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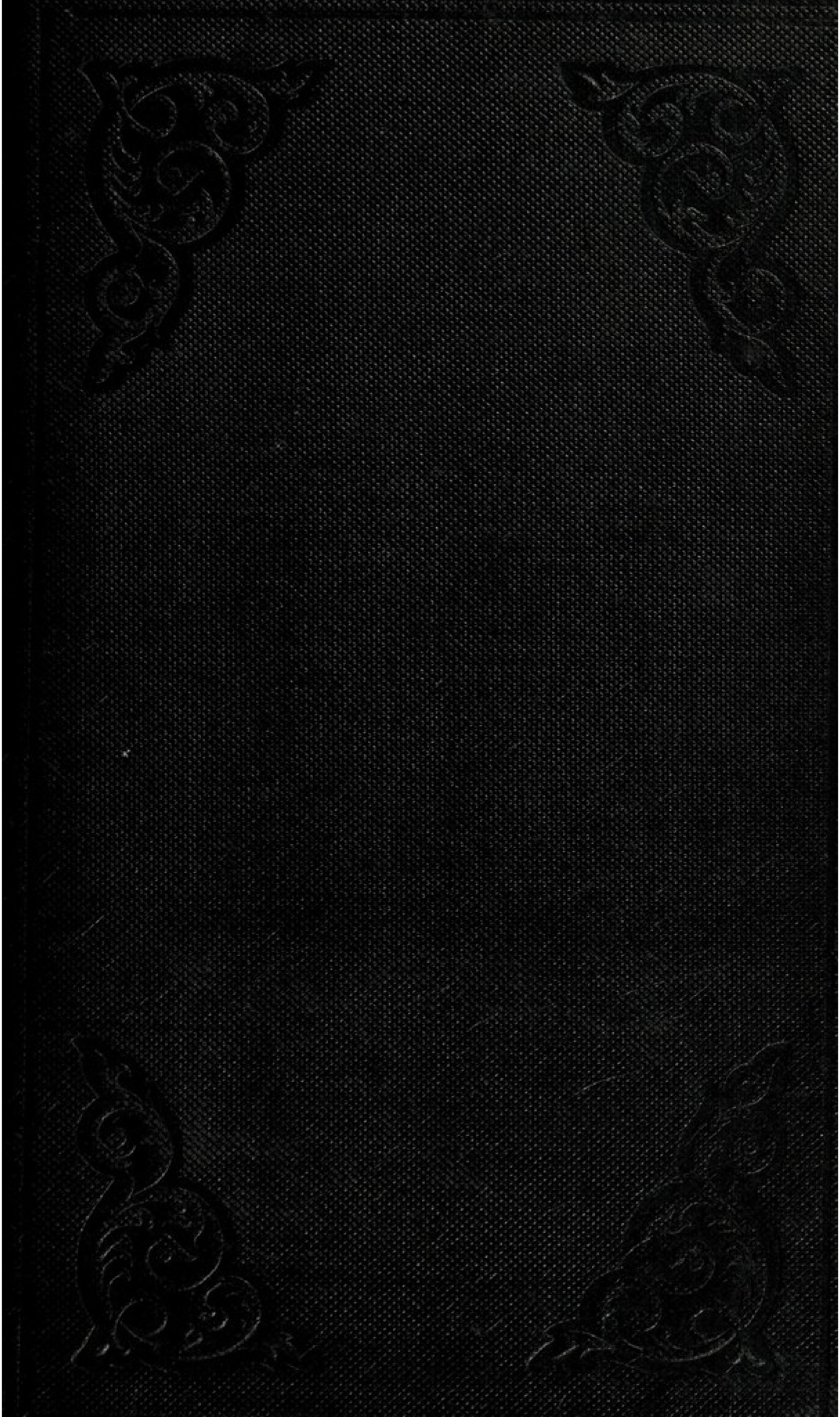

RURAL CHEMISTRY.

RURAL CHEMISTRY:

AN

Elementary Introduction

TO

THE STUDY OF THE SCIENCE

IN ITS RELATION TO AGRICULTURE.

BY

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PREFACE TO THE FIRST EDITION.

THE following pages formed the substance of a short series of articles on Chemistry, which originally appeared in the columns of the "Gardeners' Chronicle." The interest which they excited in the readers of that journal has led to their republication in a separate and more complete form. It would have been easy to have greatly increased the size of the book; and indeed it was frequently very difficult to select from the mass of information which exists, those facts which appeared most worthy of notice. The original object of the author was to give such an elementary sketch of the science as should enable those ignorant of the subject more readily to comprehend the works of the various authors who have written on Agricultural Chemistry.

As a general rule, care has been taken, as much as possible, merely to give well-established facts, or, when doubtful theories are mentioned, to state distinctly that they are more or less problematical.

PREFACE TO THE SECOND EDITION.

In preparing a Second Edition of this little book, the opportunity has been taken of correcting several errors which the First Edition contained. The whole has been carefully revised, and such additions have throughout been made, as the advanced state of knowledge rendered necessary. In particular, the Tables of Analyses have been greatly extended, by the addition of the latest and most complete Analyses of almost all those plants which are cultivated as crops, as well as of the principal substances employed as manure.

April 20, 1846.

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April 30, 1845.

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CHAPTER VIII.

INTRODUCTION.

No branch of knowledge has made more rapid progress during the last hundred years than chemistry. From being merely a confused collection of marvellous facts and incomprehensible phenomena, it has become a definite and methodical science: no longer mysterious and full of uncertainty, but based on clear and simple laws, the knowledge of chemistry at once gives us the key to a great number of natural changes and phenomena, which without it would be quite unintelligible.

Chemistry is intimately connected with all other sciences, for it embraces the study of the various forms and conditions of matter, their nature and properties, and the changes which, either from natural or artificial causes, they undergo. The study of chemistry is of the greatest importance in relation to the arts of life, which all depend, more or less, on chemical principles. Hence, a knowledge of this science enables us more readily to understand the processes of the manufacturer, points out the best and most economical mode of effecting his objects, and teaches how that which was before useless and of no value, may be converted into sources of wealth and happiness.

It is needless to point out examples of the influence which the progress of chemistry has had on our manufactures, for every one of them owes, more or less directly, its present improved condition to the labours of the chemist. Such being the case, it becomes interesting to inquire, what has chemistry done for agriculture, the most important, because the most necessary, and most extensively practised, of all the arts? It is remarkable that agriculture should have received infinitely less assistance from the labours of chemists, than any other art; but this ceases to be surprising when we consider how little attention was paid by the ancient chemists to that subject.—The chemistry of the earthy and metallic substances presented to them easier and more attractive objects of inquiry; they were led away by the visionary hope of discovering a mode of making gold, and they consequently neglected everything in order to try all sorts of experiments in the vain idea of converting lead, iron, &c., or the base metals as they called them, into gold. Hence it is not to be wondered at, that the chemistry of the metals was studied and investigated, long before the nature and properties of vegetable and animal substances were examined. The labours of the alchemists brought to light many valuable discoveries respecting the uses, nature, and properties of earthy and metallic substances; but it was only in the last century, when the constitution of the air and other gaseous bodies was discovered, that anything approaching to correct ideas respecting the nature of animal and vegetable substances was entertained.

The important discoveries of Dr. Priestley led the way to a complete revolution in the science, and may almost be said to have laid the foundation of agricultural chemistry. It is true that before his time there had been many careful and accurate observers, and multitudes of laborious and valuable experiments had been made on plants, by such men as Van Helmont—Evelyn—Boyle—Hales, and others; but before the time of Priestley, and his contemporaries, Ingenhousz, Bonnet, Henry and Percival, little progress had been made in studying the chemical changes on which the growth of plants depends. We are indebted to Hales for much curious information respecting the rise and motion of the sap in plants, the perspiration, or evaporation, which is constantly going on to a greater or less extent, from the surface of the leaves;

and the effects of various substances on plants; his chemical speculations, however, are for the most part of little value, though he was often apparently on the point of making important discoveries. The discovery of carbonic acid gas or fixed air, by Dr. Black, and the beautiful experiments of Priestley, opened a new field of inquiry and research; he observed that plants possessed the property of purifying the air; in fact, that they were able to decompose the carbonic acid gas which it always contains in small quantity; appropriating the carbon, and restoring back to the atmosphere the oxygen, or vital air, so necessary to the processes of respiration and combustion. The knowledge of this great fact, necessarily led to many minor discoveries respecting the growth of plants, and the sources of their food. After this period, Organic Chemistry began to attract a large share of the attention of chemists, the composition of vegetable substances was carefully investigated, new modes of analysis were discovered, and an immense mass of curious and useful facts was collected. A great number of chemists occupied themselves with researches in Vegetable Chemistry, but for the most part they were employed in examining the innumerable substances which plants produce; whilst the great questions as to the food of plants, their growth, and nourishment, were left very nearly in the same state which the experiments of Priestley and Ingenhousz had brought them to.

At the end of the last century, and in the commencement of the present, Organic Chemistry made rapid advances; the labours of Hassenfratz, Humboldt, Berzelius, Saussure, Senebier, Einhof, and Davy, contributed to throw light on many parts of the subject; whilst the investigations of Gay-Lussac, Hatchett, Lampadius, Lavoisier, Marcet, Prout, Thompson, Vauquelin, Thénard, and others in all parts of Europe, led to a more complete and accurate knowledge of the nature, composition, and properties of organic matter.

The first chemist who wrote on agriculture appears to have been J. G. Wallerius, who, in 1754, published a book on the Cause of Fertility. Even before this time, however, several books had been written on agriculture, in which attempts were made to explain the operations of farming on chemical principles; such, for example, were "The Rational Farmer," 1743, a curious book, containing numerous accounts of rude chemical experiments, together with a number of sound practical facts: the author, however, was evidently not a chemist. Wallerius was succeeded by several other authors, amongst whom ought to be mentioned Cullen, Pearson, Gyllenborg, De Beunie, Rückert, Einhof, and Dundonald; but the speculations of these authors (though ingenious,) were for the most part crude and incomplete. The writings of Einhof were valuable for the numerous accounts of careful experiments which they contain; the analyses, though not carried to that degree of minuteness which subsequent discoveries led to, were trustworthy and accurate, and as such will always continue of value. Humboldt's "Sketch of the Chemical Physiology of Vegetation," which appeared at this time, is a book of far higher talent than those just mentioned, and contains enlarged views and cautious generalisations, which the subsequent progress of science has in most cases confirmed. At the commencement of the present century, when Organic Chemistry was rapidly advancing, Berzelius and Davy endeavoured to apply the conclusions to be derived from chemical experiments, to agriculture. If the deductions which they made were not always correct, and if the plans which they proposed did not always produce the effects which the authors anticipated, it must be remembered that they were amongst the first to take the subject up, and that though they did so under far more favourable circumstances than their predecessors did, yet that even then the science of organic chemistry was in many respects very imperfect and incomplete.

During the last forty years, many important additions have been made to this department of Chemistry; improved and more accurate modes of chemical investigation have enabled more exact analyses to be made of the different varieties of organic matter; the composition of those substances which constitute the bodies of animals and plants, has been accurately and carefully ascertained. At the same time, many valuable observations have been made respecting the functions of plants, the conditions requisite to germination, the formation of flowers and seed, the chemical changes attendant on the ripening of fruit, the office performed by roots and leaves, and a variety of other important subjects of inquiry. The names of Liebig, Schübler, and Sprengel, in Germany; Braconnot, Boussingault, Chevreul, Colin, Chaptal, Dumas, Edwards, and Payen, in France; and of Daubeny, Johnston, Pepys, Turner, and Christison, in our own country, deserve especial mention.

Even in so short a sketch of the subject as this, it would not be right to omit altogether the name of Grisenthwaite, whose book on the theory of Agriculture (1819) is remarkable for the enlarged and extended views which it contains. It is true that the author falls into many errors, but at the same time he was the first who entertained correct views of the importance of nitrogen as an element of manure, and of the necessity of supplying phosphates as well as substances containing nitrogen to plants like wheat, chiefly cultivated for the sake of the azotised principle which render them valuable as food.

Intimately connected with the progress of Vegetable Chemistry, is the study of Vegetable Physiology; a knowledge of the one is essential to a perfect comprehension of the other, for it is impossible well to understand the chemical changes going on in the organs of plants, if we are wholly ignorant of the forms and structure of those organs; and, on the other hand, the most complete knowledge of the anatomy of vegetables could never lead any one to sound and correct conclusions respecting the nutrition of plants. It is rather to be regretted that both Chemists and Physiologists have appeared to avoid availing themselves of the advantages which each might have derived by studying the results that the others had obtained; it is only by comparing together the observations of both that correct conclusions can be formed. The observations made by the older physiologists, like those of their chemical contemporaries, were mostly imperfect, and the deductions they formed, were, in consequence, very frequently erroneous; the modes of examination, and the instruments which they employed, were far less perfect than those which have been used in more recent times. Nevertheless, the observations recorded by Grew, Malpighi, and Duhamel, are of considerable value; they may be said indeed to have laid the foundation of Vegetable Physiology. As the study of Botany itself advanced, greater care was bestowed in examining the structure and anatomy of plants, and from the labours of many zealous and careful observers, there has resulted a tolerably complete system of Vegetable Physiology. In recent years, De Candolle, Brongniart, Decaisne, Dutrochet, and Mirbel, in France; Link, Mohl, Meyen, and Schleiden, in Germany; Amici in Italy; and Brown, Griffiths, Henslow, Knight, and Lindley, in England, have, besides many others, made valuable additions to Vegetable Physiology. The relations of plants to climate, and the influence of heat, light, and moisture, have also been studied; especially by Daniell and Royle in our own country.

Amongst the names of those who have contributed to the science of Agricultural Chemistry, that of Liebig stands pre-eminent. The thanks of all are due to him, both for the valuable and laborious experiments he has performed, and likewise for the exertions which he has made to remove the many doubts and uncertainties that surrounded the very elements of the subject. But little had been done since the days of Priestley and Ingenhousz to prove how plants obtained their food, what were the sources whence they derived the elements of organic matter, and the nature of the office performed by manures. Chemists, and likewise physiologists, had formed many ingenious speculations, but they had not employed the only real mode of getting at the truth, namely, well-selected and carefully performed experiments. Liebig, in his "Organic Chemistry applied to Agriculture and Physiology," has strongly drawn attention to these important questions; he has exposed the fallacy of many of the theories which had been formed to explain them, and has established on good evidence the simple chemical rules which regulate the growth of plants.

