forms salts known as molybdates; wulfenite is lead molybdate, $PbMoO_4$. Molybdic acid is employed only in the laboratory. Ammonium molybdate is a special reagent for the detection of phosphoric acid, a small quantity added to an acid solution containing phosphates producing after some time a yellow precipitate; also used in making explosives.

The principal use of molybdenum is in the manufacture of special steels, and for this purpose ferro-molybdenum alloy is frequently used in place of the metal. Molybdenite (MoS_2) is the only source of importance, and ores containing it can be readily concentrated by a combination of table-dressing and oil-flotation. It is a widely distributed ore, but frequently occurs in small veins, or very finely scattered through the rock. Molybdenite concentrates are usually sold at so much per unit on a basis of 90 to 95 per cent. MoS_2, but sales of lower grades can be effected. The world's production of molybdenite probably does not amount to more than a few hundred tons annually, but the demand appears to be increasing. Its chief source is Australia, notably Queensland.

The minerals of molybdenum are—

Oxide	Molybdine, molybdic ochre, MoO_3.
Sulphide ...	Molybdenite, MoS_2,
Lead molybdate	Wulfenite, $PbMoO_4$ (see p. 317).

Tests.—When heated on charcoal, molybdenum compounds give in the oxidising flame a white encrustation, which becomes blue where touched by the reducing flame. Molybdenum compounds colour the microcosmic bead yellow when hot, colourless when cold, in the oxidising flame; the bead is green in the reducing flame.

Molybdine, Molybdic Ochre, Molybdite, Molybdena.

Comp.—Molybdic oxide, MoO_3.

Cryst. Syst.—Orthorhombic.

Com. Form.—Occurs as an earthy powder or encrustation, or as silky, fibrous, and radiating crystallisations.

Colour.—Straw yellow or yellowy-white.

Lustre.—Silky to adamantine; of amorphous forms, earthy and dull.

H.—1-2. *Sp. Gr.*—4·5.

Tests.—Microcosmic bead green, heated alone on charcoal, white encrustation, yellow while hot, copper red round assay; blue when touched with reducing flame.

Occurrence.—Occurs as an oxidation product of molybdenite.

MOLYBDENITE.

Comp.—Molybdenum sulphide, MoS_2.

Cryst. Syst.—May be hexagonal.

Com. Form.—Usually in scales; also massive, foliated, and sometimes granular.

Cleav.—One cleavage perfect basal; laminæ flexible, but not elastic.

Colour.—Lead grey.

Streak.—Greenish lead grey (*cf.* Graphite).

Lustre.—Metallic, opaque, sectile, and almost malleable.

H.—1–1·5, easily scratched by finger-nail. *Sp. Gr.*—4·44–4·8.

Tests.—Heated in tube, fumes of sulphur dioxide; yellow-green flame. Heated on charcoal yields a strong sulphurous odour, coats charcoal with encrustation of molybdenum oxide, which is yellow hot, white cold. White encrustation blue where touched with reducing flame, copper red near assay; microcosmic bead green.

Occurrence.—Found in pegmatite dykes and quartz veins, as at Quebec, Canada; Norway, and New South Wales. Original, or as an impregnation; as a mineral of contact metamorphism also.

Use.—For steel hardening.

URANIUM (U).

Uranium, which is not found native, is a hard, white metal, having a specific gravity of 18·7, and melting at a white heat. It is a constituent of the rare minerals, pitchblende (uraninite) and carnotite, which form the chief sources of uranium. Metallic uranium is prepared by reduction of its oxide with carbon in the electric furnace, but it is commercially of but little importance. In fact, pitchblende and carnotite are practically worked solely for their content of radium, which is contained in all uranium minerals.

Uranium forms two oxides, and from these a complex group of uranium salts is derived. The uses of the oxides as such are very limited, chiefly in glass-staining and photography.

There is practically no market for uranium, but the demand for radium is on the increase, and the minerals are valued according to their percentage of U_3O_8, which always carries a definite proportion of radium. The sources of the minerals are few. The United States are stated to have produced in 1912 carnotite equivalent to about 25 tons of U_3O_8 from the deposits of Colorado and Utah. Some pitchblende is obtained from Cornwall and Australia, but the principal source is Joachimsthal, in Bohemia.

The chief uranium minerals are—

Oxides ...	Uranic ochre, U_2O_3. Pitchblende, U_3O_4.
"*Uranites*" ...	Torbernite, $CuO.2UO_3.P_2O_5.8HO$. Autunite, $CaO.2UO_3.P_2O_5.8H_2O$.
Vanadate ...	Carnotite, vanadate of U and K.

Tests.—In the microcosmic bead, uranium compounds give a light moss green colour, both hot and cold, in the oxidising flame.

PITCHBLENDE : Uraninite.

Comp.—Very variable. May be considered as a uranate of uranium (uranyl), together with thorium, zirconium, lead, etc. Specific names — clevite, broggerite, etc.— have been given to pitchblendes of varying compositions.

Cryst. Syst.—Cubic.

Com. Form.—Commonly occurs massive, botryoidal or in grains.

Colour.—Velvet black, greyish or brownish.

Lustre.—Submetallic, greasy, pitchlike and dull ; opaque.

Streak.—Black, often with a brownish or greenish tinge.

H.—5·5. *Sp. Gr.*—6·4 (massive) to 9·7 (crystallised).

Tests.—Before the blowpipe, alone, infusible. With sodium carbonate it is not reduced, but usually gives an encrustation of lead oxide, and may evolve an arsenical odour. With borax or microcosmic salt it gives in the oxidising flame a yellow, and in the reducing flame a green bead of uranium. Dissolves slowly in nitric acid when powdered.

Occurrence.—Uraninite occurs as a primary constituent of igneous rocks, granites and pegmatites; or in veins of lead, tin, and copper minerals, as at Joachimsthal (Bohemia) and Johanngeorgenstadt (Saxony), and at many localities in Cornwall and elsewhere.

Uses.—The pitchblende of Joachimsthal is the chief source of radium.

Uranic Ochre, Uranochre, Uraconite.—A hydrated sulphate of uranium, occurring in an earthy pulverulent condition at Joachimsthal, Cornwall, Callington, etc. It is of a lemon-yellow or orange colour.

Zippeite.—A variety of the above mineral, but contains more sulphuric acid, and sometimes over 5 per cent. of copper oxide. It occurs in delicate acicular crystals, rosettes and warty crusts, and accompanies uranic ochre. Before the blowpipe, with microcosmic salt, it gives in the oxidising flame a yellowish-green, and in the reducing flame an emerald-green bead.

Carnotite.—A vanadate of uranium and potassium, found as an impregnation in sandstone in Colorado. In colour it is canary yellow. It is of importance as a source of radium.

URANITE.

This name embraces two species:

1. Torbernite, copper uranite, $CuO,2UO_3.P_2O_5.8H_2O$. Tetragonal.
2. Autunite, lime uranite, $CaO,2UO_3.P_2O_5.8H_2O$. Orthorhombic.

TORBERNITE: Copper Uranite.

Comp.—Hydrated phosphate of copper and uranium, $CuO,2UO_3,P_2O_5.8H_2O$.

Cryst. Syst.—Tetragonal.

Com. Form.—Square, thin, tabular crystals, often modified on the edges; also scaly and foliated.

Cleav.—Perfect parallel to the basal plane, giving extremely thin lamellæ, and in this respect resembling mica, whence the name *uran-mica*, by which the mineral is sometimes called. The laminæ are brittle and not flexible, and in this respect they differ from the laminæ of mica; sectile.

Colour.—Emerald or grass green.

Streak.—Rather paler than the colour.

Lustre.—Subadamantine, pearly on cleavage planes; transparent to subtranslucent.

H.—2–2·5. *Sp. Gr.*—3·4–3·6.

Tests.—Heated in closed tube, yields water. Soluble in nitric acid. Heated alone, fuses to a blackish mass, and colours the flame green. Microcosmic bead green.

Occurrence.—Occurs with other uranium minerals at Joachimsthal, Cornwall, Schneeberg, and elsewhere.

AUTUNITE: Lime Uranite.

Comp.—Hydrated phosphate of calcium and uranium, $CaO,2UO_3,P_2O_5,8H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Crystals resemble those of torbernite (*q.v.* above), the crystals being nearly square; also foliated and micaceous.

Cleav.—Perfect parallel to base. Thin brittle laminæ result.

Colour.—Citron to sulphur yellow.

Streak.—Yellowish.

Lustre.—Subadamantine, or cleavage faces pearly.

H.—2–2·5. *Sp. Gr.*—3·05–3·19.

Tests.—Gives no reaction for copper, otherwise its behaviour with reagents resembles that of torbernite (*q.v.* above).

Occurrence.—As for torbernite.

CHROMIUM (Cr).

Chromium, never found in nature except in combination, is produced by reduction of its ores by carbon in the electric furnace, or by the Thermit process described under Aluminium. It is a brilliant white metal, having a specific gravity of about 6, and melting at about 2,000° C. It possesses the properties of imparting to iron and steel a high degree of hardness and tenacity, and for that reason has become in recent years of great industrial importance. For this purpose an alloy of iron and chromium (ferro-chrome, produced in the electric furnace), is commonly used; it is cheaper to make, melts at a lower temperature, and is consequently better under control than the pure metal. The compounds of chromium are also of considerable industrial importance, and are used as pigments and in various industries, such as dyeing, tanning, and photography. Chromite is also used in the manufacture of refractory bricks for furnace linings.

The chief source of chromium is chromite (chrome iron ore), an oxide of iron and chromium, $FeO.Cr_2O_3$. The world's production of chromite is probably under 200,000 tons annually; the principal producing countries in order of importance are New Caledonia, Rhodesia, Russia and Greece.

Tests.—Chromium compounds produce a fine green colour in both borax and microcosmic beads.

CHROMITE: Chromic Iron, Chrome Iron Ore.

Comp.—Oxide of iron and chromium, $FeO.Cr_2O_3$.

Cryst. Syst.—Cubic.

Com. Form.—Occurs in octahedrons, but is commonly found massive, having a granular or compact structure.

Colour.—Iron black and brownish-black.

Streak.—Brown.

Lustre.—Submetallic, often faint.

Fract.—Uneven, sometimes rather flat; brittle.

H.—5·5. *Sp. Gr.*—4·3–4·5.

Tests.—Infusible in oxidising flame, while in the reducing flame it only becomes slightly rounded on the edge of splinters, which on cooling are magnetic. Reduced on charcoal to magnetic oxide. Borax and microcosmic beads, beautiful chrome-green. This colour may be rendered more intense by fusion on charcoal with metallic tin.

Occurrence.—Chromite occurs as a primary mineral of ultrabasic rocks, peridotites, and their altered representatives, serpentines. Usually, the chromite occurs as small grains, but by the segregation of these grains ore bodies may be formed, as those of Norway, Rhodesia, Smyrna, and New Caledonia. These ore bodies consist of a peridotite extremely rich in chromite. Being very obdurate, chromite occurs in detrital deposits.

MANGANESE (Mn).

Manganese does not occur in uncombined state in nature, but may, like chromium, be produced in the electric furnace and by the Thermit process (see under Aluminium). It is a light, pinky-grey metal, melting at about 1,900° C., and having a specific gravity of about 7·5.

Uses, etc.—The chief application of manganese is in the manufacture of alloys, such as spiegel-eisen and ferro manganese, containing from 15 to 80 per cent. manganese, and silico-manganese, containing from 15 to 25 per cent. silicon, all of which are used, and are of great importance, in the steel industry.

The chief sources of manganese and its salts are the oxide minerals. Pyrolusite is also used, as such, for a number of purposes, such as the decolorisation of glass, as a dryer in the manufacture of paint and varnish, and in dry batteries, and very largely for the manufacture of chlorine, bromine, and oxygen, of permanganates and other manganese compounds. The permanganates of sodium and potassium are used as disinfectants.

For chemical uses a high percentage of manganese in the form of peroxide is demanded, 80 per cent. Mn being taken as the basis price. Lime should be present in quantities less than 2 per cent. For metallurgical purposes 50 per cent. Mn is a common basis. Ores of iron containing manganese are smelted direct for the production of manganese pig-iron, but such ores should be regarded as iron ores, and the manganese would not be paid for except at the same rate as iron.

The world's production of manganese ores amounts to about 3,000,000 tons annually. The chief producers are India, Russia, Brazil, and Germany.

Manganese is very widely distributed, and replaces to a greater or lesser degree two sets of elements: First, the alkaline earths, calcium, barium, and magnesium; and secondly, aluminium and iron. Purely manganese minerals of the greatest importance are the oxides, others are the carbonate, silicate, and sulphide. Manganese minerals are therefore

Oxides	Hausmannite, Mn_3O_4.
	Braunite, Mn_2O_3.
	Manganite, $Mn_2O_3.H_2O$.
	Pyrolusite, MnO_2.
	Polianite, MnO_2.
	Psilomelane, hydrated oxide with Ba and K.
	Wad, like psilomelane.
	Asbolane, cobaltiferous wad.
Carbonate ...	Dialogite, $MnCO_3$.
Silicate	Rhodonite, $MnSiO_3$.
Sulphide ...	Alabandite, MnS.

Manganese minerals occur in very varied ways. Dialogite and rhodonite occur as veinstones in some silver lodes, the gossan of which carries the oxide minerals, pyrolusite, psilomelane, etc. Dialogite also occurs as a metasomatic replacement of limestones. The most important and interesting deposits of manganese, however, are those of the oxides of sedimentary, or residual origin, as described below.

Occurrence of Oxides of Manganese.—The oxides of manganese — pyrolusite, psilomelane, polianite, wad, braunite, hausmannite, and manganite — occur as sedimentary deposits, or as residual deposits. In the first type the manganese has been precipitated in beds or layers of nodules together with iron compounds (with which it is invariably associated), a process at the present time being carried on in the deep sea. By the upraising of these deep-sea deposits are formed many of the bodies of workable manganese. Another of this class of manganese deposits is formed by precipitation of manganese oxides in lakes, etc., by the action of minute plants, giving rise to the bog-manganese deposits, as in Sweden, Spain, and the United States.

The second type of manganese deposit is formed by the alteration of rocks containing manganese-bearing minerals, silicates, etc. By the weathering of such rocks, the manganese aggregates together as nodules and layers in the residual clay, which forms on the outcrop of weathered rock. Thus is formed a residual or lateritic deposit; such deposits are worked in India, Brazil, and Arkansas. It will be seen that all deposits of manganese oxides have been formed by the breaking up of the manganese-bearing minerals of igneous and metamorphic rocks.

By the metamorphism of sedimentary or residual manganese deposits there are formed workable deposits of hausmannite, braunite, and franklinite, as in Sweden, Piedmont, and at Franklin Furnace, U.S.A.

Tests. — Manganese minerals give distinctive bead reactions. The borax and microcosmic-salt beads are reddish-violet in the oxidising flame and colourless in the reducing flame. The sodium-carbonate bead is bluish-green.

PYROLUSITE (Greek, *pur*, fire, and *luo*, to wash, from its power of removing the green and brown tints from common glass).

Comp.—Manganese dioxide, MnO_2.

Cryst. Syst.—May be orthorhombic, usually pseudomorphous.

Com. Form.—Occurs in pseudomorphs after manganite, polianite, etc. Usually occurs massive or reniform, and sometimes with a fibrous and radiate structure.

Colour.—Iron grey or dark steel grey.

Streak.—Black or bluish-black, sometimes submetallic.

Lustre.—Metallic; opaque.

Fract.—Rather brittle.

H.—2–2·5; often soils the fingers. *Sp. Gr.*—4·8.

Tests.—Borax bead; amethyst in oxidising flame, colourless in reducing flame. Microcosmic bead, red-violet in oxidising flame. Sodium carbonate bead, opaque blue-green.

Occurrence.—See p. 277.

Uses.—See p. 276.

Polianite.—Manganese dioxide, MnO_2. Hardness, 6–6·5. Specific gravity, 5. Like pyrolusite in appearance and colour. Sometimes shows minute tetragonal crystals; isomorphous with tinstone, SnO_2. Occurrence as for other oxides of manganese.

PSILOMELANE (Greek, *psilos*, smooth, and *melas*, black).

Comp.—Hydrated oxide of manganese, with or without varying amounts of barium and potassium.

Form.—Amorphous.

Com. Form.—Amorphous, massive, botryoidal, reniform, and stalactitic (see Fig. 79).

Colour.—Iron black, passing into dark steel grey.

Streak.—Brownish-black and shining.

Lustre.—Submetallic, looks as if an attempt had been made to polish the mineral; opaque.

H.—5–6. *Sp. Gr.*—3·7–4·7.

Tests.— Heated in closed tube, gives water. With borax and microcosmic beads, gives the usual amethyst-coloured bead. Soluble in hydrochloric acid with evolution of chlorine.

FIG. 79.—PSILOMELANE.

Occurrence.—See p. 277.

Uses.—See p. 276

WAD (in allusion to the wadding-like form sometimes assumed by the mineral. The name "wad" is applied to graphite in Cumberland).

Comp.—Very variable, but resembling that of psilomelane.

Com. Form.—Amorphous, earthy, reniform, arborescent, encrusting, or as stains and dendrites. Often loosely aggregated.

Colour.—Dull black, bluish, lead grey, brownish-black.

Lustre.—Dull; opaque.

H.—5–6; usually quite soft. *Sp. Gr.*—3–4·28.

Tests.—Before the blowpipe, gives the usual manganese reactions with the fluxes.

Varieties—Earthy Cobalt, Asbolan.—A variety of wad, containing sometimes as much as 32 per cent. of cobalt oxide.

Lampadite.—Another variety, which yields sometimes as much as 18 per cent. of copper oxide.

Occurrence.—Wad results from the decomposition of other manganese minerals, and generally occurs in damp, low-lying places (see p. 277).

Uses.—Not as valuable as the two preceding minerals, but is sometimes used in the manufacture of chlorine, and also serves for umber paint (see also p. 276).

Hausmannite.

Comp.—Manganese oxide, Mn_3O_4.

Cryst. Syst.—Tetragonal.

Com. Form.—Commonly occurs in pyramidal forms; frequently twinned. Also massive and granular.

Colour.—Brownish-black.

Streak.—Chestnut brown.

Lustre.—Submetallic; opaque.

Fract.—Uneven.

H.—5–5·5. *Sp. Gr.*—4·72.

Tests.—Usual manganese reactions with the fluxes.

Occurrence.—See p. 277.

Braunite.

Comp.—Oxide of manganese, Mn_2O_3, usually with about 10 per cent. of silica; may therefore be considered as a silicate of manganese.

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal crystals; also occurs massive.

Colour.—Brownish-black.

Streak.—Brownish-black.

Lustre.—Submetallic.

Fract.—Uneven; brittle.

H.—6–6·5. *Sp. Gr.*—4·75–4·82.

Tests.—Usual manganese reactions (see p. 278); also gelatinises when boiled with hydrochloric acid.

Occurrence.—In veins. Also see p. 277.

Uses.—See p. 276.

Manganite.

Comp.—Hydrated manganese oxide, $Mn_2O_3.H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, often grouped in bundles, and striated longitudinally; also columnar.

Colour.—Iron black or dark steel grey.

Streak.—Reddish-brown or nearly black.

Lustre.—Submetallic; opaque.

Fract.—Uneven.

H.—4. *Sp. Gr.*—4·2–4·4.

Tests.—Heated in closed tube, gives water. Gives usual manganese reactions with the fluxes.

Occurrence.—See p. 277.

DIALOGITE (Greek, *dialoge*, doubt).

Rhodochrosite (*rhodon*, a rose; *chrosis*, colour).

Comp.—Manganese carbonate, $MnCO_3$; often with varying quantities of the carbonates of iron, calcium, and magnesium.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Crystals rare, rhombohedral; also massive, globular, botryoidal, or encrusting.

Cleav.—Parallel to the faces of the rhombohedron—*i.e.*, in three directions.

Colour.—Various shades of rose red, yellowish-grey, and brownish.

Streak.—White.

Lustre.—Vitreous, inclining to pearly; translucent to subtranslucent.

Fract.—Uneven; brittle.

H.—3·5–4·5. *Sp. Gr.*—3·45–3·6.

Tests.—Before blowpipe, infusible, but changes to grey-brown and black, and decrepitates strongly. Gives the usual manganese amethystine colour to the borax or microcosmic beads. Dissolves with effervescence in warm hydrochloric acid. On exposure to the air, the red varieties lose colour.

Occurrence.—Occurs as a veinstone in lead and silver-lead ore veins; also as a metasomatic replacement of limestones.

RHODONITE (Greek, *rhodon*, a rose): **Manganese Spar.**

Comp.—Manganese silicate, $MnO.SiO_2$. Some oxide of iron, calcium, magnesium, or zinc, usually present. Some carbonate usually present, causing it to effervesce with acid.

Cryst. Syst.—Triclinic.

Com. Form.—Tabular crystals; commonly massive and cleavable.

Cleav.—Perfect parallel to prism.

Colour.—Flesh red, light brownish-red, greenish or yellowish when impure, and often black on exposed surfaces. Colour darkens on exposure, often becomes nearly black from additional oxidation of the manganese.

Streak.—White.

Lustre.—Vitreous; transparent to opaque; usually translucent or opaque.

Fract.—Uneven; occasionally conchoidal; very tough when massive.

H.—5·5.–6·5. *Sp. Gr.* 3·4–3·6.

Tests.—Before blowpipe, blackens and fuses with slight intumescence. In the oxidising flame gives a manganese reaction with borax and microcosmic salt.

Variety—Fowlerite.—A variety containing zinc.

Occurrence.—Occurs as a veinstone in lead and silver-lead veins (as at Broken Hill, N.S.W.), associated with dialogite and quartz.

Uses.—Rhodonite, when cut and polished, is sometimes used for ornamental inlaid work. It may also be used for imparting a violet colour to glass; and on stoneware, when mixed with the common salt glazing, it forms a black or, if sparingly used, a deep violet-blue glaze.

ARSENIC (As).

Arsenic is found native, usually associated with other metals; in combination it is very widely distributed, and occurs in most pyritic minerals and in sulphur. It is usually obtained from mispickel (arsenical pyrites) by distillation in retorts. Resublimed arsenic is an extremely brittle, steel-grey metal of a brilliant lustre, and having a specific gravity of 5·7. It is employed in small quantities in the manufacture of shot and certain alloys, but its chief use is as the oxide "white arsenic" or arsenious acid (As_2O_3) in the manufacture of insecticides, and for use in glass-making, pigments, and "anti-fouling" compositions. In Cornwall and Devon white arsenic is refined from the volatilised crude oxide or "soot," obtained by roasting mispickel or tin and other ores. In the United States it is chiefly obtained as a by-product from the smelting of copper ores.

Complete statistics of the world's production of arsenic, are not available, but in 1912 it probably amounted to about 8,000 tons, of which England produced 2,200 tons, and the United States about 3,000 tons.