Although the experiments of Priestley and Ingenhousz had shown that plants possess the power of decomposing Carbonic Acid; and although they had advanced numerous arguments to prove that plants derive the carbon which they contain from the decomposition of that gas, yet this doctrine, although admitted by many physiologists, was by no means universally believed by chemists. M. Hassenfratz in particular opposed these views, asserting that plants did not derive their carbon from the decomposition of carbonic acid existing in the air, but absorbed it direct from the soil, in a state of suspension or solution; he gives the name of carbon to the brown substance left on the evaporation of dung water, and in fact to the various modifications of decaying organic matter subsequently described under the general name of Humus. Few experiments, indeed, were made to show that the explanation of Priestley and Ingenhousz was improbable; but it was conceived that plants must derive their carbon from the soil, and many theories were formed to explain the mode in which they might be supposed to obtain it. These theories have been rigidly examined by Liebig, and the results of his investigation have shown, that the old views put forth by Priestley and Ingenhousz were in truth correct.

It has long been known, that plants consist of Carbon, Oxygen, Hydrogen, and Nitrogen, and also that they invariably contain a small quantity of inorganic, or earthy and saline, matters. The presence of Nitrogen was formerly greatly overlooked, in analyses of vegetable substances; it is contained in less quantity than the other three elements of organic matter, and was very commonly regarded as being merely accidental, and not a necessary constituent of plants. Improved modes of analysis have proved that nitrogen always exists in the same proportion, in certain constituents of plants; and as it appears that these substances are also those which form the most valuable part of food, it becomes a question of the first importance, whence do the plants derive their Nitrogen ? They obtain it principally, if not wholly, from the air; they do not absorb it in the free and uncombined form, but they absorb it combined with Hydrogen and with Oxygen, in the states of Ammonia and Nitric Acid. The importance of the earthy substances in plants was, likewise, greatly overlooked formerly. It has been proved, by repeated experiments, that these substances are of the greatest importance in the growth of plants, being quite essential to their developement.

Although much has been done, and although chemists have laboured to remove the perplexities which encompassed the subject, there is still a very great deal which requires investigation; many important points are as yet imperfectly, or even not at all, explained, and many questions must be satisfactorily settled before a complete system of Agricultural Chemistry can be established. Till these difficulties are removed, it is premature to expect that Chemistry can be of more than partial assistance to Agriculture, for whilst many of the fundamental laws of Agricultural Chemistry are still scarcely understood, all attempts to apply them to practice must be incomplete, and liable to error.

The composition of the principal varieties of organic matter is well known; the substances which, by combining together, form the various constituents of plants, have been ascertained. The food of plants, the great sources whence they derive it, and the manner in which they absorb it, are known. The various changes which organic matter undergoes, the conversion of one substance into another, and the influence which these changes have on the growth of plants, is likewise easily understood; nearly all the purely chemical operations which are concerned in their nutrition can be explained by reference to simple chemical laws; but there are many most important phenomena which are as yet wholly in the dark. Thus, for example, the manner in which wood is formed, and, indeed, all those natural operations in which cellular or organised matter is generated under the influence of light and heat, are but very imperfectly explained. A knowledge of the chemical composition of soils, and the various substances employed as manures, enables us to comprehend the mode in which the latter act; and a knowledge of the nature of those substances which plants require, points out the best and most economical methods of restoring to the soil, by manures, those substances which plants remove from it; but our knowledge of this part of the subject is very far from being complete, for although it is certain that, in addition to the great elements of organic matter, which plants derive from both air and soil, they likewise absorb small quantities of inorganic or mineral substances from the soil exclusively, the office performed by the latter in the vegetable economy is not yet well understood. Many theories indeed have been formed respecting their use, but very little is positively known on the subject.

Although Agricultural Chemistry is in this imperfect state, and though much still remains to be done in that branch of science, yet it is so far advanced as to be able to render substantial assistance to the practical agriculturist. It can teach him the principles which govern the growth of plants, and, consequently, guide him in the application of artificial means to produce the most beneficial results. He must, however, not expect too much from the aid of Chemistry, nor give himself blindly up to speculations or theories. Whilst he gives due credit and belief to well-authenticated facts, he must always receive theories with caution and doubt.

Perhaps the most important advantage which a practical man may at present derive from a knowledge of Agricultural Chemistry, is connected with the use of manure. If he knows what it is that gives the fertilising powers to manure, and is aware of the nature of those substances, he will soon learn the best method of preserving and using them; he will then understand how to make the most of the various sources of manure at his disposal, and he will be enabled readily to save much, that, for the want of such knowledge, would otherwise be lost.

RURAL CHEMISTRY.

CHAPTER I.

COMBINATION—DECOMPOSITION—AIR—WATER.

1. THE object of Chemistry is to determine accurately the properties of all natural substances, to study the changes which are going on in nature, to find out the rules which govern them, and the manner in which these natural operations are influenced by circumstances.

2. In pursuing these inquiries, the chemist is obliged to proceed slowly and with great caution; it is quite impossible for him to predict beforehand the result of a new experiment; he must try it, and then, if it has been properly conducted, it always furnishes him with a new fact, for he is sure that on repeating it in the same manner, he will obtain the same result. Hence chemistry is purely an experimental science; every fact is the result of careful experiment, and every theory is deduced from the study of such facts. The greatest care must be taken to distinguish facts from theories; the former are well established and unquestionable truths, the latter are plausible conjectures, to which we are led by the atten-

tive study of facts. When a chemist has made a number of experiments, or has observed many phenomena, he endeavours to ascertain the cause of the effects he has been studying. He selects the most probable explanation, and adopting it as a theory or view, to be confirmed or disproved by future experiments, proceeds to try in all possible ways the truth of his conclusion. By thus forming a theory he is enabled to arrive at the truth more easily than if he were merely to continue making experiments at random. It is by reasoning on the result of thousands of experiments that chemists have been enabled to reduce the science into a useful form, as they have thus been led to discover certain great leading laws, which govern all chemical changes or operations.

3. Nearly all the changes which are going on in nature may be classed under two heads. The one kind of change is that which takes place when two substances come together which have, as it were, an attraction or affinity for each other. As a familiar example of what then happens, we may take the common process of soap-boiling. When an alkaline or caustic ley is boiled with tallow or fat, soap is formed. The alkali which is contained in the ley has an attraction for the fat ; the two become thoroughly mixed, and combine or unite together, and form a new substance, quite different from either the fat or the alkali, which new substance is called soap.

4. This kind of action is quite distinct from simple mixture. When we mix together two substances—such as, for example, brown sugar and sand, no change takes

place however long they are kept together, or in whatever way they are treated, for they have no affinity or attraction for each other; and therefore, if boiling water is poured upon the mixture, it will soon dissolve out all the sugar and leave the sand, and neither the sugar nor the sand will be at all altered by having been mixed.

5. When we mix two substances which have an attraction for each other, they are both changed, and the new substance formed by their union is quite different from either; and when two substances are thus united or combined together, they are not so easily separated as when merely mixed, because they require the exertion of some attraction more powerful than that which made them combine, to cause their separation. In the case of the soap just mentioned, the compound of fat and alkali does not resemble either of its components; it is different from the ley in not being caustic, and differs from the fat in being easily soluble in water.

6. It is a rule which holds good in all cases, that whenever two substances combine or unite together, and form a new substance, the properties of the new substance are quite different from those of either of its components; but when two substances are only mixed, the properties of the mixture are intermediate, or half-way, between those of its two components: thus, in the mixture of sand and sugar, we may easily recognise both substances, for the characters of neither are altered by being brought together.

7. Another common case of affinity is observed when

we slake quicklime. Quicklime has a strong affinity for water, and when it is wetted, it becomes very hot; the lime combines with a quantity of water, and when it has cooled, we find that the lime is much altered, having to a great extent lost its strong caustic properties, and become slaked, as it is termed. Here again we observe that the properties of the compound differ remarkably from its components. Dry caustic lime, in combining with water, forms a dry compound of lime and water, the water becomes solid, entering into the composition of a dry solid powder, whilst the lime no longer possesses the power of heating when water is poured over it, and has become less caustic (201).

8. It may perhaps seem as if these two examples of the change produced by attraction or affinity were processes of art, and not of nature. They will, however, serve as examples of what is going on in a great many natural operations: and as we proceed with the subject, it will be evident that this kind of change, by which two or more different substances unite and form one new substance, is exceedingly common throughout nature.

9. The second kind of change which we shall have to consider, is that which goes on whenever anything decays. This change is quite opposite in its nature to that which we have just been describing. It takes place whenever any substance is separated or divided into its component parts. Thus, to return again to the quicklime, which is made by burning chalk or limestone, we say that the chalk or limestone is decomposed, when, by burning or

heating it in a very hot fire, whatever it contains which can be roasted out by fire, is driven off, and the lime only remains (89).

10. The decomposition of a substance is also effected when it is mixed with anything which has a very strong attraction for one of its components. Soap is made by the attraction which the alkali has for fat (3); but if we add to a solution of soap in water, anything which has a stronger attraction for the alkali than the latter has for the fat, we shall decompose the soap: there are many substances which have the power of doing this, but it is sufficient now to mention one. If vinegar is poured into a solution of soap, the soap is decomposed; the fat is separated and floats on the surface, and the vinegar combines with the alkali of the soap.

11. This kind of change is always going on when anything decays or putrefies, and therefore is of considerable interest in connexion with manures; but in fact combination and decomposition are almost always going on at the same time in most natural changes, for when a compound consisting of several different substances is decomposed it is generally found that these substances again combine together, one with another, to form various other compounds (76-116).

12. Combination takes place whenever substances are brought together which have an affinity for each other, chemical action then takes place, and a compound is formed. Decomposition of a compound is caused by the

action of some substance which has a very strong affinity for one of the elements (10) of the compound; it is also caused by heat or light, and not unfrequently results from the mere spontaneous separation of the different substances which form the compound (313).

13. It is a common saying that there are only four elements, air, earth, fire, and water; and many people believe that all things are composed or made up of these four elements. This is very incorrect, because there are many substances which do not contain any of these so-called elements; and they are, besides, themselves compounded of many different substances. The term elements, in the sense in which it is used by chemists, means a certain set of simple substances, which by combining, or uniting together, form all the various matters that occur in nature.

14. To return once more to the example of soap, we may say that the elements of soap are alkali and tallow; but then the question will arise, what are the elements of tallow and alkali? which can only be ascertained by chemical experiments. In this way, then, we may analyse, or as it were pull to pieces, different substances, till at last we find that we are unable to separate or decompose them any further, and the substances which then remain are called elements, or simple substances. It is possible that chemists may hereafter discover that some of the substances now called elements are really compounds, and of course it is impossible to prove that they

are not so; all therefore that is meant by the term element, or elementary substance, is that chemists have not yet been able to prove them to be compounds.

15. There are upwards of fifty of these elements, but it will not be necessary to study the nature and properties of the whole series, because many of them are of very rare occurrence, and found only in small quantities. We will commence with those substances which are of the greatest importance, whether simple or compound, and gradually go through them, before entering upon the chemistry of vegetation. Foremost in importance, of the substances whose properties we are about to study, stands the air.

16. We are too apt to think of the AIR as being merely empty space; we move about through it without feeling any resistance, and from its being invisible and totally unlike anything else we know, many forget its existence altogether. The fact is, that every part of the surface of the globe is surrounded by air, which floats on its surface almost like water.

17. It is easy to prove that the air is really a substance. When we try to squeeze together the sides of an inflated bladder, the mouth of which is tightly tied up, we feel that the bladder is full of something which resists the pressure; this something is the air which it contains, and which, though so easily displaced, or pushed aside, by anything moving through it, resists strongly any force applied to it when thus confined in a limited space; and if whilst we are pressing the bladder we prick a hole in

it, the air then rushes out, we feel that the resistance is gone, and the sides of the bladder are easily squeezed together.

18. And again, when working a pair of bellows, it is the resistance of the air which we have to overcome by the force of the arms, which constitutes the labour of working the bellows; and if the nozzle of the bellows is stopped up, we presently find that it is impossible to go on working the bellows any longer, because having forced in as much air as it can hold, the natural tendency of the air to resist compression, prevents any more from entering.

19. Although we are so forgetful of the very existence of the air, it is of the greatest importance to all our daily occupations, and even to life itself. Without air nothing could burn; we could have neither fires nor lights; and, indeed, without air neither animals nor plants could live, for it is just as essential to the life of animals as it is to the growth of plants and the burning of coals and candles.

20. If a lighted candle is put into a large glass bottle, and the mouth of the bottle then stopped up, the candle soon gets dim, and in a short time goes out: the air is no longer able to keep it alight. If we put a second lighted candle into the bottle, it will go out immediately. Were a living animal substituted for the lighted candle, after living for a certain time in a confined portion of air, it would die, and a second animal placed in the air would immediately expire.

21. The question now will naturally arise—Is the whole of the air then spoiled or used up; and if it is, why does

not fresh air enter the bottle and supply its place? The truth is, only a small portion, about one-fifth of the bulk of the air, is able to feed the flame of a candle; the remainder, which cannot feed flame nor the life of an animal, is of a different kind from the air which can; and we find that the common air which we breathe is a mixture of two kinds of air, or GAS, as it is called by chemists;—the one kind, which we might call good air, which supports the life of animals, and is essential to the burning of fires and candles; and the other, or bad air, in which animals cannot live, and which immediately puts out fire and lights.

22. Chemists call the good air Oxygen, and the bad air Nitrogen, or Azote; but we must not suppose that because the nitrogen appears thus useless, it is really so; for it is, in fact, of very great importance, as we shall hereafter see. In the experiment just mentioned of burning the candle in a large bottle, the oxygen is all combined with the elements of the tallow, for which they have a strong affinity, whilst the nitrogen is left unchanged, because it cannot combine with them; for the same reason also, it puts out a fresh-lighted candle plunged into it.

23. OXYGEN, when obtained pure, and separate from any other substance, is a gas like common air in its ordinary characters, but remarkable for the very brilliant manner in which all kinds of combustible matter burn in it. Oxygen may be breathed with safety, but it causes all the functions of the animal system to be carried on with great vigour and rapidity, so much so that an animal

breathing pure oxygen would be soon destroyed, from the very powerful effect which the gas would have on its organs. Oxygen has a strong affinity for most of the other elements, and combines with them to form a numerous and important series of compounds.

24. NITROGEN, though it resembles oxygen in appearance, yet differs from it very remarkably in chemical characters; it extinguishes flame, and cannot support the combustion of any substance; it is irrespirable, suffocating animals if they attempt to breathe it pure, and seeming to have very little affinity for other elements: at least under ordinary circumstances, it shows very little tendency to combine with them; under particular circumstances, however, it does form compounds, (118-124) and some of them are very curious and important. Common air consists of one part of oxygen to four parts of nitrogen: it is a mixture, not a compound.

25. When a candle burns, it gradually disappears; it grows shorter and shorter, and at last, when all the tallow is burnt, the candle goes out; but we must not therefore suppose that it is utterly destroyed. A change has taken place; the tallow, or rather its elements, have combined with the oxygen of a portion of air, and two new compounds, one of which is a gas or kind of air, are produced. If we put a piece of salt into water, it will get less and less, and at last will disappear altogether, having wholly dissolved; but the salt is not destroyed, it is only dissolved in the water.

26. Now we may compare the burning of a candle to

dissolving a piece of salt; for all the solid matter of the candle remains diffused throughout the air, after it is burnt, just as the salt remains dissolved in the water; but with this difference, the salt is dissolved in the water, but not combined with it. The elements of the tallow are dissolved in the air, but they have combined with a quantity of oxygen, because they have a strong affinity or attraction for it. If the solution of salt is left for some time in a warm place, the water evaporates, and we get the salt again, unchanged; but in the case of the candle, its elements have combined with oxygen, and they cannot be separated again from it except by the action of something which, having a more powerful attraction for the oxygen than it has for the elements of the candle, causes it to relinquish them.

27. There are substances which have sufficient attraction for the oxygen to effect this: we cannot get back the tallow, it is true, but we may obtain its elements, or the simple substances of which it was composed. What has been said with regard to the burning of a candle is equally applicable to the burning of wood, coal, or in fact any combustible matter. In all ordinary cases they burn in consequence of their affinity for the oxygen of the air, and they are never destroyed when burnt, for their elements may always afterwards be found combined with oxygen in the air in which they have been burnt.

28. It must also be remembered that when the candle goes out for want of air, it does not do so because all the oxygen is burnt, but because the elements of the candle

having combined with all the oxygen of the air, or, as it were, saturated it, there is no more free oxygen left to keep up the combustion of the candle.

29. The changes occasioned by chemical action frequently proceed slowly and quietly, but in many cases, and especially when substances combine together which have a strong affinity for each other, a great deal of heat is given out. Sometimes as soon as two substances are brought together, they combine directly, and become very hot ; this is the case in the slaking of lime ; but it most usually happens that the mere bringing together of two substances, even though they have an affinity for each other, is not sufficient to cause them to combine.

30. In these cases combination cannot take place until the substances are heated up to a certain point. Thus charcoal has a strong affinity for the oxygen of the air, yet it cannot combine with it whilst both are cold ; but as soon as a part of the charcoal is heated red-hot, combination commences, and this very act evolves so much heat that the surrounding parts of the charcoal soon begin to burn, and thus the combustion, or combination of the charcoal with oxygen, continues and increases until either the charcoal is all burnt, or the oxygen in the surrounding air is saturated with carbon, and therefore unable to burn any more.

31. The common operation of lighting a fire is a daily illustration of this. The fuel contains carbon, or charcoal, ready to combine with the oxygen of the air, but unable to do so until, by applying a light to it, we heat

a portion up to the point required to commence combination: after which the heat given out by the chemical action going on keeps it alight, and causes the combustion to spread to the surrounding fuel.

32. The atmosphere is composed chiefly of two different gases, called oxygen and nitrogen: but besides this, it also contains a small quantity of a third gas or kind of air, which is not simple like oxygen and nitrogen, but a compound of charcoal (by chemists named CARBON) with oxygen, and called CARBONIC ACID GAS (79).

33. It is known that all things containing carbon will produce a quantity of this gas whilst burning; and hence we can have no difficulty in accounting for its presence in the air. Indeed we might at first suppose that it must be always increasing in quantity: this, however, is not the case, for we always find exactly the same quantity in any portion of air that we analyse. The cause of this is, that all plants contain substances which have a very strong affinity for carbon, but which cannot combine with it in its solid forms, because they are unable to come in contact with it; but which, when the carbon has combined with oxygen and become a part of the air, are able, in consequence of their having a more powerful attraction for it, to seize upon the carbon of the carbonic acid gas thus diffused throughout the air, and cause it to relinquish the oxygen with which it was previously combined (432-442.)

34. These facts show us a new use of plants, for we learn that the objects which we have only admired for

their beauty, or valued for their utility as producing articles of food, that even weeds themselves, and things we usually consider as wholly useless, are all constantly, by the agency of attraction or chemical affinity, decomposing carbonic acid gas, and thus keeping the air in a uniform and healthy state.

35. The air then always contains a regular proportion of carbonic acid gas, which is constantly produced by the burning of combustibles, and in many other ways, and as constantly decomposed by the action of plants. As we are now only considering the properties and nature of the air, we will, for the present, pass over further consideration of carbonic acid gas, to which we shall shortly return (79) when studying the nature of carbon, and merely mention now, that it is of the greatest importance to the life of plants, being the principal source from whence they derive the carbon necessary for their growth.

36. The air always contains dissolved in it some water, or rather vapour, which varies in quantity according as the air is hotter or colder. When it is hot, a larger quantity of water is evaporated or converted into vapour, and dissolved in the air, which in consequence becomes more damp; whilst on the other hand, when the air becomes cold, the vapour in the air is condensed, returning to the state of water, and the air becomes drier.

37. This, of course, is modified according to circumstances; thus, in dry barren countries where the ground contains but little moisture, the air, when it becomes hot, remains comparatively dry; whilst in moist or swampy

countries, under similar circumstances, the air becomes damp from the abundance of vapour given off; and thus some of the principal differences of climate depend mainly upon the quantity of water dissolved in the air.

38. The solution of water in the air may easily be seen by observing the steam issuing from the spout of a tea-kettle. When the water boils strongly, and there is a large volume of steam coming out of the spout, we observe that just where it comes out, the steam is almost invisible; at a little distance it becomes white and cloudy, and when it gets further out into the air it soon disappears and is again invisible. The reason of this is, that hot steam is quite colourless and invisible, like air; and it only becomes apparent to us when it is partly cooled by rushing out into the cold air, and therefore is beginning to condense, and it would fall to the ground in a shower of little drops like rain if it were not dissolved and carried away by the air as fast as it issues from the tea-kettle. When a large quantity of steam is quickly cooled, as in escaping from the funnel of a steam boat, it is condensed and falls in the form of water.

39. The quantity of moisture in the air is also rendered apparent to us whenever a cold substance is exposed to it; this cools the vapour in the air so much that it is condensed and appears again as water, in little drops on the cold surface: thus a bottle of cold water brought into warm damp air, speedily becomes covered on the outside with dew, or water thus condensed from the air.

40. The substance next in importance to air is WATER, which exists naturally in three different states: namely, in the solid state as ice; in the fluid state in its ordinary condition; and lastly, as vapour or steam. These three states of water are familiar to every one, but few are aware what causes the great difference between them.

41. When ice is placed before the fire, or exposed to the sunshine, or in any other way warmed, it absorbs heat, it melts and becomes water; and when water is heated, it assumes the form of steam or vapour. The difference between these three forms of water is entirely caused by the quantity of heat they contain; and we may truly say that water is a compound of ice and heat, and that steam is a compound of water and heat.

42. Although this seems very like chemical action, it is really quite different, and must not be confounded with it. Chemical action can only take place between material substances, or those that have weight; now heat is not a substance—it is not a thing we are able to weigh, like all the chemical elements, and consequently when it combines with any substance it only alters the appearance and outward characters of that substance, but does not at all change its chemical properties or nature.

43. When heat is thus combined with a substance it is said to be latent (hidden), which means that it is not sensible to the feel. This will be easily understood from a very simple experiment. If we put some water in a kettle on the fire, we find that it will soon begin to feel warm to the hand if immersed in it; the warmth which

we then feel is called free or sensible heat: but if we put some ice into the kettle in place of water, it will not become warm so soon, but will remain ice-cold until all the ice is melted, because all the heat supplied to it by the fire is absorbed or combined with the ice in melting; and therefore as the heat so absorbed does not make the melting ice any warmer, it is called latent. When all the ice is melted, the water will begin to get warm.

44. The general effect of heat upon substances, whether solid, liquid, or gaseous, is to expand or make them larger; thus whenever we heat a portion of water or any other fluid, it increases in size: upon this fact the construction of the common thermometer depends, which consists of a bulb and tube containing a certain bulk of mercury, or quicksilver; when this is heated it becomes larger, and when cooled the mercury shrinks or occupies less space than it did before.

45. When a substance expands or becomes larger, it of course becomes lighter. If ten measures are expanded by heat to eleven, it follows that ten measures of the heated substance must weigh one eleventh less than ten measures of it when cold. For example, air, when heated, becomes lighter, and consequently rises, because becoming larger, it weighs comparatively bulk for bulk less than the cool air around. Or when water is heated in the same way, it becomes larger and lighter, and consequently rises through the cooler portions above it. Just the reverse of this happens when substances are cooled; they then become smaller and heavier.

46. There is one remarkable exception to this rule in the case of water; when water is cooled it contracts, and this goes on till very near the freezing point, but then the water begins to expand, and in place of continuing to contract, as all other liquids do, it becomes larger; this leads to a very important result in nature. When the air above the surface of a lake or pond becomes cold, as towards the end of autumn, it gradually cools the surface of the water; the upper part becoming cold, shrinks, and consequently becomes heavier, it therefore sinks through the warmer water. This circulation or gradual sinking of the cooled water goes on, if the air continues cold, until the whole of the water is very near freezing, but then it stops, because if the surface still goes on cooling, the water begins to expand, becoming larger again, and consequently lighter; the surface therefore gets colder and freezes, whilst the lower part of the water remains considerably above the freezing point. If it were not for this curious fact, water would continue to become colder, until the whole of it froze together.

47. In passing from the liquid to the solid state, some substances contract, such as melted lead for example, whilst others expand; thus ice-cold water, in freezing, expands very considerably, and therefore ice is even lighter than the water on which it is formed. It is for this reason that ice floats on water, and if the ice did not expand in forming, the curious fact just mentioned would not prevent lakes and ponds from freezing entirely, because the ice, if it contracted in forming, would then

sink through the water to the bottom, and thus soon cool the whole mass of water.

48. This expansion of water in the act of freezing, takes place with immense force, giving rise to the bursting of water pipes and vessels full of water, in cold weather. It is often supposed that this effect is occasioned by the thaw, and not by the frost. This is a mistake ; the mischief is caused by expansion at the moment of freezing, though we only discover it on the approach of warm weather, when the ice begins to melt. Another, and very important natural result of this power, is the disintegration or breaking up of rocks, stones, and soils, by frost, during winter. A few drops of water, in freezing, are able to break asunder the hardest rocks, and this effect, year after year, gradually destroys them, causing them to crumble down into powder (389).

49. It has already been stated that water is not an elementary or simple substance ; it is a compound, and consists of two gases. This fact at first seems incomprehensible, for we can hardly believe it possible that a hard and solid substance like ice, or a weighty fluid like water, is composed of colourless and invisible gas. The difficulty, however, greatly diminishes when we remember that heat alone, without adding anything to the weight of ice, converts it into water, and that a little more heat will convert that water into an invisible colourless vapour ; for, as has already been said, (38) pure hot steam is quite invisible, and only becomes visible to us when partly condensed by the contact of the colder air, which de-

prives it of the heat necessary to keep it in a state of vapour (38-56).

50. The consideration of these facts makes the composition of water appear far less wonderful ; for we have little difficulty in believing that steam is composed of two gases, and we know that steam, water, and ice, are, chemically speaking, the same.

51. One element of water is oxygen gas, (23) that part of the air which is so essential to life and combustion : it constitutes eight-ninths of the weight of ice, water, and steam.

52. The other element, or the remaining one-ninth, is called hydrogen gas, or inflammable air, because it is very combustible, being the basis of the common coal-gas used for lighting the streets, and entering into the composition of the inflammable air or fire-damp of mines, and many other combustible substances (63).

53. Water is not like common air, a mere mixture of two gases : it is a compound, and therefore is quite different in its properties from either of its two elements. The very inflammable gas hydrogen having combined with a certain quantity of oxygen, which is the great promoter of combustion, forms water, a compound which we always regard as the greatest enemy to fire or combustion.

54. The purest kind of water which occurs naturally is rain-water, for all others, such as spring, river, or sea-water, are more or less contaminated or rendered impure by substances dissolved in them. Thus sea-water con-

tains, along with other matters, a large quantity of common salt, which in some places is procured from it by exposing it in shallow pits to the heat of the sun: this causes the water to evaporate, and leaves the salt behind.

55. The composition of sea-water from different parts of the world is found to vary slightly. The following table shows the composition of sea-water from the English Channel. (Schweitzer.)

Water	96474
Common Salt	2706
Chloride of Potassium	76
Chloride of Magnesium	366
Bromide of Magnesium	3
Sulphate of Magnesia	229
Sulphate of Lime	140
Carbonate of Lime	3
Iodine	traces
Ammonia	traces
	100000

56. Water may be artificially purified by distillation; when heated and raised into vapour, all the impurities are left behind, and accordingly condensed steam is perfectly pure water; there are numerous contrivances for thus purifying water. The common still, which consists of a vessel to generate steam in, and a pipe, passing through a tub of cold water, to condense the steam, is a familiar example.

57. This fact explains why rain-water is purer than other sorts of water, because when the heat of the sun evaporates water from the surface of the earth, all the

impurities which it contains are left behind; and of course when this vapour is cooled and falls down in the form of rain, it must be very nearly pure.