The economically important minerals of arsenic are mispickel (FeAsS) and realgar (AsS). Arsenides and sulpharsenides are very common as minerals. Briefly, it may be stated that arsenic deposits are of four main types: (1) Mispickel deposits bedded with schists; (2) mispickel as veins with Sn (Cornwall, Bohemia); (3) realgar and orpiment as a gossan of mispickel (Transylvania, China); (4) sulpharsenides of Ni, Co, Cu, Pb (Freiberg, Sudbury, and Harz).

The chief arsenic minerals are therefore—

Element... ...	Native arsenic, As.
Oxide	White arsenic, As_2O_3.
Sulphides ...	Orpiment, As_2S_3. Realgar, AsS.
Sulpharsenides ...	Mispickel, FeAsS. Cobaltite, CoAsS.
Arsenides ...	Kupfernickel, NiAs. Smaltite, $CoAs_2$.

Tests.—Arsenic compounds, when heated on charcoal, give a white encrustation far from the assay, and at the same time fumes having a garlic odour are emitted. Heated in the open tube, arsenic compounds give a white sublimate. Heated in the closed tube with sodium carbonate, a black arsenic mirror is formed.

NATIVE ARSENIC.

Comp.—Arsenic, As; often with some antimony, and traces of other metals.

Cryst. Syst.—Rhombohedral.

Com. Form.—Often occurs granular, massive, and reniform, and sometimes columnar and stalactitic.

Colour.—On recent fractures, tin white, but quickly tarnishes to a dark grey.

Streak.—Tin white.

Lustre.—Nearly metallic.

Fract.—Uneven and granular; brittle.

H.—3·5. *Sp. Gr.*—5·93.

Tests.—Before the blowpipe, volatilises without fusing, emitting poisonous fumes, with the odour of garlic.

Occurrence.—Native arsenic principally occurs in veins associated with lead and silver ores, as at Freiberg in Saxony, Joachimsthal in Bohemia, etc.

WHITE ARSENIC: Arsenolite, Arsenious Acid.

An arsenic mineral having the composition, arsenic oxide, As_2O_3. Crystallises in the cubic system. It is not a substance of common occurrence in nature, but is sometimes met with in white, fine, capillary crystals or crusts, resulting from the decomposition of arsenical ores. It is, however, extensively manufactured, and possesses high poisonous properties.

ORPIMENT (Latin, *auri pigmentum*, golden paint).

Comp.—Arsenic trisulphide, As_2S_3.

Cryst. Syst.—Monoclinic.

Com. Form.—Usually occurs foliated or massive.

Cleav.—Highly perfect, parallel to clinopinacoid. laminæ flexible, but not elastic; sectile.

Colour.—Fine lemon yellow.

Streak.—Yellow.

Lustre.—Pearly and brilliant on faces of cleavage, elsewhere resinous or dull; subtransparent to subtranslucent.

H.—1·5–2. *Sp. Gr.*—3·4–3·5.

Tests.—Heated in closed tube, reddish-yellow sublimate. Heated on charcoal, white sublimate far from assay, with smell of garlic. Heated in open tube, white sublimate and garlic smell.

Occurrence.—Occurs in veins associated with antimony ores, as at Kapnik in Transylvania, Koordistan in Asiatic Turkey, etc. It also occurs as a deposit from some hot springs, as at Steamboat Springs, Nevada, etc., and as a sublimate from volcanoes at Naples, etc.

REALGAR.

Comp.—Arsenic sulphide, AsS.

Cryst. Syst.—Monoclinic.

Com. Form.—Prismatic crystals, rare; usually occurs massive and granular.

Colour.—Fine red, or orange.

Streak.—Red or orange.

Lustre.—Resinous; transparent to translucent.

Fract.—Conchoidal or uneven.

H.—1·5–2. *Sp. Gr.*—3·5.

Tests.—As for orpiment (see above, p. 285).

Occurrence.—Occurs associated with orpiment, to which mineral it changes on exposure. Occurs as deposits from hot springs and as a volcanic sublimate. Common in veins, where it may occur as nests or nodules in clay, or associated with cinnabar, as in Tuscany, Galicia, and Spain.

MISPICKEL: Arsenical Pyrites, Arseno-Pyrite.

Comp.—Sulpharsenide of iron, FeAsS. In some varieties cobalt is present, replacing some of the iron, from mere traces up to 9 per cent.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prism, mostly terminated by horizontally striated planes of the brachydome; also massive.

Cleav.—Parallel to faces of prism.

Colour.—Tin white, or silver white, inclined to steel grey, and tarnishing pale copper colour on exposure.

Streak.—Dark greyish-black.

Lustre.—Metallic.

Fract.—Uneven; brittle. Gives sparks when struck with steel, and then emits odour of garlic.

H.—5·5–6. *Sp. Gr.*—6·3.

Tests.—Before the blowpipe, gives rise to arsenical fumes, and fuses to a globule, which is attracted by the magnet. In closed tube, gives first the red sublimate of arsenic sulphide, and second the black sublimate of native arsenic; with hydrochloric acid, gives sulphur.

Occurrence.—Occurs in tin, copper, and especially lead and silver veins. Examples of the pneumatolytic veins (tin and copper) are those of Cornwall, Tavistock, Botallock, Dolcoath, etc.; of the hydatogenetic veins (lead and silver), are those of Andreasberg, Przibram, and Saxony.

ANTIMONY (Sb).

Antimony in a free state is of extremely rare occurrence. The chief source of the metal is the sulphide, stibnite (antimonite), Sb_2S_3, which is widely distributed, but found in workable quantities in comparatively few localities. Metallic antimony is a tin white, very brittle metal, with a crystalline structure. It has a specific gravity of 6·7, and melts at 630° C. For the production of the metal, the sulphide, freed from its gangue by liquation, is reduced in reverberatory furnaces, or the crude ore is volatilised in a blast furnace, and the condensed fumes reduced in reverberatory furnaces. On the market the liquated sulphide is called "crude antimony," while the metal is called "regulus of antimony." The first quality of refined antimony is known as "star antimony," owing to the fernlike markings on its surface. The chief use of antimony is in the production of alloys, such as type and anti-friction metals and pewter. Its compounds are used in pigments and in medicine. Antimony ore is usually sold on a 50 per cent. basis, gold and silver being paid for by some smelters, more particularly in France, where the volatilisation process is employed. Antimonial lead ores, free from gold and silver, are commonly smelted direct for "hard" or "antimonial lead." There are no accurate statistics published, but the world's production of metal probably amounted to somewhere round 16,000 tons in 1912. China is the largest producer, other sources of ore and metal being France, Austria-Hungary, Italy, Japan, Portugal, etc. None is produced in the United States.

The minerals of antimony are of three types: Firstly, the sulphide, antimonite, Sb_2S_3; secondly, the oxides; thirdly, the sulphantimonides. Antimony minerals are then—

Element	Native antimony, Sb.
Oxides	Senarmontite, Sb_2O_3 (cubic). Valentinite, Sb_2O_3 (orthorhombic). Cervantite, $Sb_2O_3.Sb_2O_5$.
Sulphide	Antimonite, Sb_2S_3.
Oxysulphide	Kermesite, $2Sb_2S_3.Sb_2O_3$.
Sulphantimonides	Jamesonite, $2PbS.Sb_2S_3$. Famatinite, $3Cu_2S.Sb_2S_5$ (see p. 353). Bournonite, $3(Pb,Cu_2)S.Sb_2S_3$ (see p. 353), etc.

The oxides occur as weathered products of the sulphide ores; sulphide antimony deposits occur chiefly as veins.

Tests.—Antimony compounds heated on charcoal give a white encrustation near the assay; heated in the open tube, give a white sublimate near the assay; and heated with sodium carbonate in the closed tube, give a red-brown sublimate, which is black when hot.

NATIVE ANTIMONY.

Comp.—Antimony, Sb; sometimes with traces of silver, iron, or arsenic.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Usually occurs massive and granular, or lamellar.

Cleav.—Basal; highly perfect.

Colour.—Tin white.

Streak.—Tin white.

Lustre.—Metallic; opaque.

Fract.—Uneven; very brittle.

H.—3–3·5. *Sp. Gr.*—6·6–6·7.

Tests.—Before the blowpipe, fuses easily, giving off white fumes of antimonious oxide, which condense and form a white encrustation on the charcoal near the assay.

Occurrence.—Occurs associated with stibnite in veins.

ANTIMONITE, STIBNITE: **Antimony Glance, Grey Antimony.**

Comp.—Antimony trisulphide, Sb_2S_3.

Cryst. Syst.—Orthorhombic.

Com. Form.—Elongated prisms striated longitudinally on the lateral plane. Commonly found in masses having a columnar structure; sometimes granular (see Fig. 80).

Cleav.—Very perfect parallel to brachypinacoid.

Colour.—Lead grey.

Streak.—Lead grey.

Lustre.—Metallic; liable to tarnish, and sometimes iridescent on the surface.

Fract. — Subconchoidal; sectile; brittle, but thin lamellæ, slightly flexible.

H.—2. *Sp. Gr.*—4·5–4·6.

Tests.—Heated in open tube, antimonite gives off antimonous and sulphurous fumes, the former condensing as a white non-volatile sublimate, while the latter may be recognised by the odour. On charcoal, fuses and gives a white encrustation near the assay; also fuses easily in the flame of a candle.

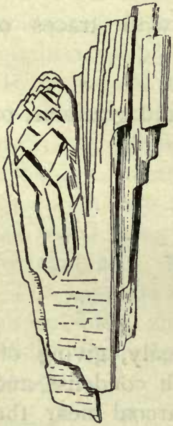


FIG. 80.—ANTIMONITE.

Occurrence.—Occurs in veins associated with other antimony ores, and having quartz, dolomite, calcite, or barytes, as a veinstone, as in Cornwall, Westphalia, Saxony, etc.

Uses.—Antimonite is the chief source of the antimony of commerce. Antimonite has long been used in Syria for darkening the eyelids.

JAMESONITE.

Comp.—Sulphide of lead and antimony, $2PbS.Sb_2S_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Acicular crystals, often with feather-like forms (plumosite, or feather ore); also fibrous or massive.

Cleav.—Perfect, basal.

Colour.—Dark lead grey.

Streak.—Greyish-black.

Lustre.—Metallic.

H.—2–3. *Sp. Gr.*—5·5–6.

Tests.—Antimony reactions in open tube. Heated on charcoal with sodium carbonate and charcoal, gives metallic bead of lead. Soluble in hydrochloric acid, precipitate of lead chloride being formed on cooling.

Occurrence.—Occurs with antimonite in Cornwall, etc.

Kermesite. Red Antimony, $2Sb_2S_3.Sb_2O_3$. Colour red, results from alteration of antimonite.

Cervantite, $Sb_2O_3.Sb_2O_5$. Yellow.

Senarmontite, Sb_2O_3. White.

Valentinite, Sb_2O_3.

BISMUTH (Bi).

Bismuth occurs in the free state in nature, often associated with silver, gold, copper, lead, and other metals. It is a greyish-white metal, with a slightly reddish tinge, lustrous, and very brittle, and having a specific gravity of 9·8, and melting at 264° C. Bismuth is obtained by smelting its ores in small reverberatory furnaces or crucibles. The main source is native bismuth, but it is also found in the anode slimes, from the electrolytic refining of copper and lead. The market for bismuth is very uncertain, and there are no reliable statistics of production available, but it may be taken as somewhere round 400 tons in 1912, of which probably two-thirds came from Bolivia. Other sources are Australia, Peru, and Spain. The uses of bismuth are limited. Fusible metal is an alloy of bismuth, lead, and tin, which melts at 94·5° C. Bismuth salts are used in medicine.

The minerals of bismuth are—

Element ...	Native bismuth, Bi.
Oxide ...	Bismuth ochre, bismuthite, Bi_2O_3.
Sulphide ...	Bismuthine, Bi_2S_3.

The oxide occurs as a weathering product of the other ores. The sulphide is found in veins associated with tin (Bolivia); the native metal is associated with cobalt (Schneeberg).

Tests.—Bismuth compounds, when heated on charcoal with sodium carbonate and charcoal, give a brittle, metallic bead. Heated with potassium iodide and sulphur, bismuth compounds give an encrustation, yellow near the assay, scarlet in the outer parts. Solutions of bismuth salts become milky on the addition of water, owing to the formation of insoluble basic compounds, which are redissolved on the addition of acids.

NATIVE BISMUTH.

Comp.—Bismuth, Bi. Sometimes with traces of sulphur, arsenic, and tellurium.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Occurs in rhombohedra, much resembling cubes in form. Usually found massive, foliated, or granular; also in reticulated or plumose forms.

Cleav.—Parallel to the faces of the rhombohedron, and perfect.

Colour.—Silver white, with a faint tinge of red.

Streak.—Silver white.

Lustre.—Metallic; easily tarnishes; opaque.

Fract.—When cold, brittle; when heated, it is somewhat malleable; sectile.

H.—2–2·5. *Sp. Gr.*—9·7–9·8.

Tests.—Heated on charcoal, native bismuth fuses and volatilises, forming an orange-red encrustation. When fused in a ladle, it crystallises readily. Dissolves in nitric acid with solution becoming milky when water is added. Heated on charcoal with potassium iodide and sulphur, gives a brilliantly coloured encrustation, yellow near assay, scarlet farther away.

Occurrence.—Occurs in veins associated with tin and silver minerals, also with pyrites, copper pyrites, quartz, etc., as in Bolivia, etc.

Uses.—This is the only ore from which the bismuth of commerce is procured in any quantity.

Bismuthine.

Comp.—Bismuth sulphide, Bi_2S_3.

Cryst. Syst.—Orthorhombic.

Comp. Form.—Small, needle-like crystals; sometimes massive.

Colour.—Lead grey, yellowish, tarnish common.

Lustre.—Metallic.

H.—2. *Sp. Gr.*—6·4–6·5.

Tests.—Before blowpipe, fuses easily; on charcoal with potassium iodide and sulphur, gives yellow and bright red encrustation. Sulphurous fumes in open tube. Soluble in nitric acid, a white precipitate being formed on addition of water.

Occurrence.—Occurs in veins associated with copper and lead minerals, as in Cornwall, Cumberland, and Saxony.

Tetradymite.—Bismuth telluride (see p. 295).

Bismuth Ochre.—A yellow, earthy, bismuth oxide (Bi_2O_3), occurring as an alteration product of bismuth and bismuthine.

TELLURIUM (Te).

Tellurium is found in small quantities, free in nature in pyrites and sulphur. It is mostly found combined with metals as tellurides, such metals being bismuth, lead, and, most important, gold and silver. Tellurium is also found with selenium in the anode slime from electrolytic copper refineries. When pure, tellurium has a greyish-white colour and a metallic lustre. It has a specific gravity of 6·3, melts at 450° C., and boils at 1,400° C. Its industrial applications are few.

The tellurium minerals are—

Element	Native tellurium, Te.
Oxide	Telluric ochre.

Tellurides ...	Tetradymite (bismuth). Hessite (silver). Calaverite (gold). Sylvanite, petzite (gold and silver).
Sulphtelluride ...	Nagyagite (gold and lead).

The tellurides are extremely important sources of gold, and occur as veins, impregnations, and lenticular deposits in Colorado (Cripple Creek), Western Australia (Kalgoorlie), and Transylvania.

Tests.—Tellurium compounds, when heated in the closed tube with strong sulphuric acid, give the latter a brilliant reddish-violet colour.

NATIVE TELLURIUM.

Comp.—Nearly pure tellurium, with a little gold and iron.

Cryst. Syst.—Hexagonal.

Com. Form.—Crystallises in hexagonal prisms with the basal edges modified; mostly found massive and granular.

Colour.—Tin white.

Streak.—Tin white.

Lustre.—Metallic; brittle.

H.—2–2·5. *Sp. Gr.*—6·1–6·3.

Tests.—Heated in the open tube, it forms a white sublimate of tellurous acid, which fuses to small transparent colourless drops before the blowpipe.

Occurrence.—Occurs in the Maria Loretto Mine, near Zalathna, in Transylvania, where it was formerly worked for the small quantity of gold (less than 3 per cent.) which it contains.

Telluric Ochre.—Said to consist of tellurous acid, and has been found at the above locality (see under Native Tellurium) in small whitish and yellowish spherical masses, and also as a yellowish earthy encrustation.

SYLVANITE: Graphic Tellurium.

Telluride of gold and silver (see p. 375).

BLACK TELLURIUM: Nagyagite.

Telluride and sulphide of lead and gold (see p. 376).

TETRADYMITE: Telluric Bismuth.

Comp.—Telluride of bismuth; sulphur and selenium sometimes present.

Cryst. Syst.—Hexagonal.

Com. Form.—Crystals often tabular; also found massive, granular, and foliated.

Cleav.—Basal and very perfect; lamellæ flexible.

Colour.—Pale steel grey.

Lustre.—Metallic; splendent.

H.—1·5–2; soils paper. *Sp. Gr.*—7·2–7·6.

Tests.—Heated in open tube, gives sublimate of tellurous acid; heated on charcoal, gives off white fumes; fuses and volatilises completely.

Occurrence.—Associated with tellurides of gold.

ZINC (Zn).

Zinc is a bluish-white brittle metal, possessing a crystalline structure, and is reported to have been found native in Australia. It melts at 520° C., and has a specific gravity of about 7·15. At a temperature between 100° C. and 150°C. it may be rolled out into sheets or drawn into wire, but at 300° C. it reverts to a brittle condition, and may be readily powdered under the hammer. It becomes superficially tarnished in moist air, and is soluble in dilute acids.

Zinc is obtained by heating in retorts at a high temperature its roasted or calcined ores in admixture with coal or coke. The zinc oxide is reduced to metal, which, being volatile, distils, and is condensed. Smelting in electric furnaces has been experimented with, but considerable difficulties must yet be overcome before this method can be pronounced a success. Metallic zinc (spelter) is used chiefly for coating (galvanising) iron, and in the manufacture of the various alloys, known as brass. Zinc oxide and zinc sulphide are both used as pigments, and are sometimes specified in place of white lead; they are less poisonous and retain their colour better than white lead, although their covering power is inferior.

The chief sources of zinc are blende and calamine. The former often exists in vast quantities associated with galena, which is an objectionable constituent from the point of view of the zinc smelter. The metallurgical treatment of this "refractory sulphide ore" has long been a problem, and although great improvements have been effected in mechanically separating the two values by wet dressing, oil flotation, etc., and various chemical and metallurgical processes have been devised, it does not yet appear to have been solved by the introduction of a process of universal application. Principally owing to the improved methods of mechanical separation, large deposits of zinc-lead sulphide ores are being opened up in Siberia, Burma, etc., in addition to those in Australia and elsewhere.

The world's production of spelter in 1912 amounted to rather less than 1,000,000 tons. The United States, Germany, and Belgium are the largest producers, but that from Belgium is entirely from imported ore. The chief zinc ore-producing country is the United States. The percentage of zinc in the ore mined is frequently very low, and often averages 3 per cent., but this is increased by concentration. The Broken Hill district in New South Wales produces about 20 per cent. of the world's production in the form of concentrates, averaging from 40 to 45 per cent. metallic zinc.

Calamine is not amenable to wet concentration, and smelters do not readily purchase such ores containing less than 35 per cent. zinc. Fluor-spar is frequently associated with zinc ores, and is an objectionable constituent.

The zinc minerals are—

Oxides	Zincite, ZnO. Franklinite $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.
Sulphide ...	*Blende*, ZnS.
Carbonate ...	*Calamine*, $ZnCO_3$.
Silicates ...	Willemite, $2ZnO.SiO_2$. Hemimorphite, $2ZnO.SiO_2.H_2O$.
Sulphate ...	Goslarite, $ZnSO_4.7H_2O$.

Tests.—Zinc minerals heated on charcoal give an encrustation, which is yellow when hot, white when cold, and which, if moistened with cobalt nitrate and strongly reheated, assumes a fine green colour.

NATIVE ZINC.

Native zinc is said to have been found in basalt near Melbourne, in Australia. It has also been reported as occurring in the auriferous sands of the Nittamitta River, in the same district, associated with topaz and corundum. The existence of native zinc is still doubted. Zinc has been artificially crystallised in hexagonal prisms, with low pyramidal terminations.

ZINCITE : Spartalite, Red Oxide of Zinc.

Comp.—Zinc oxide, ZnO. Usually contains impurities of oxides of manganese, to which it is considered the colour is due, since chemically pure oxide of zinc is white. The manganese impurities have been found to vary from mere traces up to 12 per cent. Occasionally traces of iron oxide are present.

Cryst. Syst.—Hexagonal.

Com. Form.—Crystals not common; usually found massive, foliated, granular, or in disseminated grains.

Cleav.—Basal, and very perfect.

Colour.—Deep red, but when in thin scales by transmitted light, deep yellow. Weathers to white crust of zinc carbonate.

Streak.—Orange yellow.

Lustre.—Subadamantine; translucent to subtranslucent.

Fract.—Subconchoidal; brittle.

H.—4–4·5. *Sp. Gr.*—5·4–5·7.

Tests.—Heated in closed tube, it blackens, but on cooling reverts to its original colour. Dissolves in acids without effervescence. Before blowpipe alone, infusible; in the reducing flame on charcoal, it yields a white encrustation of zinc oxide, which turns green when moistened with cobalt nitrate solution and reheated in the reducing flame.

Occurrence.—Occurs with franklinite, willemite, and calcite, in the famous Franklin furnace ore deposit, New Jersey, U.S.A., and is probably of metamorphic origin (see below, p. 299).

FRANKLINITE.

Comp.—Variable. Oxide of iron, zinc, and manganese, $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.

Cryst. Syst.—Cubic.

Com. Form.—Octahedra, often rounded at the edges; also in rounded grains, and massive.

Colour.—Black.

Streak.—Black.

Lustre.—Metallic; opaque.

Fract.—Uneven; brittle.

H.—5·5–6·5. *Sp. Gr.*—5·07–5·22.

Tests. — In oxidising flame, borax bead amethyst coloured, due to manganese; in reducing flame, bottle green, due to iron; sodium carbonate bead, bluish-green; with cobalt nitrate, greenish mass on charcoal, due to zinc.

Occurrence.—Occurs at Franklin Furnace, New Jersey, U.S.A., associated with willemite, zincite, and calcite; say 50 per cent. franklinite, 25 per cent. willemite, 5 per cent. zincite, 20 per cent. calcite. The zinc minerals occur as rounded grains in a crystalline limestone, and are probably the result of metamorphism.

BLENDE : Sphalerite, Black Jack (German, *blenden*, to blind, to delude).

Comp.—Sulphide of zinc, ZnS. Part of the zinc is, however, usually replaced by iron, and a little cadmium is often present, but never reaches 5 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Tetrahedra and rhombdodecahedra common. Often twinned and modified, the forms being then difficult to determine; also occurs massive and compact, and occasionally botryoidal or fibrous.

Cleav.—Parallel to the faces of the rhombdodecahedron and highly perfect.

Colour.—Usually black or brown; sometimes yellow, white, and rarely colourless.

Streak.—White to reddish-brown.

Lustre.—Resinous to adamantine; transparent, translucent, or opaque.

Fract.—Conchoidal; brittle.

H.—3·5–4. *Sp. Gr.*—3·9–4·2.