58. Springs which rise from the ground always contain earthy matters dissolved in them, which vary in nature and quantity with the soil through which the springs rise. The presence of these impurities in water in any quantity gives to it that peculiar character which is termed hardness. Sometimes springs contain a small quantity of iron or sulphur, and other substances, which constitute the many varieties of mineral waters. These matters, like the more common earthy impurities, are all derived from the beds of stone, sand, or clay, through which the springs rise; because the source of all springs is rain-water, which, falling pure from the clouds, becomes contaminated by filtering through the earth, and collects in holes and cavities, or porous beds of sand, constituting springs and wells.

59. The quantity of saline and earthy matter in spring water varies from about 20 grains to 1800 grains in the gallon; when above 100 grains per gallon, it constitutes a mineral water. The average quantity in ordinary spring water is from 20 to 80 grains. The most common salts are Sulphate and Carbonate of Lime (196), Sulphate, Muriate, and Carbonate of Potash and Soda.

60. The presence of phosphoric acid in some waters has recently been discovered (154). The following analysis of the deep well water from below the London clay, shows the presence of a considerable quantity of phosphoric

acid (Graham). A gallon of the water contained fifty-six and a half grains of saline matter, of which 1000 parts contained

Carbonate of Soda	207
Sulphate of Soda	429
Chloride of Sodium	226
Carbonate of Lime	110
Carbonate of Magnesia	19
Phosphate of Lime	3
Phosphate of Iron	4
Silica	8
	1000

61. Besides these saline and earthy substances, water always contains atmospheric air dissolved in it. This is essential to the life of fishes, and to the growth of water-plants, which could not exist if they were not thus supplied with common air.

62. Water is essential to the existence of all plants and animals: it constitutes a large portion of all animal and vegetable substances, it is the principal component of the blood of animals and the sap of plants, and is of the greatest importance, as being the means of introducing into their systems many soluble matters necessary for their healthy growth.

63. HYDROGEN, the inflammable element of water, is a substance of considerable interest; it is true, it is never found in nature in a pure and separate state, but its compounds are abundant, and some of them very important; when pure, hydrogen is an invisible transparent gas, like the air; very combustible, burning readily when once

inflamed, and remarkable for being so much lighter than common air, that a thin bladder, filled with this gas, would rise through the air in the same manner that a bubble of common air rises through water.

64. The most important of its compounds are water, which is formed by its union with oxygen ; ammonia, a gas which it forms by combining with nitrogen ; and coal gas or carburetted hydrogen, an inflammable gas consisting of hydrogen and carbon. The two latter will shortly come under notice (119-102).

CHAPTER II.

CARBON—NITROGEN—SULPHUR—CHLORINE—PHOSPHORUS.

65. WE now come to the consideration of an elementary or simple substance which has been already more than once alluded to, namely, carbon or charcoal. CARBON is the name applied to the pure element, but common charcoal is so nearly pure that we may consider the two words as meaning the same thing ; it is an essential part of all kinds of fuel or combustible substances, during the burning of which it combines with oxygen, and forms carbonic acid gas, the substance before adverted to as always existing in the atmosphere (32).

66. The forms of carbon which we are accustomed to see are almost all black, like common charcoal ; but this is not the case with all the varieties of carbon, for we know that the brilliant transparent gem called the diamond is really pure carbon, there being no chemical difference between that gem and common charcoal.

67. There are many substances in nature which exist in two or more different states presenting very dissimilar appearances, but being really chemically the same. Thus, chalk and marble are very different-looking substances, but they are composed of precisely the same elements ; the difference between them is not caused by heat, like

the difference between the three states of water, but is wholly of a mechanical nature. The particles composing a piece of chalk are much smaller than those composing a piece of marble, which are in fact compound particles, consisting of many joined together, and hence a piece of marble appears made of many little grains, whilst chalk is composed of particles so small that we are unable to distinguish them, and therefore appears to be a uniform substance.

68. The power which holds together the little particles composing the piece of marble or chalk, or any other substance, is called cohesion, and this power varies in strength in different substances ; thus it is far stronger in marble than in chalk, and hence a piece of marble requires a much harder blow to break it, than a piece of chalk. In the same way we say that the particles composing the diamond are held together more firmly by cohesion than the particles composing a piece of charcoal. Cohesion is, of course, quite independent of chemical attraction, for it holds the different particles of a substance together, constituting its mechanical strength ; whilst chemical affinity binds together particles of two different substances, forming a compound substance, but does not in any way affect the strength of the compound to resist mechanical force applied to it.

69. Under common circumstances, carbon is one of the most unchangeable things we know ; neither air, water, nor any of the substances commonly found in nature, have any action upon it ; and hence the practice

of charring the lower parts of wooden posts which are intended to be driven into the ground ; the coat of charcoal thus formed protects the wood from decay for a much longer period than if not charred (583). When, however, carbon is heated, its chemical affinity for oxygen is greatly increased, and it no longer appears to be the unchangeable substance which it is whilst cold.

70. Carbon has been already stated to be a necessary element of plants, which though so various in form and colour, are nevertheless composed of very few elements. They consist almost wholly of oxygen, hydrogen, nitrogen, and carbon, which by combining in different proportions, form all the principal parts of both plants and animals.

71. The greater number of vegetable substances consist wholly of oxygen, hydrogen, and carbon ; whilst animal matters mostly contain, in addition to these three elements, a quantity of nitrogen : some of the compounds of plants, however, resemble animal matter in containing nitrogen. When wood is charred, or decomposed by heat, its elements are separated from each other ; the hydrogen and oxygen combine together and form water, whilst the carbon is left behind. When wood is burnt in the open air, both its hydrogen and carbon combine with oxygen, causing flame ; the combination of carbon with oxygen proceeds slowly and steadily, the carbon continuing to glow until all is consumed ; hydrogen, on the other hand, being a gas, mixes and combines with oxygen more rapidly, burning at once, with a flame.

72. All organic substances burn with a flame, and this

alone is a proof that they contain hydrogen, because under ordinary circumstances the other elements of vegetable matter could not cause flame; and whenever the flame is bright, we are sure that it contains a good deal of carbon, for the flame of pure hydrogen is very pale indeed, and the brightness of a flame, such as that of a candle, is entirely due to the carbon contained in the tallow, which is burned at the same time with the hydrogen, both combining with oxygen.

73. As the products of the combustion of a candle are carbonic acid gas and water, it would be natural to expect that a cold substance held over the flame of a candle would take from the vapour of water thus formed the heat necessary to its existence in the state of vapour, and consequently condense it into the fluid form. This is an experiment which may very easily be made, for we have only to hold a cold glass at a little distance above the flame of the candle, and we shall soon find it lined with a fine dew of water condensed in this manner.

74. Carbon is unable to combine with oxygen at common temperatures; it requires to be heated before it can enter into combination with that substance; but when a compound substance containing carbon is exposed to the air, it usually happens that if the other elements which it contains combine with oxygen, the carbon also is then able to combine with oxygen, and forms carbonic acid gas.

75. Thus when a plant dies and decays, its elements separate and form new compounds; but the carbon is

not set free in the form of black charcoal—it is slowly combined with oxygen to form carbonic acid gas (494).

76. Hence we see that decay is very like burning, similar effects being produced by both; only that the change which is effected by combustion in a short time, and accompanied with a great deal of heat, is very slowly and gradually effected by decay, very little heat being at the same time evolved. In both cases carbonic acid gas is produced.

77. This explains one great use of decaying vegetable substances in manures; they, of course, contain carbon, which is slowly combining with oxygen, and therefore always supplying the growing plants with carbonic acid gas, which is essential to their growth, as they, being able to decompose it, thus obtain carbon (432-442).

78. Carbonic acid gas is produced in large quantity by the breathing of animals. A constant supply of fresh air is requisite for the support of life, and we know that if an animal is prevented from breathing or inhaling fresh air, it will very soon be suffocated. The chemical action which goes on in the lungs of an animal is just the reverse of that which takes place in the organs of plants: in the latter case carbonic acid gas in the air is decomposed, and the carbon which it contained is appropriated by the plant; whilst in the lungs of an animal carbonic acid is formed; for the oxygen of the air is found, on being expelled from the lungs, to have combined with carbon and become converted into carbonic acid gas. In fact the process of breathing is very

similar to that of combustion, the same results being produced in either case (373).

79. Carbonic acid gas is invisible and transparent, like common air, slightly soluble in water, and remarkable for being much heavier than air, and for extinguishing flame and destroying animal life ; it is called an acid, although it certainly is not acid or sour to the taste, like vinegar, and the other common acids we are acquainted with : it will, therefore, be proper, before proceeding any further, to explain why it is called an acid, and in fact what is meant by that term.

80. There exists in nature a numerous class of substances which are called bases ; amongst which are potash, soda, and lime, &c. Now an acid is a substance that has a strong affinity for these bases, and which in combining with one of them forms a neutral compound possessing none of the properties of either.

81. Some acids are exceedingly sour, and very corrosive substances, like oil of vitriol, and aquafortis ; but when poured upon a base, such as potash or soda, they combine with it directly, and both the acid and the base lose their caustic and corrosive qualities.

82. These compounds of acids and bases are usually called SALTS, or saline compounds, and are very numerous ; for there are many acids and many bases. Most of the acids combine with bases in two or three different proportions forming sub-salts, neutral salts, and acid, or super-salts. In the sub-salts the proportion of acid is not enough to more than half neutralise the base, in

the super-salts it is twice as much as is required to neutralise the base, and in the neutral salts, as the name indicates, the acid and base are combined in single proportionals, or perfectly equal quantities (110-112).

83. There is also a great number of salts called double salts: these are compounds of two similar salts; thus there are double sulphates, like alum, the sulphate of alumina and potash (223); and double phosphates, like the phosphate of ammonia and magnesia (219). These double salts are distinct compounds of the salts of which they consist, and possess perfectly different properties from either of their constituents; they may generally be made by merely mixing together solutions of their two components. The number of double salts is very considerable, but there is also an immense number of salts which do not thus combine together.

84. Acids have a curious property of changing certain vegetable colours. The greater number of vegetable blue colours are by acids changed to red, and this property is therefore made use of by the chemist to detect the presence of a free acid; for this power of acids ceases immediately when they are combined with bases; because their powers are then neutralised (81).

85. A very common illustration of this change of colour may be seen in the pickling of red cabbage. Every one knows that red cabbages, as they are called, are really dark purple or blue, whilst growing, and they only become red by the action of the acid vinegar employed in pickling them; the same effect would be produced if any other acid was employed.

86. If now we add to some cabbage thus reddened by acid, a little alkali, either potash, soda, or ammonia, or indeed a portion of any base, the colour will soon be restored to its original blue ; because the acid is neutralised by the base. And if the base employed be one of the three alkalies, or their carbonates, such as common pearlash, which is the carbonate of potash, the solution of cabbage will become green, because free alkalies, and likewise their carbonates, have the power of turning vegetable blues green.

87. Alkaline solutions have also the property of turning certain vegetable yellows red, such for example, as common turmeric ; these tests, as they are termed, are very easily applied, and papers stained with blue or yellow vegetable colours are consequently most useful indicators of the presence either of free acid, or free alkali, in a solution.

88. Although carbonic acid, being a gas, is not perceptibly sour to the taste like the strong acids just mentioned, it nevertheless combines with bases, and in so doing neutralises, or at least weakens to a considerable extent, their caustic properties ; but as it has a far less powerful attraction for bases than most other acids have, it is very easily expelled from compounds containing it, by the action of another acid, which seizes upon the base and sets the carbonic acid gas at liberty.

89. We have already spoken of the conversion of chalk into lime by heat, in which process the chalk is decomposed, certain matters being expelled or driven off, and the lime left caustic. Chalk is a compound of

carbonic acid gas and caustic lime, and is called a carbonate of lime.

90. The carbonic acid is combined with the lime by so weak an attraction, that heat alone is sufficient to expel the acid, together with a small quantity of water which the chalk always contains. If a piece of chalk is put into some vinegar, or indeed into any sour liquid, the chalk will be decomposed, and the carbonic acid will bubble through the fluid until the vinegar or other acid is fully combined with lime, and its acid powers entirely neutralized. The same will happen with any other carbonate.

91. In consequence of this gas being considerably heavier than common air, it frequently collects in caverns, cellars, and other similar situations, and often occasions fatal accidents, suffocating those who unfortunately enter the places thus filled with carbonic acid. Its presence in such places in the air, in any quantity, may always be easily ascertained by letting down a lighted candle into the well or cellar : if the candle continues to burn, we know that there is enough oxygen present to support the life of an animal ; whilst if the candle is extinguished we are certain that the place is full of carbonic acid gas, and therefore that it must not be entered until the heavy gas has been dispersed by proper ventilation.

92. Carbonic acid is also evolved in large quantities during the process of fermentation, and occasions the pricking taste and effervescence of cider, bottled ale, and

other liquors. Common ale is allowed to ferment in open vessels, so that nearly all the carbonic acid formed during that process (307) is dispersed; but bottled ale being confined in close vessels before its fermentation is completed, much of the carbonic acid evolved subsequently is pent up in the liquor and escapes from it in innumerable small bubbles when the cork of the bottle is removed.

93. Carbonic acid then is constantly being formed in several different ways; it is produced during the combustion of all substances containing carbon, during the respiration of animals, during the decay of almost all vegetable and animal substances, and during the process of fermentation. It is likewise, in many situations, naturally given out by the earth in large quantities.

94. To counterbalance all these sources of increase there is only the power of plants already mentioned of decomposing it, by abstracting its carbon and setting free the oxygen again (77-471).

95. When two substances combine together and form a compound, they unite in definite and invariable proportions. A given weight of carbon, in burning, always combines with a uniform quantity of oxygen, to produce a certain weight of carbonic acid gas ; and this rule holds good in all cases of chemical combination, for it is one of the distinctions between mixture and combination that we are able to mix two substances together in any relative proportion we like ; but we are only able to make substances combine in certain fixed proportions.

96. Compounds do not always consist of equal parts of their elements, for they can consist of one part of one element, and one, two, three, or more parts of another element; and indeed there can frequently be formed several different compounds by the union of two elements in various proportions. When, however, we mix together two substances which can unite together, they always combine in one of these fixed proportions; and if there is more of the one element than is requisite to form the compound, it is left unaltered.