Tests.—Before blowpipe, alone infusible, or very difficultly fusible. With sodium carbonate on charcoal in the reducing flame it colours the flame strongly green.

On charcoal, when roasted in the oxidising flame, and then intensely heated in the reducing flame, it yields an encrustation of zinc oxide, which is yellow when hot, and white when cold, and which assumes a green colour when heated with cobalt nitrate solution. Some varieties first give a reddish-brown coating of oxide of cadmium; blende is soluble in hydrochloric acid, with liberation of sulphuretted hydrogen. The solution gives a white precipitate of zinc sulphide on the addition of ammonium sulphide.

Occurrence.—Blende is extremely commonly found associated with galena in veins in which the veinstone is usually calcite, dolomite, fluor, barytes, and quartz, as in Cardiganshire, Cornwall, Colorado (Aspen and Rico), Broken Hill (N.S.W.), etc. Blende also occurs as a metasomatic deposit, replacing the calcite of limestones, as in Derbyshire, Cumberland, Westphalia, Colorado (Leadville and Silver Peak), etc.; also occurs as a chemical precipitate, as at Galena, Kansas.

CALAMINE (*calamus*, a reed). **Smithsonite** of the Americans.

Comp.—Zinc carbonate, $ZnCO_3$. The zinc, however, is often partly replaced by iron or manganese; a little lime, magnesia, or oxide of cadmium is often present.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Crystals, modified rhombohedra; commonly found massive, reniform, botryoidal, stalactitic, encrusting, granular, and earthy.

Cleav.—Rhombohedral; perfect.

Colour.—White, greyish, greenish, brownish-white.

Streak.—White.

Lustre.—Vitreous, inclining to pearly; subtransparent, translucent, or opaque.

Fract.—Uneven; brittle.

H.—5. *Sp. Gr.*—4–4·5.

Tests.—Heated in the closed tube, gives off carbon dioxide, and turns yellow when hot, white when cold; heated before blowpipe alone, infusible; heated on charcoal, moistened with cobalt nitrate, and strongly reheated, it assumes a green colour on cooling; with sodium carbonate on charcoal, gives zinc vapours, and forms the usual encrustation of zinc oxide. Soluble in hydrochloric acid, with effervescence.

Occurrence.—Calamine occurs in beds and veins, and is usually associated with blende, hemimorphite, galena, and iron and copper ores. The beds result from the metasomatic replacement of limestones. Localities are, for example, Mendip Hills (Somersetshire), Matlock (Derbyshire), Alston Moor (Cumberland), Lead Hills (Scotland), and in most lead and zinc mining centres (see also p. 311).

Calamine is a very important ore of zinc; commercially, however, the term "calamine" includes the silicates as well as the carbonates.

WILLEMITE: Wilhelmite.

Comp.—Zinc silicate, $2ZnO.SiO_2$.

Cryst. Syst.—Hexagonal.

Com. Form.—Prismatic crystals, formed by hexagonal prism, with rhombohedral terminations; also massive.

Cleav.—Two imperfect cleavages.

Colour.—Green, yellow, brown.

Lustre.—Vitreous to resinous.

H.—5–5·5. *Sp. Gr.*—4–4·1.

Tests.—Heated on charcoal, moistened with cobalt nitrate, and strongly reheated, gives green mass; gelatinises with acid.

Varieties—Troostite.—A variety of willemite occurring in large crystals.

Occurrence.—Willemite occurs associated with zincite and franklinite at Franklin Furnace, New Jersey (see p. 299). Also at Vieille Montagne and Moresnete (Belgium), and Raibl (Carinthia).

HEMIMORPHITE: Calamine of the Americans. Electric Calamine, Galmei, Silicate of Zinc.

Comp.—Hydrated silicate of zinc, $H_2O.2ZnO.SiO_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Modified orthorhombic prisms, the opposite extremities terminated by dissimilar faces; crystals frequently twinned; also massive, granular, fibrous, mammillated, encrusting, and stalactitic, or banded.

Cleav.—Perfect; parallel to the faces of the prism.

Colour.—White, yellowish-brown, sometimes faintly greenish or bluish; sometimes banded in blue or white.

Streak.—White.

Lustre.—Vitreous; subpearly on basal plane; sometimes adamantine; transparent to translucent, or opaque.

Fract.—Uneven; brittle; becomes electric when heated, and phosphorescent when rubbed.

H.—4·5–5. *Sp. Gr.*—3·16–3·49.

Tests.—Heated in the closed tube, it decrepitates, whitens, and gives off water; heated before blowpipe alone, almost infusible. On charcoal, gives a white encrustation when moistened with cobalt nitrate, and heated in oxidising flame. Gelatinises with acids; decomposed by acetic acid with gelatinisation. Soluble in a strong solution of caustic potash.

Occurrence.—Occurs both in veins or beds accompanying the sulphides of zinc, iron, and lead, and with calamine. Occurrences are as for calamine and blende (see p. 300).

Hemimorphite is a valuable zinc ore.

GOSLARITE (Goslar in the Harz): White Vitriol.

Comp.—Hydrated zinc sulphate, $ZnSO_4.7H_2O$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals; also found stalactitic and encrusting.

Cleav.—Perfect; parallel to the brachypinacoid.

Colour.—White.

Streak.—White.

Lustre.—Vitreous; transparent to translucent.

Taste.—Astringent, metallic, and nauseous; brittle.

H.—2–2·5. *Sp. Gr.*—2·1.

Tests.—Heated in closed tube, it boils and gives off water, fusing to an opaque white mass; heated on charcoal, fuses with ebullition, and gives an encrustation of zinc oxide. Cobalt nitrate test, green mass. Readily soluble in water, the solution yielding a white precipitate of barium sulphate on the addition of barium chloride solution (presence of sulphate).

Occurrence.—Goslarite results from the decomposition of blende, and is found sparingly in some of the Cornish mines and at Holywell, in Flintshire. The chief locality is the Rammelsberg Mine, Goslar. The mineral is not plentiful enough to be of much, if of any, commercial importance.

CADMIUM (Cd).

Cadmium is a bluish-white metal, having a brilliant lustre, and closely resembling zinc. It is very malleable and ductile, has a specific gravity of about 8·5, and melts at 320° C. It is usually found in nature as the sulphide (greenockite), which is, however, of rare occurrence. It also occurs in small quantities, associated with zinc sulphide and carbonate. Cadmium is obtained as a by-product in the distillation of zinc ores, in which it seldom occurs in greater amount than 0·4 per cent., and usually less. Cadmium is chiefly used in the manufacture of "fusible alloys." Artificial cadium sulphide is a valuable yellow pigment. There is no great demand for the metal, and the production during the last few years has remained practically stationary. Silesia, the chief source, produced about 42 tons in 1912, and small quantities were produced in England and the United States.

GREENOCKITE.

Comp.—Cadmium sulphide, CdS.

Cryst. Syst.—Hexagonal (hemimorphic); the opposite extremities of crystals dissimilarly modified.

Colour.—Honey, citron, or orange yellow.

Streak.—Between orange yellow and brick red.

Lustre.—Adamantine, resinous; nearly transparent.

H.—3–3·5. *Sp. Gr.*—4·8–4·9.

Tests.—Heated in closed tube, turns carmine-red, and reverts to its original colour on cooling; in open tube, gives off sulphurous fumes; heated on charcoal, yields a reddish-brown encrustation. Dissolves in hydrochloric acid, with evolution of sulphuretted hydrogen.

Occurrence.—Occurs as a coating to some zinc ores, and is associated with zinc ores. Localities are—Bishopstown (Scotland), Przibram (Bohemia), Friedensville (Pennsylvania).

TIN (Sn).

Tin is said to have been found native, but, if so, is of very rare occurrence. It is chiefly found in the form of the oxide, cassiterite (tinstone), which may be regarded as the sole source of the metal. Tin is a bright, white metal, malleable and ductile. It has a specific gravity of 7·3, and melts at 232° C. A bar of the metal, when bent, emits a crackling sound. The chief use of tin is in the manufacture of tin-plate (sheet-iron with a very thin coating of tin), and alloys such as pewter, solder, and antifriction metals, and bronze and bell metals.

Cassiterite is obtained from both lodes and alluvial (placer) deposits. In the former it may be associated with arsenic, copper and iron pyrites, wolfram, etc., and in alluvial deposits it is often associated with ilmenite or titaniferous iron, monazite, zircon, topaz, tourmaline, etc. The proportion of tin in ores is usually expressed in pounds of black tin (tinstone containing about 70 per cent. metal) per ton. In the case of alluvial deposits, less than 2 pounds per ton has been profitably worked. The alluvial or mine stuff is concentrated, up to as near 70 per cent. of metallic tin as is practicable, by means of shaking tables and other mechanical contrivances, and when associated with ilmenite, wolfram, or other magnetic minerals, by electro-magnetic separators. The dressed product or "concentrate" is smelted in reverberatory furnaces, and the metal further purified up from 99·2 to 99·9 per cent.

Salts of tin have uses in the pottery and enamelled-iron industries, and as a mordant in calico printing.

The world's production of metallic tin in 1912 amounted to about 117,000 tons, of which the shipments from the Straits, mostly smelted locally from concentrates produced in the Federated Malay States, accounted for nearly half. Bolivia exported in 1912 about 38,000 tons of black tin, and Nigeria about 3,000 tons, likely to increase to about 5,000 tons in 1913. Other producing countries, in order of importance, are—Dutch East Indies, China, Australia and Tasmania, Cornwall, and Siam. In addition to the Straits smelting plants, tin is smelted in England (about 20,000 tons yearly), Germany (10,000 tons), China (probably about 10,000 tons).

The tin minerals are—

Oxide ... Cassiterite, tinstone, SnO_2.
Sulphide... Stannine, tin pyrites, $Cu_2S.FeS.SnS_2$.

Tests.—Heated on charcoal with sodium carbonate and charcoal, tin compounds are reduced to the metal, which is soft and malleable. The encrustation given by heating tin compounds alone on charcoal, when moistened with cobalt nitrate and strongly reheated, is a blue-green colour.

CASSITERITE (Greek, *cassiteros*, tin). **TIN-STONE.**

Comp.—Tin oxide, SnO_2.

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal prisms terminated by tetragonal pyramids; crystals often twinned. Also occurs massive, and sometimes disseminated in small grains; also fibrous.

Colour.—Usually black or brown, rarely yellow or colourless.

Streak.—White or pale grey to brownish.

Lustre.—Adamantine, and, on crystals, usually very brilliant. Crystals, when of pale colour, nearly transparent; when dark, opaque.

Fract.—Subconchoidal, or uneven; brittle.

H.—6–7. *Sp. Gr.*—6·4–7·1.

Tests.—Alone infusible before the blowpipe. With sodium carbonate on charcoal, it fuses to a globule of metallic tin. Heated on charcoal with sodium carbonate, fused mass moistened with cobalt nitrate and strongly reheated, gives a blue-green colour.

Varieties—Wood Tin.—A variety of cassiterite, in which the structure is compact and fibrous internally, exhibiting concentric bands, which cause it somewhat to resemble wood; it occurs in reniform masses.

Toad's Eye Tin.—A variety showing the characters of wood tin, but on a smaller scale.

Stream Tin.—Merely cassiterite, rolled and waterworn, and has resulted from the wearing away of tin veins or of rocks containing the ore. It occurs in the beds of streams, and in the alluvial deposits which border them. Much of the tin sent into the market is derived from this source.

Occurrence.—Cassiterite occurs in pneumatolytic veins, associated with acid rocks, granites, as in Cornwall. The main occurrence of cassiterite is in quartz veins, associated with fluor, topaz, tourmaline, axinite, and apatite, as in Cornwall, Saxony, and Bolivia. Fully one half of the world's supply of tin is obtained from placer deposits, resulting from the degradation of tin veins. Localities of alluvial tin deposits are—Malay States; the islands of Banka and Billeton, near Sumatra; Cornwall; Mount Bischoff, in Tasmania, etc.

STANNINE (Latin, *stannum*, tin). TIN PYRITES. Bell Metal Ore.

Comp.—Sulphide of tin, copper, and iron, $Cu_2S.FeS.SnS_2$. Zinc is usually present in varying quantity.

Cryst. Syst.—Cubic (tetrahedral).

Com. Form.—Crystals rare, combinations of cube and tetrahedron; commonly occurs massive, granular, and disseminated.

Colour.—Steel grey when pure, iron black, sometimes bronze or bell metal colour, occasionally with a bluish tarnish; often yellowish from admixture with copper pyrites.

Streak.—Blackish.

Lustre.—Metallic; opaque.

Fract.—Uneven; brittle.

H.—4. *Sp. Gr.*—4·3–4·5.

Tests.—Heated in open tube, stannine gives off sulphur, forming fumes of sulphur dioxide, and also forms a sublimate of tin oxide close to the assay; heated on charcoal, it fuses after long roasting to a brittle metallic globule, which, in the oxidising flame, gives off sulphur, and coats the support with white tin oxide. The roasted mineral affords, in borax, the reactions for iron and copper.

Occurrence.—Occurs associated with cassiterite, copper pyrites, blende, or galena, as in Cornwall and Zinnwald. When occurring in sufficient quantity, it is worked for both copper and for tin.

LEAD (Pb).

Native lead is known, but is of exceedingly rare occurrence. Lead is a bluish-grey metal, whose freshly cut surface shows a bright metallic lustre which, however, quickly oxidises on exposure to the air. It is soft, may be scratched with the finger-nail, and makes a black streak on paper. The specific gravity of the metal is 11·40. It fuses at 325° C., and crystallises when cooled slowly. It has little tenacity, and cannot be drawn into wire, but is, however, readily rolled or pressed into thin sheets, or exuded when in a semi-molten state through dies to form piping. Its properties are materially affected by the presence of small quantities of impurities.

Lead is very easily reduced from its compounds, and is readily soluble in dilute nitric acid; hydrochloric and sulphuric acids have but little action. It forms several compounds of commercial importance; for example, litharge and red lead are oxides, white lead is a basic carbonate.

For the production of lead, the ore containing galena or cerussite is first partly roasted or calcined, and then smelted in reverberatory or blast furnaces. Most lead ores contain silver, and this metal is obtained, by cupellation or other means, from the lead.

Blende is frequently associated with galena, and as the presence of zinc causes difficulties in smelting, lead ores containing more than 10 per cent. of zinc are heavily penalised by the smelters. Mechanical separation (dressing) of the two minerals is largely resorted to, but with considerable losses of both lead and zinc. When antimony is associated with galena, the ore is frequently smelted direct for the production of antimonial lead.

The world's production of metallic lead in 1912 exceeded 1,200,000 tons, the largest producing country being the United States, with 30 per cent. of the whole, followed by Australasia, with about 12 per cent., mostly derived from the Broken Hill Mines. Mexico, in normal years, also produces about 12 per cent. of the total world's production.

The chief ore of lead is galena; deposits of galena oxidise in their upper parts into numerous oxy-salts. The chief minerals of lead are therefore—

Sulphide	Galena, PbS.
Oxide	Minium, Pb_3O_4.
Carbonate	Cerussite, $PbCO_3$.
Sulphate	Anglesite, $PbSO_4$.
Phosphate and Chloride	Pyromorphite, $3Pb_3P_2O_8.PbCl_2$.
Arsenate and Chloride	Mimetite, $3Pb_3As_2O_8.PbCl_2$.
Vanadate and Chloride	Vanadinite, $3Pb_3V_2O_8.PbCl_2$.
Chromate	Crocoisite, $PbCrO_4$.
Molybdate	Wulfenite, $PbMoO_4$.

Tests.—Lead compounds colour the blowpipe flame a pale sky blue, a poor colour, and of little value. When lead minerals are heated alone on charcoal, they give a sulphur yellow encrustation; heated with potassium iodide and sulphur, they give a brilliant yellow encrustation (a good test). Roasted with sodium carbonate and charcoal on charcoal, lead minerals are reduced to metallic lead, which shows as a lead grey bead, bright while hot, but dull when cold, which is malleable, and marks paper.

GALENA (Greek, *galene*, tranquillity, as it was supposed formerly to possess soothing medicinal properties; often called blue lead or blue ore by miners).

Comp.—Sulphide of lead, PbS. Sulphide of silver is always present, and galena is one of the most important sources of silver. When containing sufficient silver to be worth extracting, it is termed "argentiferous galena." Zinc, cadmium, iron, copper, antimony, and gold have also been detected in analyses of this mineral. There are apparently no external characters which serve to distinguish even the highly argentiferous ores from ordinary galena; the question can only be solved by analysis.

Cryst. Syst.—Cubic.

Com. Form.—Cube, often modified by octahedral and other planes (see Fig. 5); also occurs massive, and coarsely or finely granular.

Cleav.—Cubic and perfect, many specimens crumbling readily into small cubes when rubbed or struck.

Colour.—Lead grey.

Streak.—Lead grey.

Lustre.—Metallic; opaque; often dull, due to tarnish.

Fract.—Flat, even, or subconchoidal.

H.—2·5. *Sp. Gr.*—7·2–7·7.

Tests.—Heated in the open tube, galena gives off sulphurous fumes. On charcoal it emits sulphurous fumes, forms a yellow encrustation of lead oxide, and fuses to a malleable metallic globule. Heated with potassium iodide and sulphur on charcoal, it forms a brilliant encrustation. Decomposed by hydrochloric acid, with evolution of sulphuretted hydrogen. On cooling the solution, white crystals of lead chloride are deposited, which are soluble on heating.

Occurrence.—Galena occurs in beds and veins. Metasomatic lead and zinc veins occur in limestone, as at Derbyshire, Flintshire, Cumberland, Sala (Sweden), Raibl, and Bleiberg (Carinthia), Leadville (Colorado), Utah, Wisconsin, etc. Hydatogenetic or primary veins is another important mode of occurrence of galena; it is there associated with zinc blende, pyrites, quartz, and barytes, as at Cardigan, Minera, Isle of Man, Cornwall, Derbyshire, Aspen and Rico (Colorado), Broken Hill (N.S.W.), where the galena is associated with silver, and at Freiberg (Saxony).

Uses.—Galena is the most important ore of lead, nearly all the metal of commerce being derived from this source.

MINIUM: Red Oxide of Lead.

Comp.—Lead oxide, Pb_3O_4.

Com. Form.—Pulverulent.

Colour.—Bright red, scarlet, or orange red.

Streak.—Orange yellow.

Lustre.—Faint, greasy, or dull; opaque.

H.—2–3. *Sp. Gr.*—4·6.

Tests.—Before the blowpipe in reducing flame, yields globules of metallic lead. Other lead tests given.

Occurrence.—Occurs associated with galena, and sometimes with cerussite.

Uses.—The red lead of commerce, which has the same composition as minium, is artificially prepared by heating lead oxide (litharge) or carbonate, in contact with air in a furnace at a moderate temperature. Red lead is used in the manufacture of flint glass and also as a paint.

ANGLESITE (first found in Anglesey): **Lead Vitriol.**

Comp.—Sulphate of lead, $PbSO_4$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, sometimes tabular in form, and occasionally in pyramids variously modified. The faces of the prism and macropinacoid are often vertically striated; also massive and occasionally stalactitic.

Colour.—White, sometimes with a blue, grey, green, or yellow tint.

Streak.—Colourless.

Lustre.—Usually adamantine, sometimes inclining to resinous or vitreous; transparent to opaque.

Fract.—Conchoidal; very brittle.

H.—2·75–3. *Sp. Gr.*—6·12–6·39.

Tests.—Soluble in water. Before the blowpipe, decrepitates, and in the oxidising flame fuses to a clear globule, which on cooling becomes milk white. In the reducing flame, effervesces and yields metallic lead. When dissolved, barium chloride throws down a dense white precipitate of barium sulphate, if added to the solution (presence of sulphate). Sulphate is also indicated by the silver coin test (see p. 28).

Occurrence.—Anglesite, when found in sufficient quantity, is a valuable lead ore. It is usually associated with galena, and results from the decomposition of that mineral in the upper portion of lead veins. Localities are—Parys Mine in Anglesey, Cornwall, Derbyshire, Cumberland, Lead Hills, Broken Hill (N.S.W.), Mexico, etc.

CERUSSITE: Ceruse, White Lead Ore.

Comp.—Carbonate of lead, $PbCO_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, variously modified. Twin crystals common, often in cruciform or radiate arrangements. Crystals sometimes show faces of the prism, pyramid, and dome; also occurs granular, massive, compact, and sometimes stalactitic.

Colour.—White or greyish, sometimes tinged blue or green by copper salts.

Streak.—Colourless.

Lustre.—Adamantine, inclining to vitreous or resinous; transparent to translucent.

Fract.—Conchoidal; very brittle.

H.—3–3·4. *Sp. Gr.*—6·46–6·48.

Tests.—Soluble in hydrochloric acid with effervescence. Before the blowpipe, decrepitates, fuses, and on charcoal, in the reducing flame, yields a metallic lead bead.

Occurrence.—Cerussite occurs with other lead ores, and may result from the decomposition of anglesite by water, charged with bicarbonates. Anglesite results from the oxidation of galena, turning the sulphide into a sulphate. Cerussite may therefore be regarded as indirectly derived from the decomposition of galena. Localities are—Cornwall, Derbyshire, Durham, Cardigan, Lead Hills, Saxony, Harz, Bleiberg, Virginia, Wisconsin, etc.

Uses.—When found in quantity, cerussite is a valuable ore, ranking next to galena. The white lead of commerce is artificially prepared (Dutch process) by the action of acetic acid upon metallic lead cast in the form of gratings. It may also be prepared by passing carbon dioxide through a solution of basic lead acetate, but this product is usually considered inferior. White lead is sometimes mixed with finely ground barytes.

Leadhillite.—A greyish-white mineral found at Lead Hills in Scotland, and consisting of sulphate and carbonate of lead. It splits into laminæ, which are flexible.

THE "PYROMORPHITE" SET.

The "*pyromorphite*" set includes three minerals: Pyromorphite, mimetite, and vanadinite, which are isomorphous. They crystallise in the hexagonal system, and have usually long prismatic crystals. Their colours are usually vivid. Their composition is—

Pyromorphite ... ... $3Pb_3P_2O_8.PbCl_2$.
Mimetite ... ... $3Pb_3As_2O_8.PbCl_2$.
Vanadinite ... ... $3Pb_3V_2O_8.PbCl_2$.

The "pyromorphite" set occur associated with hydatogenetic lead deposits, as at numerous mines in Cornwall, Derbyshire, Cumberland, Flintshire, Lead Hills, Saxony, Bohemia, Harz, Mexico, and the United States.

PYROMORPHITE (Greek, *pur*, fire, and *morphe*, form, in allusion to the angular form assumed by the globule after fusion before the blowpipe): **Green Lead Ore.**

Comp.—Phosphate and chloride of lead $3Pb_3P_2O_8.PbCl_2$; sometimes with small quantity of arsenic and calcium.

Cryst. Syst.—Hexagonal.

Com. Form.—Prismatic crystals made up of prism, pyramid, and basal plane (see Fig. 52); crystals, usually aggregated and forming crusts; also reniform and botryoidal.