97. Thus we know that every six grains of carbon or pure charcoal require 16 grs. of oxygen to burn them perfectly, and convert them into carbonic acid; and exactly the same quantity will be required whether the carbon is burnt in a few seconds, or slowly combined with oxygen by the gradual process of decay. If we were to try to combine six grains of carbon with 20 grains of oxygen, we should find that only 16 grains of the oxygen would combine with the charcoal, and the remaining 4 grains of oxygen would be left unchanged.

98. When we try to burn charcoal so that it shall get less oxygen than is requisite to convert it into carbonic acid, we find that it is possible to do so, but that the gas produced is not carbonic acid. Carbon and oxygen are able to combine together in more than one proportion; and consequently, though when carbon is burnt in the air, or where it can get abundance of oxygen, it always forms carbonic acid, yet when burnt so that it cannot

combine with a sufficient quantity of oxygen to form that gas, it forms a different compound containing less oxygen, which is called carbonic oxide.

99. This compound is a transparent colourless gas, like carbonic acid, and resembles it also in being totally unfit to support animal life; indeed it appears to be far more dangerous than carbonic acid when taken into the lungs, even though considerably diluted with common air. It extinguishes flame, as might be expected, but it is itself combustible, burning with a pale blue flame, and at the same time is converted into carbonic acid, in consequence of having acquired more oxygen from the air in which it has burnt.

100. We frequently see on the top of charcoal or coke fires a pale blue flame, quite different in appearance from the usual bright flame of wood or coal; this is occasioned by carbonic oxide which is formed in the midst of the mass of burning fuel, where the carbon, being unable to get enough oxygen to form carbonic acid, produces this gas, which, when it reaches the top of the fuel, meets with fresh air and combines with a further quantity of oxygen. When, however, a charcoal fire is burning slowly, a quantity of carbonic oxide escapes into the air without being burnt into carbonic acid; and its poisonous nature is often shown when persons have foolishly placed a pan of burning charcoal in a close bedroom. The charcoal is not only abstracting the oxygen of the air and converting it into carbonic acid, which cannot support life, but is also forming quantities of the highly poisonous

gas, carbonic oxide, the presence of which in a room, in any considerable quantity, is sure to destroy life.

101. Besides these two compounds of carbon, there is yet a third, intermediate in composition between carbonic oxide and carbonic acid, though very different from either in its properties ; this substance is oxalic acid, a strong and very poisonous acid. Oxalic acid occurs in many plants, and may be easily formed artificially (327) ; it is a white solid substance, soluble in water, in which it forms a very sour solution, and having a strong affinity for bases. It has never been formed direct, from carbon and oxygen.

102. Although when carbon burns in the air it only combines with oxygen, it can, under some circumstances, combine with nitrogen, and also hydrogen. Thus when vegetable matters decay under water, we find that a gas is given off in bubbles which consist of hydrogen and carbon, and is therefore called carburetted hydrogen.

103. This gas is, as may be supposed, inflammable ; burning in the air with a tolerably bright flame, and forming, by the combustion of its two elements, water and carbonic acid. This gas is found in very large quantity in coal mines, where it is called fire damp, and occasions violent explosions when a light is incautiously brought into a mixture of it and common air.

104. In these cases the gas is mixed with a quantity of atmospheric air, but the affinity of the carbon and hydrogen, of which it consists, for the oxygen of the air, is not powerful enough to cause combination. When,

however, a lighted candle or lamp is brought into the mixture, that part is immediately raised to the temperature at which combination can take place, the mixture takes fire, the flame spreads with very great rapidity, and in a few seconds the mixed gases are changed from air and carburetted hydrogen, into carbonic acid gas, steam, and nitrogen. At the moment of explosion the gases are very greatly expanded by the heat of the flame, and subsequently they are suddenly condensed as the steam is cooled and converted into water. Carbonic acid and nitrogen alone being left, many of the dreadful accidents which occur in coal mines are less caused by the violence of the explosion, than by the suffocating effects of the after damp, as the foul air left after the explosion is termed.

105. There are also many other compounds of carbon and hydrogen, in which different proportions of the two elements give rise to a great variety of different substances: one of the most important of these is the common coal gas, obtained by distilling or roasting coals in close iron vessels, and which is used for lighting the streets; it differs from the fire-damp of mines in containing rather more carbon. India-rubber, coal-tar naphtha, oil of turpentine, &c., are also compounds of carbon and hydrogen.

106. In expressing the composition of any substance, chemists are in the habit of saying that it consists of such and such proportions of its elements; whatever quantity they may have taken for analysis, they generally calculate the proportion which a hundred or a thousand parts would consist of. Thus, for example, 550 grains of

pure carbonate of lime contain 308 grains of lime, and 242 grains of carbonic acid ; hence 1000 grains must contain 560 grains of lime, and 440 grains of carbonic acid ; and 100 grains of carbonate of lime contain 56 grains of lime, and 44 grains of carbonic acid.

107. This is a very simple example, but it constantly happens that the composition of substances is not so easily expressed. 1000 grains of dry gypsum, or sulphate of lime, consist of 412 grains of lime, and 588 grains of sulphuric acid. The composition of 100 grains of such a substance is represented thus :

Lime . . .	41·2
Sulphuric Acid . .	58·8

This merely means that one hundred grains contain 41 and two-tenths of a grain of lime, and 58 and eight-tenths of a grain of sulphuric acid : hence there is no real difference whether we put the dot or not ; if it is used, the figures behind it are known to be fractions ; if not, they are whole grains.

108. Sulphate of lime may be expressed either as

Lime . .	·412	4·12	41·2	412
Sulphuric Acid .	·588	5·88	58·8	588
	1 grain.	10 grains.	100 grains.	1000 grains.

In all the analyses given in the following pages, no fractions are used ; the composition of everything is given as it would be obtained if 10000 or 100000 grains were analysed.

109. Chemists are constantly in the habit of speaking

of atoms, proportions, combining numbers, and similar terms; it will be well briefly to describe what is meant by these terms. It has been already stated that the composition of all compound substances is definite (95); that a certain weight of carbon, for example, can only combine with a fixed quantity of oxygen to form carbonic acid (97).

110. Let us observe what relation there exists between the quantity of different substances which can combine together. It is found that one grain of hydrogen (for hydrogen, though a gas, can be readily weighed) will combine with eight grains of oxygen to form nine grains of steam, and this relative proportion between the two elements of water is perfectly invariable. One grain of hydrogen can combine with exactly sixteen grains of sulphur to form seventeen grains of sulphuretted hydrogen (117), a compound shortly to be described, or, with six grains of carbon, to form seven grains of carburetted hydrogen (102).

111. These numbers, then, express the quantity of each of these substances which can combine with one another, for, of course, it is perfectly the same whether we take a grain, an ounce, a pound, or any other weight. But this is not all; the number thus found for carbon, namely six, is not merely the quantity of that substance which could combine with one of hydrogen, but represents the quantity of carbon which can combine with eight parts of oxygen, to form carbonic oxide (98), or twice eight, 16, parts of oxygen to form carbonic acid;

and, again, eight parts of oxygen is not merely the quantity which can combine with one part of hydrogen, or with six parts of carbon, but is also exactly the quantity which is able to combine with a definite proportion or equivalent of any other substance.

112. The numbers which are in this manner obtained are called combining weights, proportionals, equivalents, &c.; they express the relative proportions in which substances combine together. Some compounds consist of a single proportional of each of these elements, but more commonly they contain one of one element, and two, three, or more, of the other; organic substances, for the most part, consist of nearly ten or a dozen proportionals of each of their elements (282).

113. The following table shows the proportions or combining weights of the most important simple substances.

Oxygen	8
Hydrogen	1
Carbon	6
Nitrogen	14
Chlorine	35
Phosphorus	31
Sulphur	16
Iron	27

114. When a compound is formed by the union of two elements, the equivalent or combining proportion of the compound is exactly the sum of the equivalent of its elements; thus, for example, carbonic acid consists of one equivalent of carbon, the number of which is 6, and two

equivalents of oxygen, weighing 16; the sum of 6 and 16 is 22; this then is the equivalent of carbonic acid, the quantity which will combine with an equivalent weight of any base, for example, with 28 parts of lime, 47 of potash, and so on.

115. In the following table the combining weight of some of the most important compounds is exhibited:—

Water	9
Nitric Acid	54
Carbonic Oxide	14
Carbonic Acid	22
Sulphurous Acid	32
Sulphuric Acid	40
Phosphoric Acid	71
Muriatic Acid	36
Sulphuretted Hydrogen	17
Carburetted Hydrogen	8
Ammonia	17
Potash	47
Soda	31
Lime	28
Magnesia	20
Silica	46
Alumina	51
Prot-oxide of Iron	35

116. When plants or vegetable substances, consisting of oxygen, hydrogen, and carbon, decay, their elements form new compounds, the principal of which are carbonic acid and water. We must now consider what are the products resulting from the decay of animal matters, and of those vegetable substances which, like them, consist of oxygen, hydrogen, carbon, and nitrogen; these are water, carbonic acid, and ammonia.

117. Nitrogen or azote differs from most other substances in appearing to be remarkably inert ; it seems to have little or no affinity for any other substance. It is always mixed with oxygen in the air, but it appears to have no inclination to combine with it ; and when carbon, or substances containing it, are burnt, they combine only with the oxygen, and never with the nitrogen of the air : so that it would appear as if the chief use of nitrogen in the air was to dilute the oxygen and prevent it from combining too rapidly with carbon and other substances.

118. Under some circumstances, however, nitrogen does combine with other elements, and its compounds are amongst the most curious and important substances we know. When animal or vegetable matters containing nitrogen decay, we find that it, like the carbon, is not set free in its simple and uncombined form, but that during decay it combines with a portion of hydrogen.

119. Therefore in addition to water and carbonic acid, the two principal substances arising from the decay of ordinary vegetable matters, we find a pungent, strong-smelling gas, composed of nitrogen and hydrogen, which is called AMMONIA.

120. This substance, though a transparent invisible gas, is, like potash and soda, a base ; like them it has a strong affinity for acids, and when combined with them neutralises their powers ; and, therefore, as it is evolved at the same time with carbonic acid, it combines with that acid and produces a solid salt, which is called a carbonate

of ammonia, just as the compound of carbonic acid and lime is called a carbonate of lime.

121. Ammonia is always produced when animal or vegetable substances containing nitrogen are decomposed, whether by combustion or by decay; in both these cases carbonate of ammonia is formed, which is a very volatile salt, and consequently is carried away by the air as fast as it is formed. Now water absorbs large quantities of ammonia, which, as well as all its compounds, is easily soluble in that fluid; and consequently the ammonia and salts of ammonia formed during these processes of decomposition are never retained in the air, but are dissolved and brought down to the surface of the earth by rain.

122. Ammonia was formerly called the volatile alkali, because in many properties it closely resembles the alkalies potash and soda, which are distinguished from all other bases by that name. Ammonia, however, differs from the two other alkalies in being a gas, whilst they are both solid, and almost all its compounds are more or less volatile, or capable of being converted into vapour by heat; whilst the compounds of potash and soda are all fixed, or quite incapable of being raised into vapour by any *ordinary* application of heat.

123. Ammonia has also a less powerful affinity for acids than the two other alkalies have, and consequently it is easily expelled from its compounds by either potash or soda, as well as by lime and several other bases, which set free the ammonia in the gaseous form, and

unite themselves with the acid previously in combination with the ammonia (182).

124. Ammonia is not the only compound containing nitrogen which is formed during the decomposition of animal substances; for although nitrogen and oxygen appear to have no affinity for each other, as they exist together in a state of mixture in the air, and do not enter into combination, yet when a compound already containing nitrogen is decomposed, we find that besides the compound of nitrogen and hydrogen just described, a compound of oxygen and nitrogen is also in some cases formed, which is possessed of very extraordinary powers, being a strong acid, and commonly called aqua fortis, or nitric acid.

125. Nitrogen is able to combine with oxygen in five different proportions, giving rise to as many distinct substances; four of these are of comparatively little importance, and may therefore here be passed over; the fifth, or that containing the greatest quantity of oxygen, is the only one at present worthy of consideration.

126. NITRIC ACID is never found in its free or uncombined state, but always in combination with some base; being a very powerful acid, it is easy to understand that as soon as formed it seizes upon some base to combine with, and forms a neutral salt. The commonest salts containing nitric acid, or nitrates, as they are called, are the nitrates of potash, soda, and lime, which are found native abundantly in different places.

127. The nitrate of lime is very frequently to be met with on old walls near which organic substances con-

taining nitrogen have decayed and formed nitric acid, which has combined with the lime of the mortar; and in the same way nitrate of lime may be formed artificially by mixing lime with decaying substances which can yield the acid, and, after having allowed them to remain some time together, by pouring water over the mixture: this dissolves the nitrate of lime, and forms a solution, which leaves the salt in question when the water is evaporated by heat.

128. Although nitric acid is a very strong acid, and has a very powerful affinity for bases, yet there are even more powerful acids, which are strong enough to expel it from its combinations, and we are thus able to procure the pure acid: this is usually done by what is called oil of vitriol, or sulphuric acid (140), a substance consisting of sulphur, or brimstone, combined with oxygen. When this acid is poured on a nitrate, it expels the nitric acid in the form of a very acrid or sour and biting vapour; this condensed in cold water, constitutes the intensely sour liquid called nitric acid, or aqua fortis, and was before combined with the base of the nitrate.

129. Nitric acid acts very strongly on all organic bodies, decomposing them sometimes with great violence, and causing their elements to enter into new combinations: thus when strong nitric acid is mixed with oil of turpentine, it sets it on fire. This is caused by the large quantity of oxygen which nitric acid contains, which enables it to burn substances, or at least makes them combine rapidly with oxygen, which we know is the cause of ordinary combustion.

130. When we mix nitric acid with substances which, having a strong affinity for oxygen, are able to decompose the acid, we obtain some of the other compounds of nitrogen and oxygen before alluded to, and by various processes we are able to obtain compounds of nitrogen, with most other elements, setting out with this acid as a source of nitrogen; for it seems that nitrogen hardly ever will combine with an element, except when in the nascent state, that is when being evolved or set at liberty by the decomposition of a substance in which it was already combined with some other element (494).

131. There are three other elements deserving notice, which, like nitrogen, are of little interest in themselves, but which, by combining with other substances, form important compounds: these are sulphur, chlorine, and phosphorus.