Cleav.—Parallel to the faces of the prism, in traces.

Colour.—Green, yellow, and brown, of different shades; the colours sometimes very vivid.

Streak.—White or yellowish-white.

Lustre. — Resinous ; subtransparent to subtranslucent.

Fract.—Subconchoidal or uneven ; brittle.

H.—3·5–4. *Sp. Gr.*—6·5–7·1.

Tests.—Heated in closed tube, gives a white sublimate of lead oxide ; before blowpipe, alone fuses easily, colouring the flame bluish-green. On charcoal, fuses to a globule, which, when cool, assumes a crystalline angular form, but without being reduced to metallic lead ; at the same time the charcoal becomes coated with white lead chloride and yellow lead oxide. With sodium carbonate on charcoal, yields a metallic lead bead. Chloride given by microcosmic copper oxide bead test ; soluble in hydrochloric acid. Heated with magnesium in closed tube, gives smell of phosphoretted hydrogen when moistened.

Occurrences.—Pyromorphite is found in company with other ores of lead, and, when plentiful, is smelted (see above, p. 314).

MIMETITE (Greek, *mimetes*, a mimic, from its resemblance to pyromorphite : **Green Lead Ore**.

Comp.—Arsenate and chloride of lead, $3Pb_3As_2O_8.PbCl_2$.

Cryst. Syst.—Hexagonal ; isomorphous with pyromorphite.

Com. Form.—In form resembling pyromorphite.

Colour.—Pale yellow, brown, white.

Streak.—White, or whitish.

Lustre.—Resinous.

H.—3·5. *Sp. Gr.*—7–7·25.

Tests.—Heated in the closed tube, it behaves like pyromorphite ; soluble in hydrochloric acid. On charcoal, in the reducing flame, yields metallic lead, gives off an arsenical odour, and coats the charcoal with lead chloride, lead oxide, and arsenious oxide. Flame coloration, blue and green.

Varieties—Campylite (Greek, *kampulos*, curved, in allusion to the curved faces of the crystals); a variety of mimetite occurring in barrel-shaped crystals of a brown or yellowish colour.

Occurrence.—See p. 314.

Vanadinite.—A vanadate and chloride of lead, $3Pb_3V_2O_8.PbCl_2$; isomorphous with mimetite and pyromorphite. Colour is ruby red, orange brown, or yellowish.

Linarite (Linares, in Spain).—A rare mineral, composed of sulphate and oxide of lead and copper, with water. It crystallises in the monoclinic system, has a deep azure blue colour, and gives a pale blue streak. It is found in Cumberland, Spain, Saxony, etc.

CROCOISITE (*crocos*, saffron): Crocoite, Crocoise.

Comp.—Lead chromate, $PbCrO_4$.

Cryst. Syst.—Monoclinic.

Com. Form.—Prismatic crystals modified; also occurs in an imperfectly columnar or granular condition. Faces of the prism often striated longitudinally.

Cleav.—Prismatic, tolerably distinct; basal cleavage, less so.

Colour.—Hyacinth red of different shades.

Streak.—Orange yellow.

Lustre.—Adamantine to vitreous; translucent; sectile.

H.—2·5–3. *Sp. Gr.*—5·9–6·1.

Tests.—Heated in closed tube, decrepitates and blackens, but reverts to its original colour on cooling; on charcoal is reduced to metallic lead with deflagration, and coats the charcoal with an encrustation of chromium and lead oxides. Borax bead, emerald green.

Occurrence.—Occurs with lead minerals and in some quartz veins. Localities are—Beresof (Siberia), Urals, Hungary, Philippine Islands.

WULFENITE.

Comp.—Lead Molybdate, $PbMoO_4$.

Cryst. Syst.—Tetragonal.

Com. Form.—Tetragonal pyramid and prisms variously modified, the latter forms often tabular; also occurs massive and granular.

Cleav.—Parallel to the faces of the pyramid, smooth; there is also a less distinct cleavage parallel to the basal plane.

Colour.—Wax yellow, orange yellow, yellowish-grey, greyish-white, brown, and sometimes shades of orange red and green.

Streak.—White.

Lustre.—Waxy or adamantine; subtransparent to subtranslucent.

Fract.—Subconchoidal; brittle.

H.—3. *Sp. Gr.*—6·03–7·01.

Tests.—Before blowpipe, decrepitates and fuses. With borax in the oxidising flame, gives a colourless bead, which, in the reducing flame, becomes opaque, black, or dirty green, with black specks. With microcosmic salt it gives in the oxidising flame a yellowish-green bead, which in the reducing flame becomes dark green. With sodium carbonate on charcoal, yields metallic lead. Wulfenite is decomposed when heated in hydrochloric acid; the addition of a scrap of zinc to the solution causes it to assume a deep blue colour.

Occurrence.—Occurs in veins with other ores of lead, as at Bleiberg (Saxony), Comstock (Nevada), and Arizona.

CROMFORDITE : Phosgenite, Horn Lead.

Comp.—A rare mineral, consisting of chloro-carbonate of lead, $PbCl_2.PbCO_3$.

Com. Form.—Crystals prismatic.

Colour.—White, grey, or yellow.

Streak.—White.

Lustre.—Adamantine; transparent to translucent.

H.—3. *Sp. Gr.*—6–6·31.

Tests.—Dissolves with effervescence in hydrochloric acid. Chloride given in microcosmic copper oxide bead test (see p. 23).

Occurrence.—Occurs at Cromford, near Matlock, in Derbyshire; Cornwall, etc.

IRON (Fe; Latin, *ferrum*).

Iron is, next to aluminium, the most widely distributed and abundant metal, constituting about 4·6 per cent. of the earth's crust. It is found native in meteoritic masses and in eruptive rocks, mostly associated with other metals—*e.g.*, nickel, cobalt, etc.

Metallic iron is unaffected by dry air, but oxidises to "rust" under the influence of moist air. Cast iron, wrought iron, and steel are the forms in which iron occurs in commerce. Their different properties are primarily due to the presence of varying amounts of carbon. Steel is again divided into several classes or grades, each named after its particular properties (mild, hard, etc.), the use to which it is put (tool steel, etc.), or the metal with which it is alloyed (manganese, chrome, nickel, or tungsten steel). These special steels have been found in practice to be especially valuable for different purposes, such as armour plate, guns, high-speed cutting-tools, rails, springs, etc. Nickel steel is of particular importance, its tensile strength and elasticity being enormously greater than that of ordinary steel.

Pig iron, from which all the various grades of iron and steel are obtained, is produced in the blast furnace by reduction of its ore by coke. The world's production of pig iron in 1912 approached 75,000,000 tons.

The chief ores of iron are the oxides: red hematite (Fe_2O_3), containing 70 per cent. Fe when pure; brown hematite or limonite ($Fe_2O_3.3H_2O$), containing 56·9 per cent. Fe; magnetite (Fe_3O_4), containing 72·4 per cent. Fe; and the carbonate, siderite (chalybite), or spathic iron ore ($FeCO_3$), containing 48·3 per cent. Fe. Magnetite of exceptional purity occurs in large quantities in Sweden, and is the source of the noted "Swedish iron.' Undesirable impurities in iron ores are arsenic, sulphur, and phosphorus, except in the case of the manufacture of basic or non-bessemer steels. Iron ores containing 30 per cent. Fe and upwards are profitably smelted, but the value of iron ores (in common with most other ores, of course) depends on their situation, and also on the composition of their gangue in addition to their iron content. For example, an iron ore containing 30 per cent. Fe, and a gangue of silica, alumina, and lime in such proportions to make it self-fluxing, may be more valuable than a richer ore containing impurities which it would be necessary to remove. Most iron ores in Europe require some mechanical cleaning, and in some cases electromagnetic separation is employed. Roasting or calcining is also frequently resorted to for the purpose of removing water, carbonic acid, and sulphur.

Considerable quantities of the natural oxides and silicates are mined and prepared for the market, for use in the manufacture of paints, and as linoleum fillers. For example, ochres are hydrated ferric oxides; sienna and umber are silicates of iron and aluminium, containing iron and manganese; red or brown oxides are the hydrated or anhydrous oxides, or may be produced by the calcination of carbonates, whereby a wide range of shades is obtained.

NATIVE IRON.

Comp.—Iron, Fe; usually alloyed with nickel or some other metal, or mixed with other iron compounds.

Cryst. Syst.—Cubic.

Com. Form.—Octahedra; generally massive, and with a somewhat granular structure.

Cleav.—Octahedral.

Colour.—Iron grey.

Streak.—Iron grey.

Fract.—Hackly; it is also malleable and ductile.

H.—4·5. *Sp. Gr.*—7·3–7·8.

Occurrence.—Native iron of terrestrial origin has been reported as occurring in Brazil, Auvergne, Bohemia, and in grains disseminated in basalt from the Giant's Causeway (Ireland), and elsewhere. The largest masses known to be of terrestrial origin occur in Disko Island and elsewhere on the coast of West Greenland, where masses ranging up to 25 tons in weight weather out from a basalt. Native iron also occurs as grains in some placer deposits, as at Gorge River, New Zealand, and in Piedmont. Native iron may be formed by the alteration of iron minerals, as in Eastern Canada.

Meteoric iron is found in meteorites (masses which have fallen from the outer atmosphere on to the surface of the earth, and which may consist either entirely of iron, or partly of olivine and other silicates). Meteoric iron is usually alloyed with nickel and small quantities of cobalt, manganese, tin, chromium, sulphur, carbon, chlorine, copper, and phosphorus. It rusts much less readily than terrestrial iron, on account of the nickel which it contains. The minerals olivine, enstatite, augite, and anorthite have been found in meteorites. A phosphide of nickel and iron (schriebersite) has also been detected in meteorites, and also a sulphide of iron (troilite), having the formula FeS.

MAGNETITE: Magnetic Iron Ore. Named either from the locality Magnesia, in Macedonia, or, according to Pliny, from Magnes, who is said to have discovered it from the adhesion of his shoe-nails and the iron ferule of his staff to the ground over which he walked.

Comp.—Oxide of iron, Fe_3O_4. Iron, 72·4 per cent. The iron is sometimes replaced by a small amount of magnesium or titanium.

Cryst. Syst.—Cubic.

Com. Form.—Octahedra common; also octahedra and rhombdodecahedra combined. Also occurs granular and massive.

Cleav.—Poor; octahedral.

Colour.—Iron black.

Streak.—Black.

Lustre.—Metallic or submetallic; opaque, but in thin dendrites occurring in mica it is sometimes transparent, or nearly so.

Fract.—Subconchoidal.

H.—5·5–6·5. *Sp. Gr.*—4·9–5·2.

Opt. Props.—Black by transmitted and reflected light; occurs as small square sections or shapeless grains.

Tests.—Before blowpipe, very difficult to fuse. With borax in oxidising flame, gives a bead, which is yellow when hot, and colourless when cold; if much of the mineral powder is added, the bead is red when hot, and yellow when cold. In the reducing flame it yields a bottle green borax bead; soluble in hydrochloric acid. Strongly magnetic, and often exhibits polarity.

Occurrence.—Magnetite occurs in Devonshire, Cornwall, and other localities in England, also in many places in Scotland and Ireland, and indeed in most parts of the world. In Norway, Sweden, and Siberia it is found in considerable quantities, and constitutes one of the most valuable ores of iron.

As "black sands," magnetite occurs in placer deposits, as in the St. Lawrence and Columbia rivers. Most large deposits of magnetite occur as segregations in igneous rocks, chiefly in the more basic rocks, gabbros, norites, and sometimes syenites, as at Taberg and Kiruna, in Sweden, at the Adirondacks in the United States, and in the Urals. Magnetite also occurs as lenticular bands, interfoliated with schists, as in Scandinavia, Urals, California, Saxony, etc.

HEMATITE (Greek, *haima*, blood): **Specular Iron** (Latin, *speculum*, a mirror), **Kidney Ore**.

Comp.—Oxide of iron, Fe_2O_3. Iron, 70 per cent. Clay and sandy impurities are sometimes present.

Cryst. Syst.—Hexagonal.

Com. Form.—Rhombohedron, often modified and frequently in thin and tabular forms; also in micaceous or foliated aggregates, reniform, granular, and amorphous. Commonly fibrous internally.

Cleav.—Poor; parallel to the rhombohedron and the basal plane.

Colour.—Steel grey or iron black. In particles sufficiently thin to transmit light, it appears blood red; earthy forms are red.

Streak.—Cherry red.

Lustre.—When crystallised, metallic and highly splendent (specular iron). In fibrous varieties, silky; in amorphous varieties, dull and earthy. Opaque, except in very thin plates.

Fract.—Subconchoidal or uneven.

H.—5·5–6·5. *Sp. Gr.*—4·5–5·3.

Tests.—Blowpipe reactions as for magnetite. Becomes magnetic on heating; soluble in acids.

Varieties—Specular Iron.—A variety of hematite occurring in rhombohedral crystals, black in colour, and with a metallic splendent lustre.

Micaceous Hematite.—Foliated and micaceous forms.

Kidney Ore.—A reniform variety with a metallic lustre, especially on the mammillated surface. Beneath this surface kidney ore usually displays a radiating or divergently columnar structure.

FIG. 81.—HEMATITE, KIDNEY ORE.

Reddle.—The most earthy variety of hematite, amorphous, red in colour; used in the manufacture of crayons, for polishing glass, and as a red paint.

Occurrence.—Hematite occurs in pockets and hollows, replacing limestone. As an example of this mode of occurrence, the great deposits of Ulverston, in North Lancashire, may be given. Here the hematite occurs in irregular masses on the surface of the Carboniferous limestone, and probably results from the replacement of that limestone by hematite brought from the highly ferruginous Triassic sandstones which overlie the limestones. Metasomatic deposits of a similar nature occur in Forest of Dean, Cumberland, Spain, Elba, Utah, and elsewhere. The great hematite deposits of the Lake

Superior region (Mesabi) probably result from the alteration and concentration of iron silicates. Metamorphic deposits of hematite, interfoliated with crystalline schists, occur in Scandinavia.

Martite.—Probably a pseudomorph of hematite after magnetite. It mostly occurs in small black octahedra, which give a reddish-brown streak.

LIMONITE (Greek, *leimon*, a meadow): Brown Hematite.

Comp.—Hydrated oxide of iron, $2Fe_2O_3.3H_2O$. Iron, 60 per cent.

Cryst. Syst.—Amorphous.

Com. Form.—Occurs in mammillated or stalactitic forms, having a radiating fibrous structure, resembling that of hematite; also in dull earthy condition and in concretions.

Colour.—Various shades of brown on fracture surfaces; when earthy, yellow or brownish-yellow. The exteriors of mammillated and stalactitic forms frequently exhibit a blackish glazed coating.

Streak.—Yellowish-brown.

Lustre.—Submetallic in some varieties; sometimes silky, sometimes dull or earthy.

H.—5–5·5. *Sp. Gr.*—3·6–4.

Tests.—Heated in the closed tube, gives water. Gives other iron reactions (see p. 29). Distinguished by streak and form.

Varieties—Bog Iron Ore.—A loose, porous, earthy form of limonite, found in low-lying or swampy ground, often impregnating and enveloping fragments of wood, leaves, mosses, etc.

Pea Iron Ore.—A variety of limonite having a pisolitic structure.

Ochres.—Brown and yellow ochre are earthy forms of limonite used for paint.

Occurrence.—Limonite results from the alteration of other iron minerals. From a highly ferruginous rock there may be formed by its degradation weathered residual deposits, consisting largely of ferric hydroxide, mixed with clay and other impurities. These iron caps are common over the outcrop of pyrites, and iron oxide deposits and the lateritic iron ores are formed in an analogous manner. The bog iron ores are formed as beds on the floors of some lakes, as in Sweden, where a layer of 7 inches thick accumulated in twenty-six years. The deposition of the iron compound from the stream-water flowing into the lake may be caused by minute organisms. Some limonite beds are true chemical precipitates, whereas others result from the alteration of chalybite.

GÖTHITE (Göthe, the poet).

Comp.—Hydrated oxide of iron, $Fe_2O_3.H_2O$.

Cryst. Syst. Orthorhombic.

Com. Form.—Primary form, the prism. The prisms are longitudinally striated, and are frequently flattened, so that the crystals assume a tabular form; it also occurs massive, stalactitic, and fibrous.

Cleav.—One good cleavage.

Colour.—Brownish-black, sometimes yellowish, or reddish; often blood red by transmitted light.

Streak.—Brownish-yellow or ochre yellow.

Lustre.—Adamantine.

H.—5–5·5. *Sp. Gr.*—4–4·4.

Tests.—As for limonite (see p. 29). Distinguished from limonite by being crystalline.

Occurrence.—Associated with limonite and hematite. Some localities are Lostwithiel and Botallack in Cornwall, Saxony, Lake Onega in Russia, Jackson Iron Mountain in the United States, etc.

Turgite.—A hydrated iron oxide, $2Fe_2O_3.H_2O$. Distinguished from limonite by having a red streak, and from hematite by containing water.

PYRITES (Greek, *pur*, fire): Pyrite, Iron Pyrites, Mundic.

Comp.—Sulphide of iron, FeS_2.

Cryst. Syst.—Cubic; pyrite type (see p. 67).

Com. Form.—Cube, and pyritohedron.

The faces of the cube are often striated, the striæ of one face being at right angles to those of the adjacent faces (see Fig. 21). It also occurs massive, in nodules, which have generally a radiating structure, in finely disseminated crystals or particles, and it occasionally replaces the calcite in fossil shells.

Colour.—Bronze yellow to pale brass yellow.

Streak.—Greenish or brownish-black.

Lustre.—Metallic, splendent; opaque.

Fract.—Conchoidal, uneven; brittle. Strikes fire with steel, for which reason it was formerly used instead of flint in the old wheel-lock fire arm, a steel wheel being made to revolve rapidly by means of clockwork against a piece of pyrites, from which sparks were thrown off into the pan of the weapon.

H.—6–6·5 (compare Copper Pyrites, p. 348). *Sp. Gr.*—4·8–5·1.

Tests.—Heated in closed tube, gives sublimate of sulphur, leaving a magnetic residue. Borax bead, yellow in oxidising flame, bottle green in reducing flame. Heated on charcoal with sodium carbonate, gives magnetic residue. Black stain in silver coin test. Soluble in nitric acid, insoluble in hydrochloric acid.

Occurrence.—Pyrites is a mineral of very common occurrence in many parts of the world. It occurs not commonly as an accessory mineral in igneous rocks; more often it is secondary. It occurs in veins, and as concretions and nodular forms in sedimentary rocks.

In some cases pyrites contains enough gold to pay working for that metal. Pyrites is not worked directly as an ore of iron, the sulphur which it contains rendering it comparatively worthless for that purpose; but a good deal of the sulphuric acid and sulphate of iron (copperas) of commerce is derived from its decomposition. When present in shales or clays, its decomposition and oxidation give rise, upon the roasting of the pyritous shale or clay, to sulphuric acid. This combines with the alumina present, and upon the addition of potassium compounds, alum (a hydrous sulphate of aluminium and potassium) is formed. In this way some of the alum of commerce is prepared. Sulphur is also procured from pyrites, but of late years the market has been principally supplied by native sulphur.

MARCASITE.

A mineral identical in composition with pyrites, FeS_2. Crystallises in the orthorhombic system, occurring in tabular crystals, which are often repeatedly twinned, producing pseudo-hexagonal forms (see Fig. 82). The names cockscomb pyrites and spear pyrites are given to some of the aggregates of these twinned crystals, which

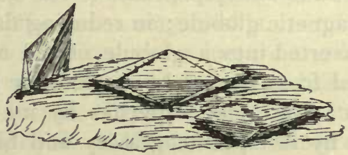


FIG. 82.—MARCASITE, TWINNED (DOVER).

occur in the Chalk and other sedimentary deposits. Also occurs in radiating forms, externally nodular. It is of a paler colour than pyrites, and decomposes more rapidly. It is used for the same purposes as ordinary pyrites, and was formerly cut and polished for ornaments.

PYRRHOTINE (Greek, *purrhote*, reddish): **Magnetic Pyrites, Pyrrhotite.**

Comp.—Sulphide of iron, Fe_nS_{n+1}. It often contains nickel, sometimes up to 5 per cent., and is then valuable as a source of that metal.

Cryst. Syst.—Hexagonal.

Com. Form.—Sometimes occurs in hexagonal prisms, which are frequently tabular; generally massive.

Cleav.—Parallel to the base.

Colour.—Reddish or brownish, bronze or copper colour; readily tarnishes on exposure.

Streak.—Dark greyish-black.

Lustre.—Metallic; opaque.

Fract.—Uneven or imperfectly conchoidal; brittle; magnetic.

H.—3·5–4·5. *Sp. Gr.*—4·4–4·65.

Tests.—Soluble in hydrochloric acid, with evolution of H_2S. Before the blowpipe, fuses in the oxidising flame to a black magnetic globule; in reducing flame on charcoal it is converted into a globule of red oxide of iron. Distinguished from pyrites by its inferior hardness and by its colour; from copper pyrites by its colour; from kupfernickel by its specific gravity and blowpipe reactions.

Occurrence.—The most important occurrence of pyrrhotine is that of Sudbury, Canada, where the mineral carries a small percentage of nickel, for which metal it is worked. The ore bodies occur as segregations fringing a basic igneous rock (norite), as impregnations, and in veins. Other less important localities are Botallack (Cornwall), Beeralston (Devonshire), Dolgelly (Wales), Kongsberg (Norway), and Andreasberg in the Harz.

CHALYBITE (Greek, *chalubs*, iron): Spathose Iron, Siderite.

Comp.—Carbonate of iron, $FeCO_3$. Iron 48·3 per cent. Often a little manganese, magnesium, and calcium are present.

Cryst. Syst.—Hexagonal.

Com. Form.—Rhombohedra, the faces of the crystals often curved; also occurs massive, cleavable, and granular.

Cleav.—Rhombohedral.

Colour.—Pale yellowish or buff brownish, and brownish-black or brownish-red.

Streak.—White.

Lustre.—Pearly or vitreous; opaque, rarely translucent.

Fract.—Uneven; brittle.

H.—3·5–4·5. *Sp. Gr.*—3·7–3·9.

Tests.—Before the blowpipe, gives iron reactions with the fluxes; alone, it blackens and becomes magnetic. Acted upon very slowly by cold acids, but in hot hydrochloric acid, it effervesces very briskly.

Varieties—Clay Ironstone.—An impure argillaceous carbonate of iron occurring as beds and nodules, especially in the Coal Measures of many countries. It is common in most of the British coalfields and in those of Pennsylvania, Ohio, etc., in the United States. Occasionally it exhibits a curious radiately disposed, rude, subcolumnar structure, causing it, when struck, to fall to pieces in conical masses, which envelop or cap one another, and to which the name of "cone in cone" structure has been given. These clay ironstones constitute very valuable ores of iron. Besides occurring in the Coal Measures, clay ironstone is also found in layers and nodules in other formations.

Oolitic Ironstone.—An iron carbonate which has replaced the calcium carbonate of an oolitic limestone, retaining the structure of the original rock, as in the celebrated Cleveland iron ore.