132. The properties of SULPHUR, or brimstone, are familiar to every one; it occurs native, both pure and also in combination with various metallic substances, entering into the composition of many ores, such as those of copper, lead, zinc, mercury, &c. Sulphur is a pale yellow solid substance insoluble in water, having hardly any taste, but a faint and peculiar smell, melting easily when warmed, and catching fire very readily, burning with a pale blue flame, and giving out at the same time a peculiar and very disagreeable smell. The compounds which sulphur forms with oxygen, and also with hydrogen, are the principal which demand attention.

133. Sulphur, like nitrogen, is able to combine with

oxygen in several proportions, and hence it forms several distinct compounds. It is only necessary to describe two of them,—sulphurous acid, and sulphuric acid or oil of vitriol.

134. When sulphur is burnt in the air, it forms sulphurous acid, a transparent invisible gas, possessing a very strong and suffocating smell ; it is easily dissolved by water, and the solution then obtained has a strongly sour taste.

135. A portion of sulphurous acid is formed whenever we light a common brimstone match ; and the peculiar suffocating smell then perceived is occasioned by this acid, and not by the sulphur alone, which has no smell, but which is used to tip the matches because it has a strong affinity for oxygen, and requires less heat to enable it to commence combination than the wood itself; but when it has once fairly got alight, it then produces heat enough to fire the wood.

136. Sulphurous acid is a transparent gas, rather heavier than common air, readily soluble in water, very poisonous when breathed, and extinguishing the flame of combustible matters ; it does not form any important compounds when combined with bases, and its principal interest consists in its bleaching powers. It has long been used to destroy colour in things desired to be bleached, which are merely hung up over some burning sulphur, and exposed to the fumes of sulphurous acid thus formed. Articles thus bleached, however, frequently retain an unpleasant smell of sulphurous acid.

137. It is likewise used in fumigation, being considered destructive of contagion ; and, therefore, sulphur is burnt in houses where persons have died of an infectious disorder, and in other circumstances where evil effects are feared from the communication of disease. In these cases sulphurous acid has really a useful influence, as it seems able to destroy a minute quantity of poisonous matter diffused throughout the air ; but it must be remembered that it can have no power of improving air which is unwholesome in consequence of the presence of a large quantity of carbonic oxide or carbonic acid, for in these circumstances burning sulphur would only tend to make the air worse, both by removing oxygen and also by adding sulphurous acid.

138. The bleaching power of this acid may be very well shown by holding a lighted brimstone match near a dark purple or blue flower, the colour of which will be immediately more or less destroyed, and we may easily thus, either in part or wholly, render the flower white.

139. Sulphurous acid contains less oxygen than the sulphuric acid ; in fact it stands in the same relation to that acid which carbonic oxide does to carbonic acid. Sulphurous acid is formed whenever sulphur is burnt in the air, because under those circumstances it is not able to combine with enough oxygen to form the more powerful acid.

140. SULPHURIC ACID is made by burning sulphur mixed with nitrate of potash, which supplies it with more oxygen than it could get by merely burning in the air ;

because the nitric acid in the nitre, when decomposed by the burning sulphur, gives rise to the formation of another compound of nitrogen and oxygen containing less oxygen, called nitrous acid, a substance which is decomposed by sulphurous acid, when water is present, giving up a portion of its oxygen to the sulphurous acid, and converting it into the sulphuric. In fact, when sulphur is thus burnt, and the fumes produced by its combustion are condensed in cold water, a very acid liquid is formed, which is called oil of vitriol, or sulphuric acid.

141. It is a heavy, very corrosive, poisonous fluid, although its elements are only oxygen and sulphur, the one being that part of the air necessary to support life, and the other a tasteless, yellow, solid substance. Sulphuric acid in its free state is chiefly remarkable as being one of the strongest acids we know, destroying vegetable and animal substances : that is to say, abstracting and combining with some of their elements, and causing the others to enter into new combinations ; and having a strong affinity for bases, with which it forms a class of compounds called sulphates, some of which are of very great importance, and must be considered hereafter (171, 181, 188).

142. Sulphuric acid is a most valuable substance to the chemist ; being one of the strongest known acids, it enables him to expel or drive out most other acids from their combinations, and thus through its agency many other acids are obtained pure and separate, from their compounds with bases (128, 148, 155).

143. Under certain conditions sulphur combines with hydrogen to form sulphuretted hydrogen,—a transparent colourless gas, remarkable for the exceedingly disagreeable smell which it possesses. It is to the presence of this gas that the nauseous, disgusting smell of putrefying animal matter is due. Sulphuretted hydrogen is very poisonous, and it would probably cause many fatal accidents, were it not that its offensive odour warns us of its presence, and induces us to take measures to disperse it by ventilation and other means.

144. Sulphuretted hydrogen is soluble in water to a considerable extent, and the solution possesses the strong and nauseous smell of the gas itself. The gas is inflammable, and in burning, produces water and sulphurous acid gas. Sulphuretted hydrogen has sometimes been called an acid, for it possesses feeble acid powers, combining with some bases and to a certain extent neutralising them.

145. Sulphur has a strong affinity for most metallic substances, forming a numerous series of compounds, which are called sulphurets; many metallic ores are sulphurets, and in the process by which the metals are obtained, the first operation consists in roasting the ores, or exposing them to a dull red heat, when the sulphur, being a volatile substance, is gradually driven off.

146. CHLORINE is an element which is never found free, but only in combination with some other element; it is a very poisonous gas, causing very great irritation when breathed, even though it is largely mixed with air; it is

transparent, has a bright-yellow colour, and is remarkable for possessing in a very great degree the power which sulphurous acid has of bleaching or destroying colours and also contagious matters. Chlorine is, therefore, very largely used in all cases where it is wished to destroy or remove colour : it is, however, a very powerful agent, and therefore must be used with great care, as otherwise if linen, for example, be bleached carelessly by means of it, the texture is destroyed, and the linen becomes rotten and useless. Common writing paper is often found to be quite decayed and useless, the rags from which it was made having been too strongly bleached with chlorine.

147. Small quantities of this gas are used with very beneficial effects in removing foul smells, and otherwise rendering sweet and wholesome the air of large buildings, such as hospitals. Chlorine readily combines with the metals, and most other of the elements, to form a series of compounds called chlorides ; thus, corrosive sublimate is a chloride of mercury, &c. It is unnecessary for us further to occupy ourselves with this element than to know that when combined with hydrogen it loses all these peculiar powers, and forms a strong acid, the muriatic, which, by combining with bases, forms a series of salts called muriates.

148. The process by which muriatic acid is procured is very simple : a quantity of oil of vitriol or sulphuric acid is poured on some common salt, acid fumes arise, they are made to pass through cold water, which absorbs

them, and in time a very sour corrosive liquid is obtained, which is the muriatic acid or the spirit of salt of the shops. In order to explain the action which takes place in this process, it is necessary to say a few words respecting the nature of common salt.

149. Common salt is a compound substance, consisting of two elements; the one is chlorine, the corrosive yellow-coloured gas just described, and the other is a white silvery-looking metal called sodium, a substance having a very strong affinity for oxygen, eagerly combining with it and forming the alkali—soda.

150. The substances, then, concerned in the process for making muriatic acid, are common salt or, to speak scientifically, chloride of sodium, sulphuric acid and of course a portion of water, as oil of vitriol is a solution of dry sulphuric acid in water. Both the chloride of sodium and the water are decomposed, the oxygen of the water combines with the sodium of the salt, whilst the hydrogen of the water combines with the chlorine of the salt, and thus soda and muriatic acid are formed; the latter is given off or expelled in the form of gas or vapour, whilst the soda combines with the sulphuric acid to form a neutral salt—the sulphate of soda. This is a very good example of combination and decomposition. In consequence of the powerful affinity which sulphuric acid has for soda, both the salt and water are decomposed; and the chlorine and hydrogen being free from their combinations, unite together to form muriatic acid (174).

151. Chlorine is procured from muriatic acid by the action of some substance capable of abstracting its hydrogen ; the most convenient for this purpose are those which contain much oxygen. The usual process is to heat together a mixture of muriatic acid and oxide of manganese, a substance which is rich in oxygen ; the oxygen which is thus given off, takes the hydrogen of the muriatic acid, with which it forms water, and sets free the chlorine.

152. Another and yet cheaper process is to heat a mixture of common salt, oxide of manganese and sulphuric acid ; in this case the sulphuric acid decomposes the salt, and muriatic acid formed, is decomposed as fast as it is set free, by the oxygen of the oxide of manganese.

153. Iodine, bromine, and fluorine, are substances hitherto undecomposed, and therefore called elements, which in many respects resemble chlorine ; like it they form acids by combining with hydrogen, and unite to the metals to form a numerous series of compounds resembling chlorides, which are called iodides, bromides, and fluorides : none of these substances are of much importance ; those most deserving of notice are the iodide of sodium, which exists with the chloride in sea-water, and the fluoride of calcium, which exists in small quantity in the bones of animals.

154. Phosphorus in several respects resembles sulphur ; like it, it is a readily fusible and very combustible solid. It is of a white colour, about as hard as wax, and has so strong an affinity for oxygen that it takes fire in the air with the greatest facility as soon as it is a little warmed.

Like the preceding element chlorine, it is never met with in a separate state, but always in combination. Its most important compound is phosphoric acid, the substance which is formed when phosphorus burns in the air or in oxygen: it is a white solid substance, very soluble in water, and eagerly combining with bases to form a class of salts called phosphates (189, 208).

155. Phosphoric acid is generally obtained by decomposing one of its compounds by sulphuric acid. The most abundant compound of phosphoric acid is that in which it is united to lime, called the phosphate of lime: this substance is an ingredient of the bones of animals, and of most vegetable substances. When sulphuric acid is mixed with phosphate of lime, the latter is decomposed and its phosphoric acid is set at liberty. The acid may be artificially made by burning phosphorus in the air, from which it abstracts the oxygen, and leaves the nitrogen unaltered, just in the same way that carbon when burnt in air forms carbonic acid: only that in that case the product of combustion is a gas, like the air, whilst the result of the combustion of phosphorus is a white solid acid.

CHAPTER III.

THE ALKALIES.—THE ALKALINE EARTHS, AND THEIR SALTS.

156. The class of substances called bases, or those with which acids can combine, is very numerous. The commonest, and therefore the most important, are the three alkalies, potash, soda, and ammonia, together with a few substances called earths, because they are the principal ingredients which enter into the composition of the earth or soil.

157. Potash never occurs pure in a free state; its most abundant source is the vegetable kingdom, and the simplest method of procuring it is by burning wood. When this is done, after all the combustible matter is burned, there remains a quantity of a white or grey substance called ashes, which when put into water forms a caustic solution. This is caused by the presence of potash, which not being altered by the heat occasioned by the burning of the wood, is left in the ashes.

158. In this way, however, we do not obtain the potash pure, because, being a powerful base, and having a strong affinity for acids, it combines with some of the carbonic acid formed by the burning of the carbon contained in the wood, and therefore the caustic substance found in the ashes of the wood is an impure carbonate of

potash. It is obtained tolerably pure by pouring water on wood ashes, straining off the clear liquor, and evaporating it; a white salt is left, which is the carbonate of potash separated from most of the other matters which were contained in the ashes, and when thus purified it is called *pearlash*.

159. Pure potash is readily obtained from its carbonate, by means of quicklime; that substance has a stronger affinity for carbonic acid than potash has, and accordingly it decomposes the alkaline carbonate and leaves the alkali in its pure state: when free from any acid, it is found to be a very caustic solid substance, which has a strong affinity for acids, and is difficult to keep perfectly pure, as when exposed to the air it rapidly acquires carbonic acid from it, and becomes converted into the carbonate.

160. Potash is not a simple substance; like soda, it is a compound of a metal and oxygen (150). By the action of charcoal at a very high temperature it may be decomposed, for at a white heat the affinity of charcoal for oxygen is so great that it is even able to take it from potassium, as the metal of potash is termed: potassium is of course never found in a native state, for its affinity for oxygen is so great, that when exposed to the air it instantly absorbs a quantity of that gas, and is soon converted into potash. It may readily be proved that potash, soda, and the earths are all compound bodies, and that they consist of peculiar metals combined with oxygen; but as the affinity which they have for that element is very great, and as they are never decomposed under

ordinary circumstances, it is quite unnecessary to study the nature of potassium, sodium, &c., further than to know that they are white, silvery-looking metals, which by combining with oxygen form potash and soda. For all practical purposes we may think of potash, soda, and the earths, as elementary substances.

161. Potash has a strong attraction for water; so that when dry pure potash is exposed to the air, it very soon becomes moist, and in a short time has attracted so much water from the air as to appear changed into a liquid. This power of attracting water from the air is common to most of the salts of potash, as well as to many other saline compounds: it is termed deliquescence, and such salts are said to be deliquescent. Pearlash, if left exposed to the air, rapidly becomes moist, and finally runs into a liquid, which is a very strong solution of that salt in water; and therefore it must always be kept in a dry place, and in well-closed vessels.

162. In the same way, we often find that common salt when kept in a damp place becomes very moist; this is not occasioned by any attraction which the salt itself has for the moisture in the air, but by certain saline impurities, usually contained in the salt, which have this power in a high degree (218).

163. Chloride of potassium may be formed by heating the metal potassium in chlorine, or by acting upon potash by muriatic acid (150); it is not a salt of much interest; it has been occasionally recommended as a manure (590).

164. One of the most important of the salts of potash,

is the nitrate, or, as it is commonly called, saltpetre, or petre, which is found native in many places as a white powdery matter on the surface of the ground, and is procured pure by washing the earth, and evaporating the solution of nitre thus obtained.

165. Nitre is a perfectly neutral salt, and is in that respect very different from the carbonate of potash, which, although far less caustic than pure potash, has still very considerable caustic powers, in consequence of which it is so commonly used in washing, and for other household purposes. Carbonic acid, in combining with the alkalies, does not seem able to neutralise them, or destroy their alkaline powers so completely as most other acids can ; and therefore it must be remembered that the carbonates of the alkalies still possess some of the powers of the alkalies themselves. The other compounds formed by the alkalies with the more powerful acids are quite neutral, and in them no traces of the alkaline nature of the bases can be found.