Occurrence.—Some chalybite deposits may be formed by direct precipitation, as in some bog iron ore deposits. These sedimentary deposits of chalybite may be altered into limonites, hematites, and magnetites, and this has occurred in the Lake Superior (Mesabi) deposits. The sedimentary chalybites include those of the Coal Measures mentioned above, typical localities being South Wales, South Staffordshire, and the other British coalfields, and the Eastern United States coalfields. The metasomatic chalybites are extremely important deposits; in them iron carbonate has replaced calcium carbonate of limestones, retaining many of the original features of the rock (oolitic structure, fossils, etc). To this class belong the Cleveland ores.

COPPERAS (Greek, *melas*, black): **Green Vitriol, Melanterite.**

Comp.—Hydrated sulphate of iron, $FeSO_4.7H_2O$.

Cryst. Syst.—Monoclinic.

Com. Form.—When crystallised, it occurs in acutely prismatic crystals, but it is more commonly found massive or pulverulent; also botryoidal, reniform, and stalactitic.

Colour.—Various shades of green to white; exposed surfaces generally of a yellowish or yellowish-brown colour, and with a vitrified or glazed appearance, at times resembling a furnace slag.

Streak.—Colourless.

Lustre.—Vitreous; subtransparent or translucent.

Fract.—Conchoidal; brittle.

Taste.—Sweetish, astringent and metallic, nauseous.

H.—2. *Sp. Gr.*—1·83.

Tests.—Heated before the blowpipe, becomes magnetic. Gives a green glass with borax. Soluble in water, the solution turning black on the addition of tincture of nutgalls.

Occurrence.—Copperas results from the decomposition of pyrites, the sulphur present in the latter mineral becoming oxidised to sulphuric acid, which, combining with the iron and taking up a certain amount of water, forms copperas. Copperas is found wherever pyrites occurs. Copperas Mount, Ohio, U.S.A., and Goslar in the Harz, are noted localities.

Uses.—Copperas is used by tanners, dyers, and ink manufacturers, as it yields a black colour with tannic acid. When treated with potassium ferrocyanide (yellow prussiate of potash), it forms the pigment known as Prussian blue.

VIVIANITE: Blue-Iron Earth.

Comp.—Hydrated phosphate of Iron, $Fe_3P_2O_8.8H_2O$. Iron peroxide is sometimes present.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals, modified prisms, generally very small, and often forming divergent aggregations; also occurs radiating, reniform, and as encrustations.

Cleav.—Clinopinacoidal; highly perfect.

Colour.—White, or nearly colourless when unaltered, but usually deep blue or green. When viewed parallel to the vertical axis, it usually appears blue, while at right angles to the vertical axis it looks green. The mingling of these two colours gives rise to the dirty blue colour which the mineral generally presents.

Streak. — Bluish-white, sometimes colourless, soon changing to indigo blue; colour of dry powder, liver brown.

Lustre.—Pearly to vitreous; transparent or translucent, turning opaque on exposure.

Fract.—Not observable; sectile; thin lamellæ flexible.

H.—1·5–2. *Sp. Gr.*—2·66.

Tests.—Before blowpipe, fuses, loses its colour, and becomes converted to a greyish-black magnetic globule. With the fluxes, gives iron reactions. Heated in glass tube, it whitens, exfoliates, and yields water; soluble in hydrochloric acid. Phosphorus indicated by magnesium test, and by yielding a blue fused mass with cobalt nitrate on charcoal.

Occurrence.—Vivianite is found associated with iron, copper, and tin ores; it also occurs in clay, mud, and peat, and especially with bog iron ore. Sometimes it is found in or upon fossil-bones and shells. Localities are—Several mines in Cornwall and Devon, in peat swamps in Shetland, in the Isle of Man (occurring with the horns of the elk and deer), Bodenmais in Bavaria, Transylvania, etc.

LIEVRITE, ILVAITE: Yenite.

Comp.—Silicate of iron and calcium, $H_2O.CaO.4FeO.Fe_2O_3.4SiO_2$. A little oxide of manganese is frequently present.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals, the sides often deeply striated longitudinally; also compact and massive.

Colour.—Black or brownish-black.

Streak.—Black, brownish, or greenish.

Lustre.—Submetallic; opaque.

Fract.—Uneven; brittle.

H.—5·5–6. *Sp. Gr.*—3·8–4·1.

Tests.—Before the blowpipe, fuses to a black globule; with borax, yields a dark green and nearly opaque bead. Soluble in hydrochloric acid, forming a jelly.

Occurrence.—Occurs in Elba, the Harz, Tyrol, Saxony, Norway, and Rhode Island.

TITANIFEROUS IRON ORES.

ILMENITE: Menaccanite.

Comp.—Oxide of iron and titanium, $FeO.TiO_2$. Very variable in composition, especially in the ratio of titanium to iron. A little magnesia is often present.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Often occurs in thin plates or scales, and massive; also as sand.

Colour.—Iron black.

Streak.—Black to brownish-red.

Lustre.—Submetallic; opaque.

Fract.—Conchoidal.

H.—5–6. *Sp. Gr.*—4·5–5.

Opt. Props.--Ilmenite can be recognised in thin sections by its black, opaque character. If viewed by reflected light, it is seen to be altered along three directions into a white substance called leucoxene, which is regarded as a variety of sphene.

Tests.—Infusible, or nearly so. Gives iron reactions with the fluxes. Heated on charcoal with sodium carbonate, dissolved in hydrochloric acid, gives a violet colour on the addition of a small particle of tin. Heated on charcoal with sodium carbonate, dissolved in sulphuric acid, and cooled; the solution diluted with an equal bulk of water gives an amber-coloured solution on addition of a drop of hydrogen peroxide.

Varieties—Menaccanite.—A variety of ilmenite occurring as a sand at Menaccan, Cornwall.

Iserine.—A variety occurring mostly in the form of loose granules or sand, and frequently in octahedral crystals, which are probably pseudomorphs.

Kibdelophane.—A variety rich in titanium.

Occurrence.—Occurs as an accessory constituent in the more basic rocks, norites especially; sometimes as large segregations, as at Taberg and Ekersund, Norway, Quebec, in the Adirondacks, Minnesota, etc. It occurs also in veins which are probably of pneumatolytic origin.

Iserine was first found near the source of the River Iser, in Silesia, whence the name. It also occurs in the form of sand, mixed with magnetite, on the shore of the Mersey, nearly opposite Liverpool. Titaniferous iron sand is also abundant in the Tertiary rocks of Victoria and along the shores of New Plymouth; in Taranaki, New Zealand, where the deposit extends for several miles to a depth of many feet.

COBALT (Co).

Cobalt is a malleable metal closely resembling nickel in appearance. It possesses a high melting-point (between 1,500° C. and 1,800° C.). It can be produced by the reduction of its oxides by carbon. Cobalt has been used for plating metals. Its artificially prepared compounds are used as pigments (blues). Other uses are in alloys and pottery.

The chief sources of cobalt are those of New Caledonia (asbolite) and Ontario, Canada, where it is associated with arsenic, nickel, and often a considerable amount of silver.

Cobalt deposits of economic value occur in three main ways: as cobalt veins carrying smaltite and cobaltite, as cobaltiferous pyrrhotine (Sudbury), and as asbolite, which results from the weathering of cobaltiferous basic rocks, and is analogous to the garnierite deposits of nickel (New Caledonia).

The minerals of cobalt are, therefore—

Arsenide	Smaltite, $CoAs_2$.
Arsenide and Sulphide ...	Cobaltite, CoAsS.
"*Bloom*"	Erythine, $Co_3As_2O_8.8H_2O$.
Oxide	Asbolite. Oxide of manganese, sometimes containing up to 40 per cent. cobalt oxide.

Tests.—Cobalt minerals colour both borax and microcosmic beads a rich blue. The residue obtained by heating cobalt minerals with sodium carbonate and charcoal is feebly magnetic.

The name cobalt is derived from the cobbolds or imps formerly supposed to reside in mines.

Cobalt minerals weather on their exterior to pinkish cobalt "blooms," the cobalt indicators.

SMALTITE : Tin White Cobalt.

Comp.—Cobalt arsenide, $CoAs_2$. Contains usually some iron and nickel.

Cryst. Syst.—Cubic.

Com. Form.—Octahedron, cube, and rhombdodecahedron, variously modified. Usually occurs massive or reticulated.

Cleav.—Octahedral, and tolerably distinct; cubic less distinct.

Colour.—Tin white, approaching steel grey when massive. Tarnishes on exposure, sometimes iridescently.

Streak.—Greyish-black.

Lustre.—Metallic.

Fract.—Granular and uneven; brittle.

H.—5·5–6. *Sp. Gr.*—6·4–7·2.

Tests.—Heated in closed tube, gives a sublimate of metallic arsenic; in the open tube, a sublimate of arsenious oxide. On charcoal, gives off an arsenical odour, and fuses to a globule, which yields with borax reactions for cobalt. The presence of cobalt is often indicated by the occurrence of a pinkish coating (cobalt bloom) on the surface of the mineral.

Occurrence.—Smaltite occurs in hydatogenetic veins, associated with calcite, quartz, barytes, and silver, nickel, and copper minerals. The main source of supply is Cobalt, Ontario. Other localities are Schneeberg, Freiberg, and Annaberg in Saxony. Less important are several mines in Cornwall, Joachimsthal in Bohemia, etc.

COBALTITE.

Comp.—Sulphide and arsenide of cobalt, CoAsS.

Cryst. Syst.—Cubic.

Com. Form.—Pyritohedron. Usually found massive, granular, and compact.

Colour.—Silver white, with a reddish tinge.

Streak.—Greyish-black.

Lustre.—Metallic.

H.—5·5. *Sp. Gr.*—6–6·3.

Tests.—Heated in closed tube, remains unaltered; in the open tube it yields the sublimate of arsenious oxide, and gives off sulphurous fumes. Cobalt bead with borax. Decomposed by nitric acid.

Occurrence.—With smaltite (see above).

ERYTHINE (Greek, *erythros*, red): Cobalt Bloom.

Comp.—Hydrated arseniate of cobalt, $Co_3As_2O_8.8H_2O$. Calcium, nickel, and iron oxides frequently present.

Cryst. Syst.—Monoclinic.

Com. Form.—Crystals prismatic, uncommon. Occurs mostly earthy, pulverulent, or encrusting, sometimes globular or reniform.

Cleav.—Parallel to the clinopinacoid. Highly perfect, giving rise to a foliated structure, the laminæ being flexible in one direction.

Colour. — Peach red, or crimson-red, occasionally greyish or greenish.

Streak.—Same as colour, but rather paler, and the powder, when dry, is lavender blue.

Lustre.—Of cleavage planes, pearly; of other faces, adamantine or vitreous; in uncrystallised specimens, dull and lustreless.

H.—1·5–2·5. *Sp. Gr.*—2·95.

Tests.—When heated slightly in the closed tube, it yields water, and on additional heating it gives a sublimate of arsenious oxide. Before the blowpipe, alone, fuses and colours the flame light blue. With borax, gives a deep blue bead. Soluble in hydrochloric acid, forming a rose-red solution.

Occurrence.—Erythine is the cobalt bloom formed by the weathering of cobalt ores, and is found associated with smaltite and cobaltite (see p. 336).

EARTHY COBALT, ASBOLAN (Greek, *asbole*, soot): Black Oxide of Cobalt.

Comp.—This mineral is essentially wad (see p. 279), or hydrated oxide of manganese, containing a variable percentage of cobalt oxide mechanically mixed with it, sometimes amounting to nearly 40 per cent. Sulphide of cobalt and oxides of copper, iron, and nickel are at times present.

Com. Form.—Amorphous, earthy.

Colour.—Black or blue-black.

Streak.—Black, shining, and resinous.

Occurrence.—Occurs with the other ores of cobalt, and of manganese, especially at Mine La Motte, in Missouri, U.S.A. A very important occurrence is in New Caledonia, where the asbolan deposits represent the superficial alteration of a cobaltiferous serpentine (*cf.* Garnierite and Nickel).

NICKEL (Ni).

Nickel, which never occurs native, is a white malleable metal, unaffected by moist or dry air, and capable of taking a high polish. It is obtained by the reduction of its oxide or by the "Mond" process, which consists in the formation of a volatile nickel carbonyl produced by passing carbon monoxide over heated nickel oxide, and the dissociation of this compound at a higher temperature into nickel in a great state of purity and carbon monoxide, which can be used again. The ore is usually first treated for the production of matte, and within recent years the copper-nickel ores of Canada have been successfully smelted for the direct production of "monel metal," an alloy of nickel and copper, whose applications are of increasing importance.

Except for deposition by electrolysis on other metals (nickel-plating), the use of nickel in a pure form is unimportant, but it has very extensive applications in the form of alloys with other metals—for example, German silver (an alloy of copper, nickel, and zinc in varying proportions), white metal, nickel bronzes, etc. The manufacture of nickel steel alloys containing from 2·5 to as much as 35 per cent. nickel absorbs the largest proportion of the nickel produced. Nickel steel has a greater hardness and tensile strength than carbon steel, and is used for armour plate, structural, and other purposes.

About 25,000 tons of nickel were produced in 1912, the most important source being the nickeliferous pyrrhotine (with which is associated arsenic, copper, and cobalt, and which often contains a considerable amount of silver) of Sudbury, Ontario; this district produced in 1912 about 800,000 tons of ore, averaging about 3 per cent. nickel and 1·5 per cent. copper. New Caledonia follows with a production in 1912 of about 80,000 tons. Nickel deposits may be divided into three types similar to the cobalt deposits—that is, veins, nickeliferous pyrrhotines, and nickeliferous serpentine (garnierite).

The minerals of nickel are—

Arsenides	Kupfernickel, $NiAs$. Chloanthite, $NiAs_2$.
Sulphide	Millerite, NiS.
"*Blooms*"	Emerald nickel, $NiCO_3.2Ni(OH)_2.4H_2O$. Nickel vitriol, $NiSO_4.7H_2O$. Nickel bloom (annabergite), $Ni_3As_2O_8.8H_2O$.
Silicate	Garnierite, hydrated nickeliferous magnesium silicate.

Tests.—Blowpipe reactions for nickel are poor. In the borax bead, nickel compounds give a reddish-brown colour in oxidising flame, which changes to a flecked opaque grey in the reducing flame; in the microcosmic bead the colours are reddish-browns. Nickel compounds give a feebly magnetic residue when heated on charcoal with sodium carbonate. Nickel ores oxidise on the surface to a green colour, the nickel blooms, due to the formation of oxysalts of the metal.

KUPFERNICKEL (German, *kupfer*, copper, and *nickel*, false). NICCOLITE: Copper Nickel, Arsenical Nickel.

Comp.—Nickel arsenide, NiAs. Antimony and traces of cobalt, iron, and sulphur, are sometimes present.

Cryst. Syst.—Hexagonal.

Com. Form.—Usually found massive.

Colour.—Pale copper red, like that of a new penny; sometimes with a tarnish.

Streak.—Pale brownish-black.

Lustre.—Metallic; opaque.

Fract.—Uneven; brittle.

H.—5–5·5. *Sp. Gr.*—7·3–7·6.

Tests.—Before the blowpipe, gives arsenical fumes, and fuses to a globule, and this fused substance, if subsequently heated in a borax bead, affords reactions for nickel (oxidising flame, reddish-brown; reducing flame, opaque grey), and also for cobalt and iron. Soluble in nitric acid.

Occurrence.—Kupfernickel is usually associated in hydatogenetic veins with cobalt, silver, and copper ores, and is one of the principal sources of metallic nickel. Chief localities are—Cobalt (Ontario), Cornwall, Saxony, Harz, etc. (see Occurrences of Smaltite, p. 336).

CHLOANTHITE: White Nickel.

Comp.—Nickel arsenide, $NiAs_2$. At times much cobalt replaces the nickel, causing the mineral to graduate into smaltite; sometimes iron is also present.

Cryst. Syst.—Cubic.

Com. Form.—Cube; usually massive.

Colour.—Tin white.

Streak.—Greyish-black.

H.—5·5–6. *Sp. Gr.*—6·4–6·7.

Tests.—As for kupfernickel (see p. 340).

Occurrence.—It usually occurs with smaltite at localities cited for that mineral (see p. 336), especially at Cobalt, Ontario. Chloanthite is a valuable nickel ore.

Breithauptite : Antimonial Nickel. — A mineral consisting mainly of antimony and nickel, being nickel antimonide, NiSb, often with a considerable amount of lead sulphide. It crystallises in the hexagonal system, crystals rare; usually massive. In colour is a light copper red when freshly broken, and possesses a highly metallic lustre. Hardness, 5·5. Specific gravity, 7·5. It occurs at Andreasberg, in the Harz.

MILLERITE : Nickel Pyrites, Capillary Pyrites.

Comp.—Nickel sulphide, NiS. Traces of cobalt, copper, and iron often present.

Cryst. Syst.—Hexagonal (rhombohedral).

Com. Form.—Usually occurs in capillary crystals of extreme delicacy, whence the name *capillary*, or *hair pyrites*. Sometimes, but rarely, occurs in columnar, tufted coatings; also in rhombohedra, rarely.

Cleav.—Rhombohedral, and perfect.

Colour.—Brass yellow to bronze yellow; often tarnished.

Streak.—Greenish-black.

Lustre.—Metallic.

H.—3–3·5. *Sp. Gr.*—4·6–5·6.

Tests.—Heated in open tube, gives sulphurous fumes. Before blowpipe, after previous roasting, it gives, with borax and microcosmic salt, a violet bead in the oxidising, and a grey bead, owing to the reduction to metallic nickel, in the reducing flame. The impurities, also, often give reactions in the beads. Heated on charcoal with sodium carbonate and carbon, gives a metallic magnetic mass of nickel.

Occurrence.—Occurs chiefly as nodules in clay ironstone, as in South Wales; also associated in veins with other nickel and cobalt minerals, as at Cobalt (Ontario), Cornwall, Saxony, and especially the Gap Mine, Lancaster Co., Pennsylvania, U.S.A.

Emerald Nickel: Zaratite.

Comp.—Hydrated carbonate of nickel, $NiCO_3.2Ni(OH)_2.4H_2O$. In some of the paler varieties a little of the nickel is replaced by magnesium.

Com. Form.—Occurs as an encrustation, sometimes minutely mammillated and stalactitic; also massive and compact.

Colour.—Emerald green.

Streak.—Paler than the colour.

Lustre.—Vitreous; transparent to translucent.

H.—3–3·25. *Sp. Gr.*—2·5–2·6.

Tests.—Heated in closed tube, gives off water and carbon dioxide, leaving a dark, magnetic residue. Gives the usual nickel reaction with borax. Dissolves with effervescence when heated in dilute hydrochloric acid.

Occurrence.—Occurs as a coating to other nickel minerals, and is associated with chromite and serpentine.

Nickel Indicators.

The hydrated and oxidised nickel minerals form on the exterior of other nickel minerals, and are known as "nickel blooms" or nickel indicators. They are all green in colour, and the main species are—

1. Emerald nickel (see above).
2. Nickel vitriol (moresonite), $NiSO_4.7H_2O$.
3. Nickel bloom (annabergite), $Ni_3As_2O_8.8H_2O$.

Annabergite, $Ni_3As_2O_8.8H_2O$. — A hydrated arseniate of nickel resulting from the decomposition of kupfernickel, and occurring as a coating of capiliary apple-green crystals.

GARNIERITE, NOUMEITE.

Comp.—Essentially a hydrated nickel magnesium silicate, but very variable.

Com. Form.—Amorphous; soft and friable.

Colour.—Apple green to nearly white.

Lustre.—Dull.

Sp. Gr.—2·3–2·8.

Tests.—Adheres to the tongue. Heated in closed tube, gives water. In borax bead, gives nickel reactions. In microcosmic bead, gives nickel reaction, and leaves an insoluble "skeleton" of silica, indicating a silicate.

Occurrence.—Occurs in serpentine near Noumea, New Caledonia, in veins associated with chromite and talc. A residual deposit, rich in nickel, is formed by the decay of the nickeliferous serpentine. Also at Riddle (Oregon), Webster (North Carolina), and Revda (Urals). An important source of nickel.

Genthite.—A hydrated nickel magnesium silicate, related to garnierite.

COPPER (Cu).

This metal which in combination is a widely distributed and abundant element, is also found native. Copper has a specific gravity of about 8·9, and melts at about 1,080° C. It is a comparatively soft but extremely tough metal, very ductile and malleable when pure, and, next to silver, the best conductor of electricity.

Copper is obtained from its ores (usually sulphide) by an elaborate series of metallurgical operations, commonly consisting of roasting, to expel part of the combined sulphur, fusion in blast or reverberatory furnaces for the production of a concentrated doubl sulphide of copper and iron (called matte), which is reduced to crude metallic copper in a reverberatory furnace or in a Bessemer converter. Blast-furnaces are sometimes used for ores rich in sulphur, for the production of copper matte (pyritic smelting—*i.e.*, utilising the heat produced by the oxidation of the sulphides, with the aid of little or no fuel), or for the further concentration of matte from the first reverberatory furnace fusion. Oxidised ores may be reduced in a blast-furnace with coal or coke, but are best smelted in admixture with sulphide ores. In the case of native copper, the ore is crushed and the metal, separated from its gangue by dressing, melted in some form of reverberatory furnace. Copper of the necessary purity for use as conducting-wires is obtained from the crude metal by electrolysis. From poor ores and residues from the pyrites used in the manufacture of sulphuric acid, copper is obtained by roasting with common salt, leaching out the soluble copper chloride with water, and deposition of the metal on scrap-iron or by electrolysis.

Copper is extensively used in the manufacture of alloys, such as bronze, gun-metal, bell-metal (copper and tin), brass (copper, zinc, and sometimes tin), and some others of great technical importance, such as phosphor and manganese bronzes (copper and tin, with small percentages of phosphorus or ferro-manganese).

The chief sources of copper are native copper, copper pyrites, erubescite, and malachite. Associated with copper ores are frequently found the following metals, recoverable at one or other stage of their treatment : gold, silver, platinum, palladium, bismuth, etc.

The United States produced in 1912 about 50 per cent. of the world's production of rather more than 1,000,000 tons of metallic copper. The percentage of metal in the ores mined in the United States, primarily for their copper content, and not including other ores in which copper was of secondary importance, varied from under 1 per cent. to nearly 16 per cent., with an average content of under 2 per cent. of copper. Spain and Portugal together produce annually between 50,000 and 60,000 tons, and an increasing amount is now produced in Africa.

Sulphide ores, with the exception of some containing erubescite, are usually readily amenable to wet concentration ; but carbonate ores, of which huge deposits occur, are not easily so treated. Large deposits containing copper carbonate exist in remote parts of Africa, the United States, etc., which, owing to difficulties of treatment, are at the present time of no commercial value.