166. One of the principal uses of nitre is in the manufacture of gunpowder, which consists of nitre, charcoal, and sulphur, finely powdered, and very carefully mixed together. The chemical action which takes place during the burning or explosion of gunpowder is very simple. The nitre consists of potash and nitric acid, the latter substance containing a large quantity of oxygen, combined by a comparatively weak attraction with a portion of nitrogen. The finely-powdered charcoal has a very strong attraction for oxygen, and when sufficiently heated is able to decom-

pose the nitre, seizing upon the oxygen of the nitric acid, and forming carbonic acid, a small portion of which combines with the potash of the nitrate, and forms carbonate of potash.

167. The use of the sulphur in gunpowder is similar to its use in the lighting of a common sulphur match ; it very easily catches fire, and the flame thus produced instantly heats the charcoal so much that it is able to decompose the nitre.

168. The mechanical force of gunpowder when fired, is occasioned by the instantaneous production of a large quantity of gas from a small bulk of solid matter : as the whole of the nitrogen, and the greater part of the carbonic and sulphurous acids formed are given off in the gaseous state, and comparatively little is absorbed by the potash.

169. During the burning of gunpowder, a small portion of sulphuretted hydrogen is commonly formed, which occasions the bad smell (143) commonly perceived : the hydrogen necessary for the formation of this gas is derived from a little moisture which gunpowder generally contains ; pure and perfectly dry gunpowder contains no hydrogen, and hence, in its firing, no sulphuretted hydrogen can be found.

170. Nitre is one of the few compounds of nitric acid which are found native, and indeed it was till lately almost the only source of that acid. It is also used as a manure, and will therefore come before us again on a future occasion (597).

171. Sulphate of potash is a soluble salt readily

formed by acting on any of the ordinary salts of the alkali, such as the carbonate or nitrate ; it is chiefly used by the manufacturers of alum (223).

172. Salts of potash are met with in a great many plants in small quantities ; they are likewise almost always to be found in the soil, and potash is by no means uncommon in stones : indeed, it is evident that the salts of potash found in the soil must have been derived from the gradual breaking down and decomposition of stones and rocks containing compounds of potash.

173. The second alkali, SODA, is in its general characters similar to potash ; it is a very caustic solid white substance, has a powerful attraction for acids, and is consequently never found in a pure and separate condition, but always in combination with an acid or some other substance. The most abundant source of soda is common salt, which exists in very large quantities in sea-water, and is likewise found native in the earth, when it is called rock-salt, to distinguish it from the salt obtained by the evaporation of sea-water, and called sea or bay-salt.

174. Common salt has already been stated to be a chloride of sodium (150), a compound of chlorine with a white brilliant metal called sodium. It used formerly to be called a muriate of soda, because it was known that sulphuric acid poured on salt expels muriatic acid, whilst on the other hand there are substances which can take away the acid and leave caustic soda. It is now known that dry salt contains nothing but chlorine and sodium ; and when it is decomposed by sulphuric acid or in any

other way, the muriatic acid and soda evolved, were not contained in the salt, but are formed by the decomposition of a portion of water, the oxygen of which unites with the sodium to form soda, whilst the hydrogen combines with the chlorine to form muriatic acid. Hence, though strictly speaking, common salt is a chloride of sodium, yet for practical purposes it may be considered as a muriate of soda; because whatever change it undergoes, or in whatever manner it is decomposed, soda and muriatic acid are given out just as if they were really the components of salt. Soda is an oxide of sodium (160).

175. The only other compound of soda, which occurs native in any quantity, is the nitrate or cubic nitre, as it is commonly called. It is found native in large quantities in certain parts of South America, and is used to a considerable extent as a manure. When it was first brought over to this country, some few years ago, it was proposed to substitute it for the nitrate of potash in the manufacture of gunpowder, and in the preparation of nitric acid. It was, however, found that it possessed the property of attracting moisture from the air; and hence being always more or less damp, it could not be used by the gunpowder-makers. When first imported its price was low, and it was accordingly advantageously substituted for the more expensive nitrate of potash in the manufacture of nitric acid; but as the price of nitrate of soda soon rose, it was no longer found profitable to use it for this manufacture, and now almost the only purpose for which it is employed is as a manure. It appears to resemble the

nitrate of potash in its effects on growing plants, and like it to exert considerable influence on the fertility of certain kinds of land (601).

176. The "soda" of commerce is, as will be readily supposed, not the pure alkali soda, but is a carbonate, and, like the carbonate of potash, possessed of considerable caustic properties. It was formerly for the most part procured by burning sea-weed, the ashes of which contain a large quantity of carbonate of soda, and immense quantities of sea-weed were annually collected and burnt for the purpose of obtaining weed-ash, kelp, or barilla, as the crude salt was called. Of late years, however, means have been discovered of obtaining the carbonate of soda by decomposing common salt; from which it is now manufactured so cheaply, that it has not only superseded the use of kelp or barilla for all purposes where carbonate of soda is required, but has also from its low cost been substituted to a great extent for potash and pearlash; and hence the carbonate of soda, or "soda" as it is commonly called, is very largely used in the arts of glass and soap-making, and other processes where an alkali is employed.

177. In order to obtain carbonate of soda by the decomposition of common salt, it is first of all necessary to convert the salt into a sulphate: this is done by mixing it in certain proportions with oil of vitriol or sulphuric acid, and heating the mixture in a furnace. Muriatic acid is expelled, and the sulphuric acid, which has a powerful attraction for the soda, combines with it and forms sulphate of soda (148).

178. The second process is to mix the sulphate of soda thus formed, with chalk and pounded coal, and to strongly heat the mixture in a furnace ; the sulphate is decomposed at a high heat by the charcoal or carbon of the coal, which takes oxygen both from the sulphuric acid and from the soda, forming a sulphuret of sodium. This in turn is decomposed by the chalk, and a carbonate of soda is produced, which is of course impure, containing charcoal and an insoluble compound of lime ; so that by pouring water on the crude salt after being taken out of the furnace, a clear colourless solution is procured, yielding, on evaporation, a clean and nearly pure carbonate of soda.

179. This " soda " contains a large quantity of water, although apparently dry ; and when left exposed to the air, it does not, like the carbonate of potash, attract water from the air, but, on the contrary, parts with it and becomes drier, at the same time crumbling down to a fine powder, which is found to be less caustic than it was before it underwent this change. The reason of this is, that when the carbonate of soda, by exposure to the air, parts with a quantity of water, and consequently becomes much lighter, it at the same time gradually combines with a second dose of carbonic acid, which it obtains from the air, and its caustic qualities become more fully neutralised than they are in the common carbonate.

180. The salts of soda are for the most part white, and easily soluble in water ; and, like the compounds of potash, are widely diffused throughout nature. They

are found, besides the sources already mentioned, in many rocks and soils: a great many plants, more especially those which grow near the sea or in salt marshes, contain large quantities of salts of soda; and a good many of the compounds which this alkali forms with different acids are found native, though in far smaller quantities than the nitrate.

181. The sulphate of soda is also found native in Spain and other countries, and is frequently met with in mineral waters; it is also called Glauber's salts, and Cheltenham salts, as it is the principal ingredient in the mineral springs of Cheltenham. Sulphate of soda is left after the process for obtaining muriatic acid (150): it is occasionally recommended as a manure.

182. The third alkali, ammonia, has already been before us (119): in its pure state it is a colourless, invisible, and very pungent-smelling gas, readily soluble in water; but, like potash and soda, it has a very strong affinity for acids, and is therefore hardly ever met with in its free state, but always in combination with carbonic, or some other acid. It is far less abundant or common than the other alkalies, potash and soda; for its principal source is the decay of animal and vegetable substances which contain nitrogen.

183. The most important of the salts of ammonia are the carbonate, the muriate, the sulphate, and the phosphate: the carbonate, which is the salt produced during the decay of organic matters, was formerly called salt of hartshorn, because it was mostly procured by burning horn;

it is now, however, obtained from the tar-water and refuse ammoniacal liquors of the gas-works, a considerable quantity of ammonia being formed during the distillation of coal, which always contains a little nitrogen, and therefore gives off a small quantity of ammonia, which combines with a portion of the carbonic acid formed by the burning of the carbon of the coal, and collects in the hydraulic main, or first condenser, of the gas-works; hence, also, carbonate of ammonia is always an ingredient of soot.

184. Carbonate of ammonia is not obtained direct from the gas liquor, as it would then be impure from the tar and other substances which exist in the gas-water. The ammoniacal water is generally first converted into a sulphate or muriate, and this, decomposed by heating it with chalk, carbonate of ammonia, which is volatile, rises in vapour, whilst sulphate or muriate of lime is left. Carbonate of ammonia possesses the peculiar pungent smell of pure ammonia, though far less powerfully; because being but partially neutralised by carbonic acid and united to it by but a feeble affinity, it is constantly gradually escaping from its compound, and evaporating into the air. Like the carbonates of potash and soda it possesses the property of reddening many vegetable yellows, though less powerfully than the pure alkali.

185. The muriate of ammonia, commonly called salammoniac, which used also formerly to be obtained by burning animal substances, is now procured from the refuse of the gas-works, which contain carbonate and

other salts of ammonia. They are first of all converted into a sulphate by the action of oil of vitriol, which expels the carbonic and other weaker acids, and the sulphate thus obtained is decomposed by mixing it with common salt and heating the mixture.

186. The nature of this operation is very simple. Sulphate of ammonia, water, and common salt or chloride of sodium, are heated together, and are decomposed, because sulphuric acid has a stronger affinity for soda than it has for ammonia; a portion of water is decomposed at the same time with the salt, supplying oxygen to the sodium to form soda, and hydrogen to the chlorine to form muriatic acid; the former unites with the sulphuric acid, whilst the latter combines with the ammonia.

187. Muriate of ammonia, like many other of the salts of ammonia, is volatile at a certain heat; that is to say, it becomes a vapour, and reassumes the solid form when cooled again: in the process for obtaining the muriate of ammonia, therefore, it is converted into vapour by the heat applied to the mixture, and is condensed in the solid form again in the upper part of the vessel in which it is heated, which is kept cool on purpose. The uses of sal-ammoniac in the arts are numerous; its principal consumers are the dyers and workers in metals.

188. Ammonia has a strong affinity for sulphuric acid; the sulphate may either be formed directly by mixing together sulphuric acid and caustic ammonia, or its carbonate, as in the process just described for pre-

paring the muriate from gas liquor; or it may be obtained by substituting for the sulphuric acid, added to the gas liquor, a sulphate in which the acid is held by a less powerful affinity than that which it has for ammonia; when this is done, the ammonia seizes the sulphuric acid and causes it to relinquish the weaker base with which it was previously combined, and which thus unites with the carbonic acid, of the carbonate of ammonia. When, for example, a solution of carbonate of ammonia is mixed with a quantity of sulphate of lime, they are both decomposed, the ammonia combines with the sulphuric acid, and the lime takes the carbonic acid. Sulphate of ammonia has a strong saline taste, but no smell: it is a perfectly neutral salt, and may be kept any time without undergoing change. It is readily soluble in water.

189. Phosphate of ammonia may be formed by adding a solution of ammonia, or its carbonate, to phosphoric acid; it is very soluble in water, and decomposes when heated, the ammonia passing off in the gaseous state and leaving the phosphoric acid pure. A rough salt may be made by mixing the impure phosphoric acid obtained by acting on bone earth by oil of vitriol, with gas liquor, and evaporating the solution; it is then, however, apt to contain lime, tarry matter, and other impurities. It is sometimes employed as a manure (519).

190. Ammonia often seems to combine with substances for which it really has no affinity: this is merely a mechanical effect. Such substances have the power of

absorbing a large quantity of the gas, which is condensed or packed up in the pores of the substance, but not combined with it, and is ready to be given off again on the application of heat. Thus, freshly burnt charcoal, and, indeed, most porous substances, absorb or condense a large volume of this gas.

191. The earth, or soil, consists of a mixture of various ingredients; but the greater part of it is composed of certain substances which are called earths. Some of these are bases, and resemble the alkalies; whilst the remainder are not bases: that is to say, they seem to have no affinity for acids, and cannot combine with them to form salts. The most important of the earths which are bases, are called lime, magnesia, and alumine; the two former are called alkaline earths, to distinguish them from the last, as they possess the property of reddening vegetable colours, though in a far less powerful manner than the alkalies, whilst alumine does not.

192. Lime, in its pure condition, is a highly caustic whitish-gray solid substance, slightly soluble in water, but far less so than the alkalies are. It has a very strong attraction for acids, being even able to decompose the salts of the alkalies, in consequence of the superior attraction which it has for the acids contained in them; and it is for this reason that it is customary to mix quicklime with woodash, which contains comparatively little free potash, as the greater part is combined with carbonic acid (158), when it is desired to make a very strong caustic ley: the quicklime decomposes the carbonate of potash,

combines with the carbonic acid, and becomes converted into carbonate of lime; whilst the potash, being no longer combined with an acid, is able to exert its caustic powers. Lime is the oxide of a metal called Calcium (160).

193. In consequence of its strong affinity for acid, lime never occurs native in a pure and simple state, but always in combination with some acid; the most common compounds of lime are the carbonate and the sulphate; the former of these, especially, is a very abundant substance, existing naturally in immense quantities in the different forms of chalk and limestone; it is also very commonly an ingredient of the soil, and constitutes a considerable part of the bones of animals, and shells.

194. As has already been stated (90), lime has a less powerful attraction for carbonic acid than it has for any other acid; and therefore when we pour a quantity of any acid over carbonate of lime, great bubbling, or frothing, is occasioned by the escape of the carbonic acid which is set at liberty when the lime combines with the new acid (88).

195. This bubbling, or effervescence, as it is called, enables us very easily to ascertain whether a stone be limestone or not, and likewise whether any particular soil contains carbonate of lime; for if any acid, such as vinegar, does not occasion any effervescence, it is certain that no carbonate of lime is present; and if, on the other hand, it does expel bubbles of gas, we may be quite sure that a portion of some carbonate is present, and by far the most common is the carbonate of lime.

196. All the forms of this substance are tasteless, and quite insoluble in pure water; but rain-water, which commonly contains dissolved in it a very small quantity of carbonic acid, has the power of dissolving carbonate of lime: hence we commonly see the surface of chalk or limestone appearing to be gradually corroded or worn away by the rain; and for the same reason buildings of freestone or limestone are much less durable than those which are built of granite, a stone which does not contain carbonate of lime, and is, therefore, not thus acted on by rain-water.