The sulphides of copper, which occur in depth in a copper lode, are converted by oxidation and other chemical actions in the surface portion to the native metal, oxides, and oxy-salts. The copper minerals are therefore—

Element ...	... Native copper, Cu.
Oxides ...	... Cuprite, Cu_2O.
	Tenorite, CuO.
Sulphides ...	... Copper pyrites, $Cu_2S.Fe_2S_3$.
	Copper glance, Cu_2S.
	Erubescite, Cu_3FeS_3.
"*Grey Coppers*" ...	Tetrahedrite, $4Cu_2S.Sb_2S_3$.
	Tennantite, $4Cu_2S.As_2S_3$.
	Famatinite, $3Cu_2S.Sb_2S_5$.
	Enargite, $3Cu_2S.As_2S_5$.
	Bournonite, $3(PbCu_2)S.Sb_2S_3$.
Sulphate ...	... Chalcanthite, $CuSO_4.5H_2O$.

Carbonates	Malachite, $CuCO_3.Cu(OH)_2$. Azurite, $2CuCO_3.Cu(OH)_2$.
Silicates	Chrysocolla, $CuO.SiO_2.2H_2O$. Dioptase, $CuO.SiO_2.H_2O$.
Chloride	Atacamite, $CuCl_2.3Cu(OH)_2$.

Tests.—Copper oxides colour the flame emerald green when moistened with nitric acid, and copper chloride colours the flame an intense sky blue. The microcosmic bead is green in the oxidising flame, and opaque red in the reducing flame. The borax bead is somewhat similar. When heated with sodium carbonate and carbon on charcoal, copper compounds give a reddish mass, which speedily blackens.

NATIVE COPPER.

Comp.—Pure copper, sometimes containing a little silver and bismuth.

Cryst. Syst.—Cubic.

Com. Form.—Crystals frequently twinned, no cleavage; also occurs massive. Sometimes in thin sheets or plates, filling narrow fissures. Arborescent forms are also of frequent occurrence, and at times it is found in confused threads, filiform.

Colour.—Copper red.

Streak.—Metallic and shining.

Lustre —Metallic.

Fract.—Hackly; ductile and malleable.

H.—2·5–3. *Sp. Gr.*—8·8.

Tests.—Before blowpipe, fuses easily, and on cooling becomes coated with black oxide of copper. Dissolves in nitric acid, and affords a blue solution on addition of ammonia.

Occurrence.—Native copper occurs as a metasomatic deposit, filling cracks, amygdules, and forming the cement of sandstones and conglomerates. The immense Lake Superior deposits are of this type. The copper is associated with native silver, and a mass of 420 tons weight has been found. Other localities of this type are Chili, Queensland, Zwickau (Germany), Rhodesia, and Wisconsin. Native copper also occurs in the upper part of copper lodes—the gossan, or zone of weathering. The Burra Burra, and other localities in Australia have also yielded large supplies of native copper.

CUPRITE (Latin, *cuprum*, copper): **Red Oxide of Copper.**

Comp.—Oxide of copper, Cu_2O. Copper, 88·8 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Octahedron and rhombdodecahedron; sometimes massive or earthy, and occasionally capillary.

Cleav.—Parallel to faces of octahedron.

Colour.—Different shades of red, especially cochineal red.

Streak.—Brownish-red and shining.

Lustre.—Adamantine, or submetallic to earthy; subtransparent to nearly opaque.

Fract.—Conchoidal, uneven; brittle.

H.—3·5–4. *Sp. Gr.*—5·8–6·15.

Tests.—Before the blowpipe, colours the flame emerald green. On charcoal, fuses to a globule of metallic copper. With the fluxes, it gives the usual copper reactions. Soluble in acids.

Varieties—Ruby Copper.—Crystallised cuprite.

Tile Ore.—A red or reddish-brown earthy variety, generally containing oxide of iron.

Chalcotrichite.—(Greek, *chalkos*, copper, and *thrix*, hair). Consists of delicate, straight, interlacing fibrous crystals, of a beautiful cochineal red colour.

Occurrence.—Occurs in the zone of weathering, or gossan, of copper lodes. Localities are — Cornwall, Chessy (France), Linares (Spain), Lake Superior, Chili, Peru, Burra Burra (South Australia).

Tenorite, Melaconite.

Comp.—Copper oxide, CuO. Copper, 79·85 per cent.

Com. Form.—Occurs mostly in a black powder; also in dull, black masses, and in botryoidal concretions. Sometimes in shining and flexible scales.

H.—3. *Sp. Gr.*—6·25 when massive.

Tests.—Gives the usual copper reactions with the fluxes, but is infusible alone in the oxidising flame. Soluble in acids.

Occurrence.—In the zone of weathering, or gossan, of copper lodes. Abundant in the copper mines of the Mississippi Valley and in Tennessee, U.S.A., where it is worked. Formerly worked in the Lake Superior copper region.

COPPER PYRITES, CHALCOPYRITE.

Comp.—Sulphide of copper and iron, $Cu_2S.Fe_2S_3$. Copper 32·5–34 per cent.

Cryst. Syst.—Tetragonal.

Com. Form.—Crystals approximate to cubic form. Wedge-shaped forms are common. Frequently twinned. Generally found massive.

Colour.—Brass yellow, frequently with a tarnish, which is sometimes iridescent (peacock copper).

Streak.—Greenish-black; very slightly shining.

Lustre.—Metallic; opaque.

Fract.—Conchoidal, uneven.

H.—3·5–4. *Sp. Gr.*—4·1–4·3.

Tests.—Decrepitates when heated in the closed tube, and gives a sublimate of sulphur. Before blowpipe on charcoal, fuses to a metallic globule, and gives off sulphurous fumes. With fluxes, affords reactions for both copper and iron. Copper pyrites may be distinguished from iron pyrites by its inferior hardness, the former crumbling when cut with a knife, the latter resisting the attempt to cut it. Iron pyrites also emits sparks when struck with steel; copper pyrites does not. The powder of iron pyrites is black, of copper pyrites greenish-black. Copper pyrites may be distinguished from gold by its brittleness and non-malleability, gold being soft, malleable, and very easily cut with a knife.

Occurrence.—Copper pyrites is the principal commercial source of copper. The most important mode of occurrence of the mineral is in hydatogenetic veins associated with quartz, pyrites, etc. Some localities are—Wallaroo (South Australia), Great Cobar and Broken Hill (New South Wales), Mount Morgan (Queensland), Shasta County (California), Sonora (Mexico), Bisbee (Arizona), Alaska, Chili, Monte Catini (Italy), Urals, Rhodesia, Namaqualand. Metasomatic copper pyrites veins occur in the Urals, Bisbee, and Monte Catini. Pneumatolytic veins occur in Cornwall, Norway, Oregon, Mexico, Chili, etc. Magmatic segregations of copper pyrites are known, but are not important. Copper pyrites also occurs in the famous Kupferschiefer of Permian age at Mansfeld (Germany), where the mineral occurs as grains in a sandstone, and has probably resulted from the reduction of copper sulphates by the action of decaying vegetation.

COPPER GLANCE, CHALCOCITE, REDRUTHITE: Vitreous Copper Ore.

Comp.—Sulphide of copper, Cu_2S. Traces of iron are usually present.

Cryst. Syst.—Orthorhombic.

Com. Form.—Combinations of prism and pinacoids.

Twinning frequently gives a stellate grouping of three individuals. Also occurs massive, and with a granular or compact structure.

Cleavage.—Poor ; prismatic.

Colour.—Blackish lead grey ; often with a bluish or greenish tarnish.

Streak.—Same as colour ; sometimes shining.

Lustre.—Metallic.

Fract.—Conchoidal.

H.—2·5–3. *Sp. Gr.*—5·5–5·8.

Tests.—On charcoal, boils, ultimately fusing to a globule of copper. Soluble in hot nitric acid, but leaving a precipitate of sulphur. Other copper reactions given.

Occurrence.—Copper glance is a very valuable ore, but does not occur in very great abundance. Occurs in veins and beds associated with other copper ores, as in Cornwall, Siberia, Saxony, Kongsberg (Norway), Monte Catini (Italy), Mexico, Peru, Bolivia, Chili, etc.

COVELLINE.

A copper sulphide, CuS, occurring massive usually, but known in hexagonal crystals. Indigo blue in colour. Is formed in the zone of secondary enrichment in copper veins. This zone is situated between the gossan and the unaltered zone, and in it occur products of the chemical action between the original vein stuff and descending solutions, and it often forms the richest part of the lode. Covelline is found in Chili, Mansfeld (Germany), etc.

ERUBESCITE (Latin, *erubesco*, to redden), BORNITE : Variegated Copper Ore.

Comp.—Sulphide of copper and iron. Composition varies, the ratio of iron and copper being expressed for the average by the formula, Cu_3FeS_3.

Cryst. Syst.—Cubic.

Com. Form.—Crystals of cube and octahedron known, but most commonly massive.

Colour.—Copper red, or pinchbeck brown; tarnishes speedily on exposure.

Streak.—Pale greyish-black, and slightly shining.

Lustre.—Metallic.

Fract.—Small, conchoidal, and uneven; brittle.

H.—3. *Sp. Gr.*—4·9–5·4.

Tests.—Heated in open tube, yields sulphur dioxide fumes, but gives no sublimate. Fuses in the reducing flame to a brittle magnetic globule. Soluble in nitric acid, leaving a deposit of sulphur. Distinguished by its tarnish and by the red colour on a fresh surface.

Occurrence.—Erubescite is a very valuable ore of copper. It occurs in the zone of secondary enrichment of copper lodes, associated with copper pyrites, covelline, etc. It occurs in some of the Cornish mines, where it is known as horse-flesh ore; Monti Catini (Italy); Mansfeld (Germany); Norway, etc.

SULPHIDES OF COPPER, ARSENIC, AND ANTIMONY.

Tetrahedrite, $4Cu_2S.Sb_2S_3$.
Tennantite, $4Cu_2S.As_2S_3$.
Famatinite, $3Cu_2S.Sb_2S_5$.
Enargite, $3Cu_2S.As_2S_5$.

TETRAHEDRITE: Grey Copper, Fahlerz.

Comp.—Sulphide of copper and antimony, $4Cu_2S.Sb_2S_3$. Part of the copper is often replaced by iron, zinc, silver, or mercury. Part of the antimony is often replaced by arsenic, seldom by bismuth. It sometimes contains 30 per cent. silver in place of part of the copper, and is then called argentiferous grey copper ore, or silver fahlerz, but is then more of the nature of stephanite (p. 367).

Cryst. Syst.—Cubic, tetrahedrite type (see p. 69).

Com. Form.—Tetrahedral crystals, usually modified; crystals frequently twinned. Also massive, with a compact, granular, or cryptocrystalline structure.

Colour.—Between steel grey and iron black.

Streak.—Nearly the same as the colour.

Lustre.—Metallic; opaque, but very thin splinters of it are subtranslucent, and appear cherry red by transmitted light.

Fract.—Subconchoidal or uneven; rather brittle.

H.—3–4·5. *Sp. Gr.*—4·5–5·1.

Tests.—This mineral varies in its chemical behaviour according to the different substances which the varieties contain. In the closed tube they all fuse, affording a deep red sublimate of antimony sulphide. In the open tube, fuses and gives off sulphurous fumes, and forms a white sublimate inside the tube. The mercurial varieties give minute globules of quicksilver. On charcoal, fuses and yields, according to the constituents present, white encrustations of antimony oxide, arsenic oxide, or zinc oxide, or a yellow encrustation of lead oxide. The zinc encrustation becomes green when moistened with cobalt nitrate and reheated. Heated before the blowpipe with sodium carbonate, yields scales of metallic copper. Soluble in nitric acid; arsenic oxide, antimony oxide, and sulphur remaining.

Occurrence.—Occurs associated with other ores of copper, and with pyrites, galena, blende, etc. Localities are Levant (Cornwall), Andreasberg (Harz), Freiberg (Saxony), Przibram (Bohemia), Chili, Bolivia, and Arkansas and Colorado (U.S.A.).

TENNANTITE.

Comp.—Sulphide of copper and arsenic, $4Cu_2S.As_2S_3$. Often contains antimony, causing it to grade towards tetrahedrite.

Cryst. Syst.—Cubic; tetrahedral.

Com. Form.—Tetrahedral crystals; usually massive and compact.

Colour.—Blackish lead grey to iron black.

H.—3–4. *Sp. Gr.*—4·37–4·49.

Occurrence.—Occurs associated with other copper ores in Cornwall, Freiberg (Saxony), and in Colorado.

Famatinite.—*Comp.*—Sulphide of copper and antimony, $3Cu_2S.Sb_2S_5$. Isomorphous with enargite (*q.v.* below). In colour, is greyish to copper red. Occurs in the Sierra de Famatina, Argentine.

ENARGITE.

Comp.—Sulphide of copper and arsenic, $3Cu_2S.As_2S_5$. Antimony often present, when the mineral grades into famatinite.

Cryst. Syst.—Orthorhombic.

Com. Form.—Usually occurs massive and granular. Small crystals known, often repeatedly twinned.

Cleav.—Good; prismatic.

Colour.—Greyish-black to iron black.

Lustre.—Metallic.

H.—3. *Sp. Gr.*—4·43–4·45.

Occurrence.—Occurs with other ores of copper, especially at Butte (Montana), also in Peru, Chili, Argentine, Mexico, etc.

BOURNONITE: Wheel Ore, Endellionite.

Comp.—Sulphide of copper, lead, and antimony, $3(Pb,Cu_2)S.Sb_2S_3$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Modified prisms, often twinned, producing a cruciform or cog-wheel-like arrangement, whence the name wheel ore (Radelerz), given to it by the German miners (see Fig. 83). Also occurs massive.

Colour.—Steel grey or lead grey, and sometimes blackish.

Streak.—Same as colour.

Lustre.—Metallic; opaque.

Fract.—Conchoidal or uneven; brittle.

H.—2·5–3. *Sp. Gr.*—5·7–5·9.

Tests.—On charcoal, fuses easily, giving at first a white encrustation of antimony oxide, and afterwards a yellow one of lead oxide. The residue heated with sodium carbonate on charcoal yields reddish flakes of metallic copper.

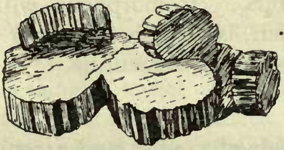


FIG. 83.—BOURNONITE, WHEEL ORE.

Occurrence.—Occurs with other ores of copper. First found in St. Endellion (Cornwall); also occurs at Kapnic (Transylvania), Saxony, Clausthal, Andreasberg, and Neudorf (in the Harz), Chili, Bolivia, etc.

CHALCANTHITE, BLUE VITRIOL: Cyanosite, Copper Vitriol.

Comp.—Hydrated sulphate of copper, $CuSO_4.5H_2O$.

Cryst. Syst.—Triclinic.

Com. Form.—In triclinic crystals; also compact massive, stalactitic and encrusting.

Colour.—Sky blue, sometimes greenish.

Streak.—Colourless.

Lustre.—Vitreous; subtransparent to translucent.

Fract.—Rather brittle.

Taste.—Nauseous and metallic.

H.—2·5. *Sp. Gr.*—2·12–2·3.

Tests.—Heated in the closed tube, gives water. Soluble in water, the solution coating a clean strip of iron with metallic copper. By this means much copper may often be procured from the water pumped from copper mines. Heated on charcoal with sodium carbonate and carbon, yields metallic copper.

Occurrence.—Results from the alteration of copper pyrites, and occurs therefore in the zone of weathering or gossan of copper lodes, as in Cornwall, in the Rammelsberg mine in the Harz, etc.

Brochantite, Warringtonite, Langite.—These three minerals are hydrated sulphates of copper, of an emerald green colour.

MALACHITE (Greek, *malache*, marsh-mallow, from its green colour).

Comp.—Hydrated carbonate of copper, $CuCO_3.Cu(OH)_2$.

Cryst. Syst.—Monoclinic.

Com. Form.—Commonly occurs massive, encrusting, stalactitic, or stalagmitic, and with a smooth, mammillated or botryoidal surface (see Fig. 84). Internal structure often divergently fibrous and compact. Also occurs granular and earthy.

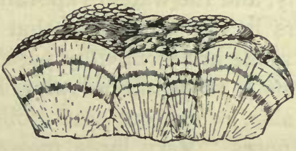


FIG. 84.—MALACHITE, STALACTITIC.

Colour.—Bright green; different shades of the colour following a concentrically banded arrangement.

Streak.—Of the uncrystallised variety, paler than the colour.

Lustre.—Slightly silky on surfaces broken parallel with the fibrous structure. Sometimes earthy or dull. The crystals have an adamantine lustre inclining to vitreous, and they are translucent or subtranslucent. In the massive, mammillated, stalactitic, and stalagmitic conditions, the mineral is opaque.

H.—3·5–4. *Sp. Gr.*—3·7–4.

Tests.—Heated in closed tube, it gives off water and blackens. Dissolves with effervescence in acids. Before blowpipe, alone fuses, and colours the flame emerald green. On charcoal, reduced to metallic copper. Colours borax bead green.

Occurrence.—Malachite is found in the zone of weathering or gossan of copper lodes. Localities are—Cornwall, Cumberland, Chessy (France), Spain, Siberia, Burra Burra Mine (South Australia), Chili, Pennsylvania, etc. The colour-banding marks the successive deposits of the mineral, which has, in most cases, resulted from the percolation of water through copper-bearing rocks, and the subsequent deposition of the dissolved carbonate in fissures or cavities, the solution having apparently dripped in slowly, and the water evaporated, thus forming a series of layers in the same way that stalactites and stalagmites of calcite are formed by percolation of water through limestone. Malachite is valuable as an ore of copper. It is also, when cut and polished, used for ornamental purposes. Very large masses of malachite have been procured both from Siberia and Australia.

AZURITE, CHESSYLITE: Blue Carbonate of Copper.

Comp.—Hydrated carbonate of copper, $2CuCO_3.Cu(OH)_2$. Compare composition of malachite.

Cryst. Syst.—Monoclinic.

Com. Form.—Modified prisms; also massive and earthy.

Colour.—Deep azure blue, whence the name.

Streak.—Blue, but lighter than the colour.

Lustre.—Of crystals; vitreous, verging on adamantine. Crystals transparent to nearly opaque; massive and earthy varieties, opaque.

Fract.—Conchoidal; brittle.

H.—3·5–4·25. *Sp. Gr.*—3·5–3·8.

Tests.—As for malachite (*q.v.*, p. 356). Distinguished from malachite by its azure-blue colour.

Occurrence.—It is found associated with other copper ores in the zone of weathering or gossan of copper lodes, and when occurring in sufficient quantity, is a valuable source of copper. Localities are—Cornwall, Chessy (France), Thuringia, Siberia, California, and the Eastern United States.

CHRYSOCOLLA (Greek, *chrusos*, gold, and *kolla*, glue, from its resemblance to a substance known by that name, which was used by the ancient Greeks for soldering gold).

Comp.—Very variable from the presence of impurities; but it is essentially a hydrated silicate of copper, $CuO.SiO_2.2H_2O$. It is sometimes considered to contain a variable amount of free silica, and some specimens are sufficiently hard to scratch glass and to be cut and polished for jewellery.

Com. Form.—Amorphous. Usually occurs in encrustations or in thin seams; botryoidal and massive, with a compact and enamel-like texture.

Colour.—Bluish-green, sky blue, or turquoise blue.

Streak.—White when pure.

Lustre.—Vitreous to earthy; translucent to opaque.

Fract.—Conchoidal; rather sectile; brittle when translucent.

H.—2–4 (see under Composition). *Sp. Gr.*—2–2·23.

Tests.—Heated in closed tube, blackens and gives off water. Before blowpipe, infusible, but decrepitates and colours the flame emerald green. With sodium carbonate on charcoal, yields metallic copper. Is decomposed by acids without effervescence (which serves to distinguish it from malachite). It is not, however, completely soluble. With the fluxes, it gives the usual copper reactions.

Occurrence.—Occurs in the zone of weathering or gossan of copper lodes, and when found in sufficient quantity, constitutes a copper ore of some value, and is easily reduced when mixed with limestone. It seldom, from its impurities, yields more than 10 per cent. copper. Localities are — Cornwall, Saxony, Bavaria, Siberia, South Australia, Chili, and the United States.

Dioptase (Greek, *dia*, through, and *optomai*, to see): **Emerald Copper.**

Comp.—Hydrated silicate of copper, $CuO.SiO_2.H_2O$.

Cryst. Syst.—Hexagonal, rhombohedral.

Com. Form.—Crystals, combinations of prism and rhombohedron; sometimes found massive.

Cleav.—Rhombohedral and perfect.

Colour.—Emerald green.

Streak.—Green.

Lustre.—Vitreous; transparent to subtranslucent.

Fract.—Conchoidal or uneven; brittle.

H.—5. *Sp. Gr.*—3·2–3·3.

Tests.—Resembles chrysocolla in its reactions, but differs from it in yielding gelatinous silica when dissolved in hydrochloric acid.

Occurrence.—In the zone of weathering or gossan of copper lodes, as at Chili, Nassau, Siberia. Dioptase is, from its rarity, of no industrial importance.

ATACAMITE: Remolinite (both names from localities in South America).

Comp.—Hydrated oxychloride of copper, $CuCl_2.3Cu(OH)_2$.

Cryst. Syst.—Orthorhombic.

Com. Form.—Prismatic crystals not common; frequently massive and lamellar.

Colour.—Bright deep green to blackish-green.

Streak.—Apple green.

Lustre.—Adamantine to vitreous; translucent to subtranslucent.

H.—3–3·5. *Sp. Gr.*—4–4·3.

Tests.—Heated in closed tube, it gives off water and forms a grey sublimate. Easily soluble in acids. On charcoal, fuses in time to metallic copper, colouring the flame azure blue (chloride), and forming a brownish and greyish-white deposit on the charcoal, which volatilises in the reducing flame, again giving an azure-blue coloration.

Occurrence.—Occurs in the zone of weathering or gossan of copper lodes. Occurs at Botallack and St. Just (in Cornwall), Los Remolinos and the Atacama Desert (in South America), Spain, South Australia, etc.

Libethenite.—A hydrated phosphate of copper, $4CuO.P_2O_5.H_2O$, of a dark olive green colour, occurring both crystallised and massive in Cornwall, Hungary, the Urals, etc.

Phosphochalcite.—A hydrated phosphate of copper, $6CuO.P_2O_5.3H_2O$, of an emerald or blackish green colour, sometimes crystallised, but mostly encrusting and massive. Hardness, 4·5–5. It is found near Bonn, on the Rhine, in Hungary, and Cornwall.

Liroconite.—A hydrated arsenate of aluminium and copper, variable in composition. In colour, sky blue or verdigris green. Orthorhombic. Hardness, 2·5. Occurs in Cornwall, Hungary, etc.

Clinoclase and **Olivenite** are also arsenates of copper.

Libethenite, phosphochalcite, liroconite, clinoclase, and olivenite occur in the gossans of copper lodes, and are of no commercial value.

MERCURY (Hg).

Mercury (quicksilver) exists native, but as such is an unimportant source of the metal. It is a silver white metal, liquid at ordinary temperatures. It boils at 360° C., and has a specific gravity of 13·59. When pure it is unaffected by dry or moist air. Mercury combines with most metals to form alloys, called amalgams, which decompose on being heated, with volatilisation of metallic mercury.

Mercury is usually obtained from its ore, cinnabar (HgS), by roasting in an oxidising atmosphere, whereby the sulphur is oxidised to sulphurous acid, and the freed metal volatilised and condensed. It may also be obtained by distillation in retorts in presence of lime or iron, which, combining with the sulphur, liberates the mercury. The presence of antimony in the ore is not uncommon, and renders the collection of the mercury difficult.

The demand for mercury does not appear to be on the increase. Its chief uses are for the extraction of gold and silver from their ores, for the manufacture of fulminates, mirrors, pigments, anti-fouling paints, and in medicine. It is also stated to be employed in place of rollers for "floating" the revolving lights of lighthouses.

The only source of the metal is cinnabar, and many of the ores treated are extremely low in that mineral. In California the average yield amounts to between 0·6 and and 0·7 per cent. of metal per ton of ore.

In 1912 the total world's production amounted to rather over 4,000 tons, practically all derived from the following countries: Spain (1,500 tons), Italy (980 tons), United States (850 tons), and Austria-Hungary (780 tons).

Mercury is sold in flasks containing 75 pounds.

The mercury minerals here considered are—

Element ...	... Native mercury, Hg.
Amalgam ...	... Native amalgam, Hg_2Ag.
Sulphide ...	... Cinnabar, HgS.
Chloride ...	... Calomel, Hg_2Cl_2.

Tests.—Mercury compounds, heated in the closed tube with sodium carbonate and charcoal, give a metallic mercury mirror. Heated with potassium iodide and sulphur, mercury compounds give a greenish-yellow encrustation and greenish-yellow fumes.

NATIVE MERCURY: QUICKSILVER.

Comp.—Pure mercury, Hg; a little silver sometimes present.

Cryst. Syst.—Cubic. Crystallises only when frozen. Freezes at - 40° C., and crystallises in octahedra.

Com. Form.—Occurs in small fluid globules disseminated through the matrix in which it occurs.

Colour.—Tin white.

Lustre.—Metallic; opaque.

Sp. Gr.—13·59.

Tests.—Dissolves readily in nitric acid. Before blowpipe, volatilises with little or no residue. Should any residue be left, the presence of silver may be detected by fusion with sodium carbonate on charcoal.

Occurrence.—Native mercury occurs as fluid globules scattered through the mercury sulphide, cinnabar (see p. 363), as at Almaden (Spain), Idria (Carniola), Austria, etc. It is sometimes found in some quantity filling cavities. Native mercury occurs rather sparingly, and the mercury of commerce is derived from cinnabar.

Native Amalgam : Silver Amalgam.

Comp.—Silver and mercury. Mercury 65·2 per cent., silver 34·8 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Rhombdodecahedron ; also occurs massive.

Colour.—Silver white.

Streak.—As colour.

Lustre.—Metallic ; opaque.

Fract.—Conchoidal ; uneven ; brittle, and grates under the knife when cut.

H.—3–3·5. *Sp. Gr.*—10·5–14.

Tests.—Heated in closed tube, the mercury sublimes and condenses on the cold portion of the tube, leaving a residue of silver. Before blowpipe, mercury volatilises, and a globule of silver is left. Dissolves in nitric acid. Amalgam, when rubbed on copper, communicates a silvery lustre.

Variety—Arquerite.—A less argentiferous form of amalgam found at the mines of Arqueros, in Coquimbo, Chili. It is soft and ductile.

Occurrence.—Occurs with cinnabar at Almaden (Spain), etc.

CINNABAR.

Comp.—Sulphide of mercury, HgS. Usually contains impurities of clay, etc.

Cryst. Syst.—Hexagonal (rhombohedral).

Com. Form.—Occurs in rhombohedra, prisms, etc., crystals often tabular. Usually massive, granular, and sometimes forming crusts.

Cleav.—Prismatic and perfect.

Colour.—Cochineal red, sometimes brownish or dark coloured.

Streak.—Scarlet.

Lustre.—When massive, often dull; of crystals, adamantine, subtransparent to opaque.

Fract.—Subconchoidal; uneven; sectile.

H.—2–2·5. *Sp. Gr.*—8·99.

Tests.—Heated in open tube, yields a sublimate of metallic mercury, also a black one of sulphide of mercury and fumes of sulphur dioxide. Heated in closed tube, gives a black sublimate, which becomes red if detached and rubbed on a streak plate. Heated with sodium carbonate and carbon in the closed tube, gives metallic mercury. Heated on charcoal with potassium iodide and sulphur, gives greenish fumes and slight greenish encrustation.

Variety—Hepatic Cinnabar.—A variety of liver-brown colour, and sometimes giving a brownish streak.

Occurrence.—Cinnabar occurs as hydatogenetic veins, impregnations, and stockworks. Common associates and veinstones are—Copper pyrites, mispickel, realgar, stibnite, quartz, calcite and often bitumen. The most important locality is Almaden (Spain), where the mineral occurs as impregnations or small veins in quartzite. Idria (Carniola) is also an important locality. Other localities are—Tuscany, Servia, California (New Almaden, New Idria), Texas, Mexico, China, etc. The veins occur mostly in slates and limestones, sometimes in igneous rocks.

Cinnabar affords nearly all the mercury of commerce. The paint "vermilion," which has the same composition, is prepared from this ore.

Calomel.

Mercury chloride, Hg_2Cl_2, found associated with cinnabar. Colour: whitish, greyish, and brownish. Hardness, 1–2. Specific Gravity, 6·48.

SILVER (Ag; Latin, (*argentum*).

Silver occurs in nature in the free state, occasionally 99 per cent. pure, but generally containing copper, gold, or other metals. It is a white metal, which, next to gold, is the most malleable and ductile of all metals. Its specific gravity is 10·5, and it melts at 961·5° C. It is unaltered by dry or moist air. Silver occurs also as sulphide and sulpho salts, as arsenide, antimonide, and chlorides, and also associated with lead, copper, zinc, and other ores. The main source of silver is the native and "dry" or siliceous ores—*i.e.*, mined primarily for their silver contents. A large and increasing proportion of the world's output is, however, derived from the smelting of metalliferous ores, such as copper and lead, when the silver is finally recovered from the crude metals. Silver is recovered from its ores chiefly by amalgamation with mercury, chlorination, or by cyanidation, but the latter process is not applicable when the silver is present in anything but a very fine state of division, as sodium or potassium cyanide acts too slowly. Silver and gold are always recovered together in the form of an alloy, which is afterwards refined, or "parted." Silver containing gold is called "doré silver." Refined silver usually contains from 997·5 to 999·0 parts of silver per 1,000, pure silver being 1,000 fine. On the London market the price is quoted in pence per standard ounce troy, 925 fine, which is the standard alloy employed in England for coin, plate, and jewellery. The silver coinage of most other countries is rather below the English standard.

The total world's production of silver in 1912 was approximately 250,000,000 ounces troy. Mexico is the largest producer, with something under 90,000,000. The next largest producers are the United States (62,000,000 ounces), and Canada (32,000,000 ounces). It is estimated that of the total production in the United States in 1912, only a little more than 0·25 per cent. was derived from alluvial deposits, while 41 per cent. was obtained from silver ores proper, 27 per cent. from copper ores, and 25 per cent. from lead ores.

The silver minerals are—

Element	Native silver, Ag.
Chloride	Horn silver, AgCl.
Sulphide	Argentite, silver glance, Ag_2S.
Complex Sulphides ...	Stephanite, $5Ag_2S.Sb_2S_3$.
Red Silver Ores ...	Pyrargyrite, $3Ag_2S.Sb_2S_3$. Proustite, $3Ag_2S.As_2S_3$.
	Frieslebenite, $5(Pb,Ag_2)S.2Sb_2S_3$.
	Polybasite, $9(Ag,Cu)_2S.(Sb,As)_2S_3$.

Tests.—Silver compounds, heated with sodium carbonate and charcoal on charcoal, give a silver white bead.

NATIVE SILVER.

Comp.—Silver, Ag, is always found associated with other metals, such as copper, gold, mercury, platinum, bismuth, etc.

Cryst. Syst.—Cubic.

Com. Form.—Octahedron; mostly found filiform or arborescent; also massive.

Colour.—Silver white. Tarnishes readily.

Streak.—Silver white and shining.

Lustre.—Metallic.

Fract.—Hackly, sectile, malleable, and ductile.

H.—2·5–3. *Sp. Gr.*—10·1–11·1.

Tests.—Soluble in nitric acid. A clean piece of copper immersed in the solution becomes coated with silver, and a pinch of common salt or a drop of hydrochloric acid when added to the solution throws down a white precipitate of silver chloride. Before the blowpipe, on charcoal, fuses readily to a silver globule, which crystallises on cooling.

Occurrence.—Native silver occurs in the zone of weathering or gossan of silver sulphide lodes, as at Kongsberg (Norway), Comstock Lode, Sierra Nevada, Saxony, Bohemia, etc. Native silver occurs in eruptive and sedimentary rocks, forming strings or veins. It is frequently associated with native copper and galena, but is often so finely disseminated that it is invisible to the naked eye.

ARGENTITE, SILVER GLANCE.

Comp.—Silver sulphide, Ag_2S. Silver, 87·1 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Cube and octahedron; also occurs reticulated, arborescent, and, most commonly, massive.

Colour.—Blackish lead grey.

Streak.—Same as colour, and shining.

Lustre.—Metallic; opaque.

Fract.—Small, subconchoidal, or uneven; sectile.

H.—2–2·5. *Sp. Gr.*—7·19–7·36.

Tests.—Heated in open tube, gives off sulphurous fumes. On charcoal, in oxidising flame, fuses with intumescence, gives off sulphurous fumes, and yields metallic silver. Soluble in dilute nitric acid.

Occurrence.—Argentite is about the most common ore of silver, and affords a large proportion of that metal. Argentite is found precipitated with copper pyrites in the Kupferschiefer of Mansfeld (see p. 349). Silver glance chiefly occurs as hydatogenetic veins, associated with other silver minerals and with pyrites, and other metallic sulphides and with calcite. The most important locality for this type is Butte (Montana). Others are Tonopah (Nevada), Cobalt (Ontario), Broken Hill (New South Wales), Mexico, Peru, Bolivia, Chili, Saxony, Bohemia, Kongsberg (Norway), etc.

STEPHANITE: **Brittle Silver Ore.**

Comp.—Sulphide of silver and antimony, $5Ag_2S.Sb_2S_3$. Silver, 68·5 per cent.

Cryst. Syst.—Orthorhombic.

Com. Form.—Commonly in flat tabular prisms; crystals frequently twinned. Also occurs massive and disseminated.

Colour.—Iron black.

Streak.—Iron black.

Fract.—Uneven; brittle.

H.—2–2·5. *Sp. Gr.*—6·26.

Tests.—Heated in closed tube, fuses with decrepitation, and gives a slight sublimate of sulphide of antimony after long heating. On charcoal, it fuses to a dark metallic globule, and encrusts the support with antimony oxide. The globule heated in the reducing flame with sodium carbonate yields metallic silver. Soluble in dilute nitric acid, leaving a residue of sulphur and antimony oxide. A clean strip of copper placed in the solution becomes coated with silver.

Occurrence.—Occurs in veins with other ores of silver at many of the localities given for argentite—Saxony, Hungary, Bohemia, Harz, Mexico, Peru, and California.

RED SILVER ORES, RUBY SILVER.

Of these there are two species :

1. *Pyrargyrite*, $3Ag_2S.Sb_2S_3$.—Dark red ore.
2. *Proustite*, $3Ag_2S.As_2S_3$.—Light red ore.

Occurrence.—Occur in veins associated with other ores of silver, especially Andreasberg (Harz), Saxony, Bohemia, Kongsberg (Norway), Spain, Cornwall, Mexico, Chili, Colorado, etc.

PYRARGYRITE (Greek, *pur*, fire, and *arguros*, silver) : Dark Red Silver Ore.

Comp.—Sulphide of silver and antimony, $3Ag_2S.Sb_2S_3$. Silver, 59·9 per cent.

Cryst. Syst.—Hexagonal (rhombohedral).

Com. Form.—Hexagonal prism, terminated by rhombohedron, and variously modified crystals ; sometimes twinned ; commonly occurs massive.

Cleav.—Rhombohedral ; rather perfect.

Colour.—Black to cochineal red.

Streak.—Cochineal red.

Lustre.—Metallic ; adamantine ; translucent to opaque.

Fract.—Conchoidal.

H.—2–2·5. *Sp. Gr.*—5·7–5·9.

Tests.—Heated in the open tube, gives sulphurous fumes and a white sublimate of antimony oxide. On charcoal spirts and fuses easily to a globule of silver sulphide, and coats the support white. The globule heated with sodium carbonate and charcoal on charcoal yields metallic silver. Decomposed in nitric acid, leaving a residue of sulphur and antimony oxide.

Occurrence.—See above.

PROUSTITE: Light Red Silver Ore.

Comp.—Sulphide of silver and arsenic, $3Ag_2S.As_2S_3$. Silver, 64·5 per cent.

Cryst. Syst.—Hexagonal (rhombohedral).

Com. Form.—Pointed crystals; commonly occurs granular and massive.

Colour.—Cochineal red.

Streak.—Cochineal red.

Lustre.—Adamantine; subtransparent to subtranslucent.

Fract.—Conchoidal or uneven.

H.—2–2·5. *Sp. Gr.*—5·42–5·56.

Tests.—Heated in open tube, gives off sulphurous fumes and yields a white sublimate of arsenic oxide. On charcoal, yields metallic silver. Decomposed with nitric acid.

Occurrence.—See above (p. 368).

FRIESLEBENITE.

Comp.—Sulphide of silver, lead, and antimony, $5(Pb, Ag_2)S.2Sb_2S_3$. Silver 22–23 per cent.

Cryst. Syst.—Monoclinic.

Com. Form.—In prismatic crystals, and massive.

Colour.—Light steel grey to dark lead grey.

Lustre.—Metallic.

Fract.—Subconchoidal or uneven; brittle; sectile.

H.—2–2·5. *Sp. Gr.*—6–6·4.

Occurrence.—Found associated with other silver ores, galena, etc., in Spain, Saxony, Hungary, and when moderately plentiful, is a valuable ore.

Polybasite.

Comp.—Sulphide of silver, antimony, copper, and arsenic, $9(Ag,Cu)_2S.(Sb,As)_2S_3$. Silver, about 70 per cent.

Cryst. Syst.—Monoclinic.

Com. Form.—Prismatic crystals, and usually occurs massive.

Colour.—Iron black.

Lustre.—Metallic.

H.—2–3. *Sp. Gr.*—6–6·2.

Occurrence.—Occurs with other silver ores in Mexico, California, and Chili.

Horn Silver, Kerargyrite, Cerargyrite.

Comp.—Silver chloride, $AgCl$. Silver, 75·3 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Cube; usually occurs massive and wax-like, and frequently in encrustations.

Colour.—Pale shades of grey, sometimes greenish or bluish, and, when pure, colourless. Assumes brownish tints on exposure.

Streak.—Shining.

Lustre.—Resinous, passing into adamantine; transparent to subtranslucent, or nearly opaque.

Fract.—Somewhat conchoidal; sectile, cutting like wax.

H.—1–1·5. *Sp. Gr.*—5·5.

Tests.—Soluble in ammonia, but not in nitric acid. Fuses in the candle flame. On charcoal, yields a globule of metallic silver. When placed in the microcosmic-salt bead, to which copper oxide has been added, it gives, when heated in the oxidising flame, an intense azure blue colour to the flame (presence of chlorine). A plate of iron rubbed with the mineral becomes silvered.

Occurrence.—Occurs with native silver and oxidised silver compounds in the zone of weathering or gossan of silver sulphide lodes. Some localities are Saxony, Broken Hill (New South Wales), Atacama (Chili), Comstock Lode (California), etc.

GOLD (Au; Latin, *aurum*).

Gold occurs very widely diffused in nature, chiefly in the free state, but invariably alloyed with silver or copper, and occasionally with bismuth, mercury, and other metals. Native gold has been known to contain as much as 99·8 per cent. gold, but as a rule ranges from 85 per cent. to 95 per cent., the balance being usually silver for the most part. Gold, when pure, is the most malleable and ductile of all metals, but becomes brittle in the presence of small amounts of bismuth, lead, arsenic, etc. It has a specific gravity of 19·3, and it melts at about 1,060° C. Native gold is recovered from alluvial deposits by some form of water concentration, followed by amalgamation with mercury. That occurring in veins is milled and ground previous to amalgamation in the case of "free milling" ores; or, when of a partly "refractory" nature, or when the gold is very finely divided, by cyanidation—*i.e.*, by solution in sodium or potassium cyanide. In many mines, treatment by mercury is often followed by cyanidation of the tailings for the recovery of the unamalgamated fine and combined gold. Fine grinding of ores and treatment by cyanide is becoming more usual in practice; but it is sometimes previously necessary to roast ores to eliminate arsenic and antimony compounds which decompose the cyanide, thus causing excessive consumption. Gold is also recovered by chlorination, and also by smelting with lead ores.

Gold is chiefly used for coinage and jewellery. It is usually alloyed with silver or copper to withstand wear better. The purity, or "fineness," of gold is expressed in parts per 1,000, the standard for coin in the British Empire being 916·6 parts of gold to 83·4 of copper. In England the legal standard for jewellery is the carat of 22, 18, 15, 12, or 9 parts per 24. Pure gold is worth £4 4s. 11½d. per ounce troy.

The proportion of gold in such alloys is known as "fineness," and is expressed either in carats (twenty-fourth parts) or thousandths. Thus pure or fine gold is said to be 24 carats, or 1,000 fine. British gold coin is 22 carats fine, or 916·6 thousandths fine. The gold coin of countries following the French system, the United States and Germany, is 900 fine. Austrian ducats are of nearly fine gold, or about 23 carats fineness. For purposes of plate, jewellery, watch-cases, etc., the standard of 18 carats or 750 is legal, but the lower standards of 16 and 14 carats are also general. The Mint price of fine, or 24 carat, gold is 84s. 11½d. per ounce, and of standard, or 22 carat, gold, 77s. 9d.

The total world's production of gold amounted to nearly 23,000,000 ounces fine in 1912, of which nearly 40 per cent. was produced in the Transvaal, and nearly 20 per cent. in the United States. Other of the large producing countries are Australia, Russia, Mexico, India, and Rhodesia. The British Empire is responsible for about 60 per cent. of the entire world's output. An official United States publication states that, of the gold produced in that country, 24 per cent. was from alluvial deposits, 68 per cent. from deep mines, 5½ per cent. from copper ores, and 1¼ per cent. from lead ores.

Gold occurs in two classes of deposits—alluvial (free gold), and vein (free gold and tellurides).

The chief of the tellurides are—Petzite, $(Ag,Au)_2Te$; sylvanite, $(Au,Ag)Te_2$; calaverite, $(Au,Ag)Te_2$; nagyagite, $Au_2Pb_{14}Sb_3Te_7S_{17}$; and maldonite, Au_2Bi.

NATIVE GOLD.

Comp.—Pure gold, Au, or gold alloyed with silver, the latter metal having been known to amount to over 26 per cent. Copper, iron, palladium, and rhodium have also been found in gold; 43 per cent. of rhodium has been afforded by a variety called "rhodium gold" from Mexico.

Cryst. Syst.—Cubic.

Com. Form.—Crystals rare, cubes, octahedra, and rhombdodecahedra, etc. Usually found in grains or scales in alluvial deposits associated with zircon, ruby, corundum, topaz, garnet, and other precious stones; also in rounded masses (nuggets), which are frequently imbedded in quartz veins. Occasionally the metal occurs in strings, threads, etc. The names, grain gold, thread gold, wire gold, foil gold, moss gold, tree gold, mustard gold, sponge gold, indicate the varied forms assumed by the metal.

Colour.—The yellow colour of native gold from different localities varies in shade; and some specimens from Cashmere possess a coppery or bronze yellow colour. When much silver is present, as is sometimes the case, the metal may appear almost silver white. In thin leaves by transmitted light, gold is green.

Lustre.—Metallic; opaque.

Fract.—Hackly, very ductile, malleable, and sectile, being easily cut with a knife.

H.—2·5–3. *Sp. Gr.*—12–20. The variation being due to the metals with which it may happen to be alloyed.

Tests.—The colour, combined with the malleability, weight, and sectility of gold, serves to distinguish it from other minerals. Iron pyrites, which has sometimes been mistaken for gold, cannot be cut with a knife, whilst copper pyrites crumbles beneath the blade and gives a greenish-black streak. Heated on charcoal with sodium carbonate, all gold compounds give a yellow malleable globule of gold.

Occurrence.—An exceedingly important source of gold is deposits of placer or alluvial type; these deposits are derived from the weathering and disintegration of the primary gold-bearing rock. Gold is found in the residual or lateritic deposits formed on the outcrop of weathered gold-bearing rock. The great placer deposits, however, occur in the valleys, and may be of recent or ancient date, and may be at the surface or at a great depth (deep lead). Such placer deposits are exemplified by the banket, or conglomerates of the Rand, South Africa, the shallow placers of the Urals and Siberia, India, China, Gold Coast, Alaska (Klondyke), British Columbia, Western United States (California, Montana, etc.), South America (Equador, Chili, Bolivia, etc.), Australia (Ballarat, River Torrens, etc.). Alluvial gold is found in small quantities in the deposits of several British rivers, in Cornwall, North Wales, Wicklow, Leadhills, and Sutherlandshire.

The alluvial gold has been derived from the true veins —the "reefs" of the gold miner. These reefs are true veins of quartz, pyrites, and free gold usually associated with acid rocks, but sometimes with trachytes, andesites, and even with basalts. Such occurrences are—Bendigo and Ballarat (Australia), Mount Morgan (Queensland), Sierra Nevada (California), Nova Scotia, Treadwell Mine (Alaska), Chili, Brazil, Saxony, Urals, Mysore. In Great Britain gold is worked in North Wales, in quartz veins in the Menevian slates of Middle Cambrian age. The mines are situated north of Dolgelly, on the Trawsfynnydd Road.

Gold Amalgam.

Occurs in small white or yellowish-white grains, which crumble easily. It is sometimes found crystallised. *Comp.*—Gold and mercury with silver, the gold averaging about 40 per cent. The mineral is usually associated with platinum, and occurs in California, Columbia, Urals, and Australia, etc.

GOLD TELLURIDES.

Occurrence.—The gold tellurides occur in veins associated with pyrites and other sulphides, and with free gold. The chief localities at which gold tellurides are worked are Western Australia (Kalgoorlie), Colorado (Cripple Creek), and Transylvania (Nagyag, etc.). The gold tellurides are—

1. *Sylvanite.*—Telluride of gold and silver.
2. *Calaverite.*—Telluride of gold and silver.
3. *Nagyagite.*—Telluride and sulphide of lead and gold.

SYLVANITE: **Graphic Tellurium.**

Comp.—Telluride of gold and silver, $(Au,Ag)Te_2$.Au, 24·5 per cent.; Te, 62·1 per cent. Antimony and lead sometimes present.

Cryst. Syst.—Monoclinic.

Com. Form.—The crystals are often arranged in more or less regular lines, bearing a fanciful resemblance to writing, whence the name graphic. Also occurs massive and granular.

Colour. — Steel grey to silver white; sometimes yellowish.

Streak.—Same as colour.

Lustre.—Metallic.

Fract.—Uneven.

H.—1·5–2. *Sp. Gr.*—5·73–8·28.

Tests.—In the open tube, behaves like native tellurium (*q.v.*, p.294). Before the reducing flame, gives on charcoal a yellow malleable metallic globule after long heating. An encrustation of telluric acid is also formed on the charcoal.

CALAVERITE.

A telluride of gold and silver, $(Ag,Au)Te_2$. Pale yellow in colour. Hardness, 2·5. Specific gravity, 9. Higher percentage of gold than has sylvanite. Occurs in Calaveras County, Colorado.

NAGYAGITE: Black Tellurium.

Comp.—Telluride and sulphide of gold and lead. Antimony is usually present. The gold varies from less than 6 to more than 12 per cent.

Cryst. Syst.—Tetragonal.

Com. Form.—Usually found foliated and massive.

Colour.—Dark lead grey.

Streak.—Dark lead grey.

Lustre.—Metallic; opaque.

Fract.—Sectile; thin laminæ; flexible.

H.—1–1·5. *Sp. Gr.*—6·85–7·2.

Tests.—Heated in open tube, it gives a sublimate of antimoniate and tellurate of lead, and antimonous and tellurous acid in the higher parts of the tube. The antimonous acid volatilises when reheated, and the tellurous acid, at a high temperature, fuses to colourless transparent drops.

PLATINUM (Pt).

Platinum occurs native, and in that form constitutes practically the sole source of the metal. It is a greyish-white, lustrous metal, having a specific gravity of 21·46, and melting at 1,760° C. It is malleable and ductile, and may be welded at a bright red heat. Its resistance to acids and to chemical influence generally renders it of particular use in the laboratory and in the electrical and other industries. It is also largely used as a catalytic agent in the manufacture of chemicals by the contact process in dentistry and in jewellery. Platinum is refined and separated from associated metals by a somewhat complicated series of operations.

The chief source of platinum is alluvial deposits, where the crude platinum contains anything from 60 per cent. to 80 per cent. Pt, and is associated with gold, and usually with about 10 per cent. of other metals of the platinum group, which includes the closely related metals iridium, rhodium, palladium, osmium, and ruthenium. A small but increasing amount of platinum metals is obtained in refining bullion and mattes. The world's output in 1912 was estimated to amount to about 315,000 ounces troy, of which Russia produced about 300,000 ounces, and Colombia about 12,000 ounces. The market price for refined platinum has been steadily rising for years, and there are no large unworked deposits known.

NATIVE PLATINUM (Spanish, *plata*, silver).

Comp.—Platinum, alloyed with iron, iridium, osmium, gold, rhodium, palladium, and copper. In twenty-one analyses cited by Dana, the amount of platinum ranges from 45 to over 86 per cent.

Cryst. Syst.—Cubic.

Com. Form.—Crystals rare; usually found in grains and irregularly shaped lumps. The largest yet found weighed 21 pounds troy, and came from the Urals.

Colour.—White steel grey.

Streak.—White steel grey.

Lustre.—Metallic; opaque.

Fract.—Hackly; ductile.

H.—4–4·5. *Sp. Gr.*—21·46.

Tests.—Sometimes exhibits magnetic polarity, some Uralian specimens being said to attract iron filings more powerfully than an ordinary magnet. The high specific gravity, the infusibility and insolubility of platinum, serve to distinguish it from other minerals.

Occurrence.—Platinum is found in grains in placer deposits of the Urals, Choco (South America), Antioquia (Brazil), etc. The Ural deposits are the most important, and are treated chiefly at Nischne Tagilsk. The platinum is derived from basic igneous rocks, peridotites with chromite, etc. Other important occurrences of platinum are known from metamorphic and sedimentary rocks, and in some sulphide ore veins.

PALLADIUM (Pa).

Palladium occurs native in crude platinum, and in small quantities in cupriferous pyrites, particularly those containing nickel and pyrrhotine. It is a silver white metal, as hard, but not so ductile, as platinum; it oxidises more readily than that metal. Hardness, 4·5–5; specific gravity, 11·3–12; melting-point, 1,546° C.

Palladium is much used in dental alloys, as a catalyser, for coating the surfaces of silver reflectors used in searchlights, etc., and in the construction of delicate graduated scales.

The chief source of supply is the copper-nickel ore of Sudbury, Ontario, from whose matte it is recovered. The estimated production of palladium in the States in 1911 from domestic and imported sources amounted to about 2,400 ounces; while the United States is stated to have imported in 1912 nearly 5,000 ounces, which would probably equal about half the total world's production. The metal is also found with platinum in Brazil, San Domingo, and the Urals, and usually contains iridium as well as platinum.

OSMIUM (Os).

Osmium occurs native in crude platinum and in osmiridium, an alloy with iridium. It is a bluish-grey metal, and has a specific gravity of 22·48, and melts above 2,300° C. It is the heaviest and least fusible of metals. No reliable statistics are available as to production. It is of little commercial importance, and the supply is in excess of the demand.

IRIDIUM (Ir).

Iridium occurs native in crude platinum, and alloyed with osmium as osmiridium. It is a steel-white metal, having a specific gravity of 22·39, and melting at about 1,950° C. Its chief application is for hardening platinum and for tipping the points of gold nibs. Its chief source is crude platinum. There are no available statistics relating to this most costly metal of the platinum group. The demand is steadily increasing.

IRIDOSMINE, OSMIRIDIUM.

Comp.—An alloy of iridium and osmium in variable proportions.

Cryst. Syst.—Rhombohedral.

Com. Form.—Occurs chiefly in small, flattened grains.

Colour.—Tin white to steel grey.

Lustre.—Metallic. *Sp. Gr.*—19·3–21·12.

Occurrence.—Both this mineral and iridium are found with platinum in gold washings in the Urals, Bingera (New South Wales), in South America, and in Canada.

Use.—Iridosmine is used for tipping the nibs of gold pens.

RHODIUM (Rh).

Rhodium occurs in native platinum and in the copper ores of Sudbury, Ontario. It is a white metal, ductile, and malleable at a red heat. It has a specific gravity of 12·1, and melts at about 2,000° C. Its chief source is crude platinum, in which it is said to exist to the extent of 2 per cent. on the average. It has few applications, but is used in the manufacture of thermo-couples, and for crucibles.

RUTHENIUM (Ru).

Ruthenium occurs native in crude platinum, in whose refining it is obtained together with osmium. It is a white, hard, and brittle metal, of a specific gravity of 12·2. It has no industrial application, and no statistics are available.

GLOSSARY OF TERMS USED IN ECONOMIC GEOLOGY

Accessory Mineral.—A mineral whose presence in an igneous rock has no effect on the character of the rock as a whole. For example, in a granite, rare crystals of andalusite, sphene, zircon, apatite, etc., may occur as accessory minerals; but the minerals whose presence is necessary before the rock may be considered a granite are quartz, felspar, and mica, wherefore these latter minerals are termed **Essential Minerals.**

Acid Rock.—An igneous rock which contains over 66 per cent. of silica. Characteristic minerals are quartz and orthoclase. Typical examples are granite, quartz-felsite, and rhyolite. See below.

Alluvial Deposits, Detrital Deposits, Placer Deposits.—Deposits formed by stream action and found where the velocity, and hence the carrying power, of the river has decreased. Such deposits consist, therefore, of gravelly or sandy material, which becomes finer as the depositing stream is followed from its mountain source. In these alluvial deposits the minerals are concentrated into fractions according to their specific gravity, and minerals of somewhat similar specific gravity are thus found together, and form useful guides to the prospector. Chief in the economic sense of alluvial deposits are the gold placers, with the gold being associated magnetite (black sand), chromite, zircon, etc. Alluvial gem deposits, platinum, tin, and wolfram alluvials are other examples. Alluvials are thus the result of the breaking up from their parent source, and of the subsequent transportation and concentration of minerals which may exist in very small quantity in rocks at the head of the river system; hence by following the alluvial deposits upstream it is often possible to locate the original home of the precious minerals—gold is traced to a gold-bearing quartz reef, platinum to an ultrabasic igneous rock, gems to metamorphic limestones, etc. Alluvial deposits occur "fossil" in the geological formations; among such deposits may be placed the Rand conglomerate. See p. 373.

Andesite—A sub-basic volcanic igneous rock, consisting of plagioclase felspar with hornblende, or augite, or mica, sometimes with quartz The plagioclase occurs in laths, and some glass is usually present.

Basalt.—A basic volcanic igneous rock, consisting of laths of labradorite felspar, with augite, or olivine, and glass; ophitic structure common. Occurs as sheets or dykes. Often amygdaloidal.

Basic Rocks.—Igneous rocks containing less than 52 per cent. of silica, and characterised by the minerals labradorite felspar, augite, and olivine. Examples are gabbro, dolerite, and basalt.

Bedding.—A characteristic of sedimentary deposits which have been laid down in successive layers, each layer having had time to become individualised before the deposition of the next. A broader term, **stratification**, is used when the beds are of different natures.

Breccia.—A rock consisting of angular fragments bound together in some kind of cementing material. If the rock fragments are well rounded, evidencing thereby transportation, the resulting rock is a **conglomerate.**

Contact Metamorphism.—The alteration of a rock by heat, usually supplied by the intrusion of an igneous body, and hence the term is broadly equivalent to **Thermal Metamorphism.** See under Metamorphism.

Country Rock.—The rock in which a lode or vein is situated. In Cornwall the killas, a slate, is the country rock of the tin-copper veins.

Detrital Deposits.—See above under Alluvial Deposits.

Diorite.—A sub-basic plutonic igneous rock, containing plagioclase felspar, with some orthoclase, and hornblende. Holocrystalline.

Dolerite.—A basic hypabyssal igneous rock, containing labradorite felspar, augite, and olivine; usually ophitic in structure.

Dyke.—An igneous intrusion having a wall-like form, usually vertical, and appearing at the surface as a thin band of rock, often traceable for great distances. A **Sill** is a sheet of igneous rock lying nearly horizontal. A dyke may become a sill, and *vice versâ.*

Enrichment, Secondary. — Secondary enrichment is of great economic importance in silver, copper and other lodes. These lodes decompose at the surface, and the sulphides become converted into oxysalts, which are carried deeper into the lode by descending waters. In the zone intermediate between the weathered outcrop and the unaltered sulphides—that is, in the zone of secondary enrichment—chemical action takes place between the descending waters bearing oxysalts and the unaltered sulphides, with the result that a new series of minerals is formed whose members are often very rich in the valuable metal of the lode. By this chemical concentration workable ore bodies may result from rather low-grade ores. See p. 351.

Fissure - Veins. — Ore bodies which have filled pre - existing fissures. Often such fissure-veins may show a banding of the contents, indicating successive depositions.

Gabbro.—A basic, plutonic, igneous rock, composed of labradorite felspar and diallage, sometimes with olivine or hypersthene. Holocrystalline in structure. A **Norite** is a hypersthene gabbro, containing labradorite, diallage, and hypersthene.

Gangue, Veinstone.—The minerals of no particular economic value that occur with the valuable minerals in veins and lodes.

Geodes.—Cavities, usually in igneous rocks, into which project well-formed minerals.

Gneiss, Schist.—Metamorphic rocks produced by pressure, and hence shearing, on all kinds of rocks, the characters of the resulting gneiss or schist depending on the nature of the original unaltered rock. The constituent minerals of these rocks show a parallel or foliated structure, which is coarse in the gneisses and finer in the schists. For example, by the shearing of a porphyritic granite the quartz is ground down, the large felspar crystals have their corners rounded off, and the mica is drawn out into streaks, often wrapping round the felspars; thus is produced an augen or eyed-gneiss. Both igneous and sedimentary rocks are metamorphosed to produce gneiss and schists.

Gossan.—The weathered or decomposed upper part of an ore deposit. In this region of the ore body the minerals of depth have been altered into oxysalts. For example, a lode carrying galena and blende at depth, consists in the gossan of cerussite, anglesite, calamine, hemimorphite, and other oxysalts of lead and zinc. Native metals frequently occur in the gossan, and often concentration takes place by the removal of lighter or less stable material, thereby producing rich residual deposits capping a lower-grade ore.

Granite.—An acid plutonic igneous rock consisting of quartz, orthoclase and mica. Holocrystalline in structure.

Granulite.—A rock of somewhat doubtful origin, probably resulting either from the complete grinding down by movement or by the intense thermal metamorphism of an igneous rock. The minerals are in rounded, closely packed grains.

Hydatogenesis.—A process of ore deposition in which the ore body has been deposited from solution, and represents the final stage in the intrusion of an igneous magma. This final stage consists of the evolution of heated waters of enormous chemical activity, capable of dissolving and transporting most metals of economic value. These solutions may find their way great distances from their parent source, but eventually, by cooling or chemical action, they are compelled to deposit their load, and do so either in cavities or fissures (lodes), or between the grains of loose sediments (impregnations).

Igneous Rocks.—Those rocks which have consolidated from a state of fusion. Their structure depends on their mode of cooling and occurrence, and hence igneous rocks are divided into three groups:

1. *Plutonic Rocks*—those that have cooled slowly at a great depth, and hence possessing a coarsely holocrystalline structure, and occurring in great masses.
2. *Hypabyssal or Dyke Rocks*—those that have been rather rapidly cooled by being intruded nearer the surface as dykes or sills. The common structures are the porphyritic or ophitic, and glass may be present.
3. *Volcanic Rocks*—those rocks that have been poured out at the surface, and have therefore been rapidly cooled, allowing little scope for crystallisation. They are glassy or fine-grained, often possessing steam cavities or amygdules, and showing flow structures due to movement during consolidation.

The second great division of the igneous rocks depends on the the silica percentage of the rocks. The silica percentage finds expression in the constituent minerals of any particular rock. The following skeleton table will be found useful:

Division.	Silica Percentage	Minerals	Plutonic Representative.	Hypabyssal Representative.	Volcanic Representative.
Acid	> 66	Quartz Orthoclase Mica	Granite	Quartz Felsite	Obsidian Pitchstone Rhyolite
Intermediate:					
Sub-acid ...	66–52	Orthoclase Mica Hornblende	Syenite	Porphyry	Trachyte
Sub-basic...	66–52	Plagioclase Hornblende	Diorite	Porphyrite	Andesite
Basic ...	< 52	Plagioclase Pyroxene Olivine	Gabbro	Dolerite	Basalt

There is a small division containing less than 45 per cent. silica, called the ultrabasic or peridotite group, characterised by olivine. Examples are dunite (olivine), picrite (olivine, pyroxene, or amphibole, and a little felspar), and serpentine.

Intermediate Rocks.—Igneous rocks containing from 66-52 per cent. silica; divided into two branches—one, the sub-acid, characterised by a predominance of orthoclase, and the other, the sub-basic, by a predominance of plagioclase. Sub-acid rocks are syenite and trachyte; sub-basic are diorite and andesite.

Lode, Vein.—General terms for ore bodies occurring in forms having great depth and length, but of no great thickness compared with those dimensions. The origins of lodes are various —hydatogenetic, pneumatolytic, etc.

Magmatic Segregation.—A mode of formation of ore deposits dependent upon the concentration of minerals of economic value in particular parts of a cooling igneous rock magma. The ore body shades off gradually into the igneous rock, and is usually marginal in position. Examples are the Sudbury nickel deposits, many magnetite deposits of Scandinavia, etc.

Metamorphism.—In the widest sense, a term meaning all the changes that a rock has undergone, but usually limited to imply the results of two processes: (1) that of movement, known as *Regional Metamorphism;* and (2) that of heat, known as *Contact* or *Thermal Metamorphism.* The effect of Regional Metamorphism—that is, of deep burial, folding, shearing, etc. —are evidenced by the production of foliation and cleavage, as in the gneisses, schists, and slates; in the more advanced stages the rock may be entirely reconstructed. The intrusion of a hot igneous body is responsible for Contact Metamorphism, and the results obviously depend largely upon the character of the rock into which the igneous body is intruded. Sandstones are converted into quartzites, pure limestones into marble, clay rocks into andalusite slates, phyllites, etc. The effects of the metamorphism become more severe as the igneous intrusion is approached.

Metasomasis.—A mode of formation of ore deposits by the complete or partial replacement of a pre-existing rock by the ore body, which therefore comes to be a pseudomorph on a large scale. Limestone is usually the rock replaced, and the degree of replacement is greatest along joints, shatter belts, and porous bands in the rock. Metasomatic ore deposits may be recognised by the occurrences of fossils and characteristic sedimentary structures preserved in the ore. As an example, the Cleveland iron ore is an oolitic iron carbonate which has replaced a limestone, retaining in the process the oolitic structure of the original rock. Many veins, some zinc and lead deposits, etc., are of metasomatic origin.

Obsidian.—An acid volcanic igneous rock, the result of the rapid cooling of an acid magma. Glassy, and with a conchoidal fracture.

Original Mineral.—See under Primary Mineral, below.

Outcrop.—The area over which a particular rock comes to the surface of the ground. The dimensions and form of the outcrop depend on the nature of the rock, its inclination (if bedded) to the horizontal—that is, its dip—and the form of the ground.

Pegmatite.—A variety of acid igneous rock, very important from an economic point of view. Consists of quartz, orthoclase, and mica, with an extremely coarse structure. Represents the last portion of an igneous magma, and in it are concentrated substances existing only in very small amounts in other parts of the magma, thereby leading to the formation of such minerals as garnet, tourmaline, zircon, cassiterite, fluor, etc. Pegmatites were intruded in a very fluid state, and occur as dykes, strings, and veins around the borders of granite masses. Economically important for mica, orthoclase, and tin.

Peridotite.—See under Igneous Rock. Rocks poor in silica, containing much olivine, little or no felspar.

Phonolite.—A trachyte (see above, under Igneous Rock), containing felspathoid—that is, nepheline, leucite, nosean, or hauyne.

Pitchstone.—An acid volcanic igneous rock. Chiefly glass; has a dull, pitchy lustre and a flat fracture. Blackish or greenish.

Placers.—See under Alluvial Deposits.

Pneumatolysis.—A process of ore formation brought about by the agency of heated gases and vapours representing a late stage in the intrusion and cooling of an igneous magma. These gases are chemical agents of great power, and by their interaction with water, etc., lead to the formation of many valuable lodes. The pneumatolytic ore deposits accompany in most cases intrusions of granite, and are associated with a peculiar set of minerals which forms a useful indication to the prospector—tourmaline, topaz, zinnwaldite, lepidolite, fluor, axinite, etc. The tin deposits of Cornwall are of pneumatolytic origin, and are associated with large granite intrusions.

Primary Mineral, Original Mineral.—A mineral which was formed at the same time as the rock in which it is found, in contradistinction to a **Secondary Mineral** formed later than the rock. For example, biotite in a granite is an original mineral. If the biotite is altered to chlorite, the chlorite is spoken of as secondary, since its formation was later than that of the granite in which it occurs.

Quartz Felsite.—An acid hypabyssal igneous rock, composed of crystals of quartz and orthoclase set in a finer ground-mass; occurs as dykes or sills.

Rhyolite.—An acid volcanic igneous rock, exhibiting flow structure, and carrying sporadic crystals of quartz and orthoclase.

Saline Residue.—The deposits formed by the drying up of enclosed bodies of salt water. The substances occurring in this way are chiefly chlorides, iodides, and sulphates of Na, K, Mg, Ca, with nitrate of Na and borates of Ca and Mg. The great German deposits of Stassfurt are of enormous value, and in them a definite order of deposition of the minerals has been found (see p. 137). Deposits of rock salt are common in most countries, and are the accompaniments of desert conditions, (see p. 137).

Secondary Enrichment.—See above.

Sedimentary Rocks.—All rocks that have an origin other than that of igneous action; therefore those rocks that have been formed by the agency of running water, by marine action, by chemical means, etc. They occur in layers, beds, or **Strata,** and are called the **Stratified Rocks**, and are divided by their organic contents into groups of varying ages, called the **Geological Systems** (*q.v.*, p. 388). The Sedimentary Rocks may be classified by their mode of origin into several divisions:

1. Mechanically formed rocks—conglomerates, grits, sandstones, clay.
2. Organically formed rocks—limestones, coals, flint, phosphate, etc.
3. Chemically formed rocks—saline residues, sinter, travertine, etc.

Segregation, Magmatic.—See under Magmatic Segregation.

Syenite.—A subacid plutonic igneous rock, composed of orthoclase and hornblende (augite, mica), with a little plagioclase. Holocrystalline.

Trachyte.—A subacid volcanic igneous rock, consisting of phenocrysts of orthoclase set in a ground-mass of laths of the same mineral and glass.

Tuff.—A rock composed of fragments of volcanic origin which have been thrown out during an eruption, and have consolidated into rock around the volcano.

Ultrabasic Igneous Rock.—See above.

Vein.—See above.

Zones of Lode.—A lode is divisible into three zones:

1. The *Depth*—a zone composed of the unaltered ore.
2. The *Gossan*—the surface portion of the lode containing native metals, oxides, and oxysalts, the result of the weathering of the ore.
3. The *Zone of Secondary Enrichment*—a zone intermediate between the first two zones, in which interaction between the unaltered ore and waters from the gossan has resulted in the production of new minerals, usually of great economic importance.

THE GEOLOGICAL SYSTEMS

	Name.	Notes.
TERTIARY.	PLEISTOCENE ...	Superficial deposits, glacial deposits, brick-earth, etc. Worked for brick-earth and gravel in Britain.
	PLIOCENE ...	The "crags" of East Anglia. Formerly worked for marling and for phosphate nodules.
	MIOCENE ...	Not represented in Britain. Lignites abroad.
	OLIGOCENE ...	Occurs in the Isle of Wight. Contains a thin limestone.
	EOCENE ...	Occurs in the London basin and the Hampshire basin. Sands at base, followed by the London clay, and that by the Bagshot sands. Economically useful for bricks and glass sand.
MESOZOIC.	CRETACEOUS ...	Covers a large area of South-Eastern England. At the base is the Weald clay, followed by Greensands and Gault, and then by the Chalk. Important for bricks, building-stone, cement, lime, and water.
	JURASSIC ...	Occurs in a belt stretching from Yorkshire to Dorset. Lias clays below, followed by Oolite limestones and clays above. Important for building-stone, iron ores, gypsum, and water.
	TRIAS	Two divisions in England: Bunter pebble beds below, Keuper sandstones and marls above. Provides salt, building stone, gypsum, and water.
PALÆOZOIC.	PERMIAN	Red sandstones of Penrith, magnesian limestone of Northumbria. Building-stone.
	CARBONIFEROUS	Three main divisions: at the base Carboniferous Limestone, followed by Millstone Grit, followed by the Coal Measures. Great economic value for coal, ironstone, fire clay, limestone, building-stone, lead, and road metal.
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