197. In this kind of action no chemical change is effected: the carbonate of lime is merely dissolved by water holding in solution carbonic acid: hence when either from heat or any other cause the carbonic acid is expelled from the water, it is no longer able to hold the carbonate of lime in solution, which is therefore deposited again unaltered.

198. Spring-water, for example, which often holds carbonate of lime thus dissolved, becomes milky or turbid when boiled, and not unfrequently deposits fur in the inside of boilers and kettles; such water is of course not fit for domestic uses, cooking, &c.; but by simple boiling it is at once rendered far better, the chalk being then separated.

199. The uses of carbonate of lime are very numerous: one of the most important is for burning into lime. This is a very curious process, for heat generally increases the attraction which two different substances have for each

other; yet in this and some other cases, it rather diminishes it, and the strongest heat is unable to drive off carbonic acid from its combination with potash or soda, though lime, which parts with it so readily when heated, is able when cold to take it from either of the alkalies.

200. When quicklime is mixed with vegetable or animal substances, it generally accelerates their decay: it, however, renders the process of putrefaction far less noisome than it is under ordinary circumstances, because the lime absorbs many of the products of decay.

201. When quicklime is slaked with water, it crumbles down to a powder, and is found to have combined with a quantity of water; although it appears quite dry, for the water is chemically combined with the lime: if this lime thus slaked is left exposed to the air, it combines with carbonic acid, and becomes changed into carbonate of lime, and at the same time parts with the water with which it had previously combined. Slaked lime is less strongly caustic than quicklime, because part of the action of lime on organic matter is caused by its strong affinity for water; nevertheless, even slaked lime possesses strong caustic properties.

202. Common mortar, which consists of slaked lime mixed with sand, chopped hair, &c., is a hydrate of lime; its setting depends chiefly on the absorption of carbonic acid from the air, which forms again with it a kind of chalk or limestone. Hence mortar gradually improves, becoming harder after a time, when it has absorbed a

sufficient quantity of carbonic acid from the air to be wholly converted into carbonate.

203. Sulphate of lime is less common and abundant than the carbonate; it is however a frequent ingredient in the soil, in spring and mineral waters, and is found sometimes in large beds, constituting what is called plaster-stone, gypsum, and alabaster; these are all compounds of lime and sulphuric acid, and precisely similar in composition. Common plaster of Paris is dry sulphate of lime, or gypsum deprived by heat of the water which it naturally always contains, and when mixed with a small quantity of water, it recombines with it and becomes a hard, dry, solid substance.

204. The burning of gypsum to make plaster of Paris is quite different from the burning of chalk to make quicklime: in the former case the native sulphate of lime, which contains water, is heated and the water thus expelled; whilst in the burning of lime not only is the water expelled which the chalk usually contains, but also the acid itself, with which the lime was combined.

205. Sulphate of lime is dissolved in small quantity by water, and accordingly we find it almost always present in spring-water, which derives it from the soil through which it rises; it is the presence of this substance in spring-water which gives it that hardness which distinguishes it from common river-water, and renders it less pleasant to use than soft water; in fact, one of the great distinctions found between hard and soft water is the presence or absence of sulphate, or carbonate of lime,

which, though contained in but small quantity, greatly influences its usefulness for domestic purposes (198).

206. Nitrate of lime is a white salt, easily soluble in water and readily formed by acting on lime or its carbonate by nitric acid. It is also formed whenever organic matters containing nitrogen are suffered to putrefy in contact with lime; when animal manure and lime are left together, nitrate of lime is formed; the same salt is frequently found in the mortar of old walls, particularly those of stables and similar outhouses. When mixed with a solution of carbonate of potash, both salts are decomposed. Nitrate of potash and carbonate of lime being formed by this process, nitre has often been made by what are called nitre-beds.

207. Muriate of lime, or, more properly speaking, chloride of calcium, is a very soluble salt, easily formed directly from lime and muriatic acid, and remarkable for its great attraction for water (161). It exists in sea water, and consequently is often found in common salt. Mixed with a solution of carbonate of ammonia, both salts are decomposed, chalk and muriate of ammonia being formed; this is remarkable, because those two salts, when mixed together dry and heated, form muriate of lime and carbonate of ammonia (184).

208. There is only one other compound of lime of much importance, and which has already been mentioned; this is the phosphate. It is found in small quantity in most plants, and forms a great part of the solid matter of the bones of animals (364, 542, 583).

209. Phosphate of lime is by no means abundant in nature, but it exists in small quantity in a great many substances. Traces of phosphoric acid are found in a great number of rocks and stones, in the soil, in almost all plants, and in animal matters. It never occurs free, or uncombined, but always in combination with a base, and this is very commonly lime. Thus we always find phosphate of lime in wheat and all those vegetable substances which constitute part of the food of man and animals ; and we find it in a very considerable quantity associated with carbonate of lime in the bones of all animals, who obtain it from the substances on which they feed. Phosphate of lime is insoluble in water, but readily dissolves in solutions containing a little free acid.

210. Phosphate of lime is easily decomposed by the more powerful acids, such as sulphuric acid and muriatic acid ; in the former case an insoluble sulphate will be formed, and phosphoric acid left in solution ; and in the latter, a clear solution will be obtained containing phosphoric acid and muriate of lime, a salt which is very easily soluble in water (155).

211. Sulphuric acid does not wholly decompose phosphate of lime, though it takes from it the greater part of the lime which it contains ; the phosphoric acid is still combined with a small quantity of lime, constituting a bi-phosphate of lime (546) ; the results of the action of sulphuric acid, therefore, are sulphate of lime, a super- or bi-phosphate of lime, and free phosphoric acid ; the two latter may be readily separated from the gypsum by the

addition of water, they being very soluble, whilst the latter is very little soluble in that fluid. A mixture of phosphate of lime and sulphuric acid is frequently called super-phosphate of lime, and is much used as a manure.

212. MAGNESIA is an earth somewhat similar to lime, but far less common and abundant; like lime, it is the oxide of a very combustible metal, which, exposed to the air, soon takes oxygen and forms the earth. The base of magnesia is called magnesium (160). Magnesia occurs usually in connection with lime, forming what is called magnesian limestone, which is a mixture of carbonate of lime and carbonate of magnesia.

213. The commonest forms in which magnesia is found are the carbonate, the sulphate, the muriate, and the phosphate. The carbonate is sometimes found native, pure, but by far more frequently it is mixed with carbonate of lime or limestone, the properties of which it considerably modifies. When carbonate of magnesia is strongly heated, it parts with its carbonic acid, and the pure earth magnesia is obtained.

214. This earth is almost insoluble in water, and far less strongly caustic than lime; it also has less affinity for carbonic acid, so that when left exposed to the air, it does not, like lime, rapidly become converted into carbonate by absorbing carbonic acid from the air, but remains for a long time caustic; and hence, when a magnesian limestone is burnt in a limekiln, the quicklime obtained of course contains caustic magnesia, which, if

exposed to the air, will remain caustic long after the lime has become reconverted into carbonate; it is for this reason that limestone containing magnesia cannot be used for some purposes, where the caustic powers thus retained are objectionable (580).

215. The carbonate of magnesia, like the carbonate of lime, and indeed all other compounds of that acid, is easily decomposed by any more powerful acid (88).

216. When magnesia or its carbonate is acted on by sulphuric acid, sulphate of magnesia is formed, which is a salt easily dissolved by water, and distinguished by a peculiar sweet-bitter taste. It is found in many mineral waters, and exists in unusually large quantity in some springs near Epsom, in consequence of which it is commonly called Epsom salts. A solution of sulphate of magnesia is readily decomposed by the alkaline carbonates; carbonate of potash, soda, or ammonia, throwing down carbonate of magnesia.

217. The compound of muriatic acid and magnesia, or chloride of magnesium, is also frequently found in mineral waters, and exists in some quantity in sea-water; it is very soluble in water, and therefore when sea-water is evaporated in order to procure the common salt which it contains, it is never wholly evaporated; but when the greater part has been driven off by heat, and a large quantity of common salt is deposited, the remaining liquor, commonly called bittern, which contains a little common salt, and nearly all the muriate of magnesia, and other easily soluble salts, is drawn off.

218. The muriate of magnesia, like the muriate of lime, is a very deliquescent salt; that is to say, it has a very strong attraction for water, and hence when exposed to damp air, it soon becomes moist, and at last we find, instead of the solid salt, a very strong solution of it in water. It is to the presence of a small quantity of these two salts in common sea-salt that its deliquescent properties before alluded to are due (162).

219. The phosphate of magnesia, like the carbonate, is seldom found alone, but usually mixed with the phosphate of lime: thus we find it associated with that substance in small quantity in many animal and vegetable matters, and likewise in the soil; like the phosphate of lime, it is insoluble in water, but readily soluble in dilute acids. Phosphate of magnesia has a considerable tendency to form double salts (83); thus a double phosphate of magnesia and ammonia is very frequently found in plants and animals; it is readily formed artificially by adding phosphate of ammonia to a solution of sulphate of magnesia; it is slightly soluble in water, and has lately been strongly recommended as a manure. The uses of magnesia are limited, and the most important purposes to which its compounds are applied are as medicines.

CHAPTER IV.

THE EARTHS—METALS—METALLIC OXIDES, AND SALTS.

220. Alumina, or pure clay, is a very abundant and widely-diffused substance. It occurs native both pure and in combination, but it is most usually met with mixed with another earth called silex, and combined with a quantity of water. It is sometimes found pure and free from water or any acid, and constitutes the hard gems called the ruby and sapphire; but these are very rare, and seldom met with. Alumina is the oxide of a metal called aluminum.

221. The properties of alumina, in the ordinary state in which it occurs in the soil, are very different from those of the bases described in the last chapter; it combines with acids to form salts, but it is quite insoluble in water, has no caustic powers, and does not absorb carbonic acid from the air. It has a strong attraction for water, and when thoroughly wet it appears in the form of a very tenacious paste, remarkable for its great plasticity, and the ease with which it may be moulded into any form. All the varieties of clay derive their tenacious properties from the large quantity of this earth which they contain; and the whole of the art of making pottery, bricks, tiles, &c., is in great part dependent on this property of alumina.

222. This earth is able to combine with acids, but the salts which it forms are mostly of very little importance, and we need not inquire into their characters. The only one which is found native is the phosphate, but this is by no means of common occurrence; it is only found in certain districts and in very limited quantity.

223. The sulphate of alumina is largely manufactured from certain kinds of slate or shale which contain alumina and sulphur. When sulphate of alumina is mixed with sulphate of potash, the two salts combine and form a double salt, the sulphate of alumina and potash, or common alum. If a little potash is added to a solution of alum, the sulphate of alumina will be decomposed, pure alumina will be separated, and sulphate of potash alone remain in solution.

224. SILICA or silex is the only other earth of much importance besides the three already mentioned; it is found abundantly, both pure, and mixed or combined with alumina and other substances, constituting, in a nearly pure condition, quartz, sand, flint, &c., and when associated with alumina, forming clay and a numerous series of stones; being in fact an essential ingredient of the greater number of the hard stones with which we are acquainted.

225. Silica differs from the preceding earth, alumina, in not being a base—in being unable to combine with acids; indeed it has rather the character of an acid, for it is able to combine with the alkalies so much in the manner of acids, that it is by some chemists termed silicic acid.

Silica is the oxide of a peculiar substance having many of the properties of a metal, and to which the name of Silicon has been given.

226. Silica, in its common forms, is quite insoluble in water, unacted on by the air, and under ordinary circumstances a very unchangeable substance: when, however, combined with the alkalies, it is easily dissolved in water, and the compound thus formed is sometimes present in very small quantity in mineral waters.

227. When silica is obtained by the decomposition of any of its soluble compounds, it appears in the form of a transparent jelly, which dries into a very fine white powder, like flour; when freshly precipitated from a solution, this jelly is slightly soluble in water and in dilute acids, a property, however, which it loses by being thoroughly dried.

228. The ordinary forms of silica or silicic acid, such as sand or flint, are very little acted on by potash; but when finely-pounded silica is mixed with potash or soda, and strongly heated, they melt and form a clear transparent substance, which is in fact glass. Indeed so strong is the affinity which silica has for potash and soda, that if fine sand or pounded flints are mixed with the carbonate of either of those bases, and strongly heated, the carbonic acid is expelled, and the silica and alkali unite to form a glass. Such a compound is called a silicate.

229. Common glass always contains other substances, but the basis of all good glass is this compound of silica

and alkali—either silicate of potash or soda. The proportions taken of the two ingredients are always such that the glass obtained shall be perfectly unacted on by water; but if more alkali be employed than is requisite to form a good glass, a silicate will be obtained which is readily soluble in water. A solution thus made is easily decomposed by any acid, as the potash has comparatively but a weak attraction for the silica, and hence that substance is separated from its solution on the addition of almost any acid.

230. Though potash is scarcely able to combine with silica at common temperature in its usual states, yet when the silica is in an exceedingly fine powder, the alkali is able to dissolve a small quantity; but this action is far slower and less perfect than when the two are strongly heated together.

231. Silica is almost always an ingredient of the soil, and exists there not only in its solid and insoluble form of sand, but also in the soluble condition of silicate of potash or soda; it will easily be seen that as many stones contain silica, they will, whilst gradually decomposing and crumbling down by exposure to the air, constantly add to the soil silica in a very finely divided state, and therefore well adapted to combine with either potash or soda; and as a number of different stones also contain a small quantity of alkali, considerable quantities of soluble silicates of potash and soda are constantly being formed.

232. Silica is found in many plants, such as for

example corn and grasses, the stalks of which mainly derive the strength requisite to enable them to grow erect from the silica which they contain. Plants derive this earth from the soil, and are only able to absorb by their roots the silica which, by having combined with alkali, has become soluble in water, and is consequently able to enter into the structure of the plant.

233. When a stack of hay or straw has been burnt, so that all the volatile or combustible matters have been dissipated, there is found a large quantity of a dark glassy-looking substance, which consists principally of silicate of potash previously existing in the plants, and which being unaltered by the heat given out during their burning, is merely melted, together with other substances contained in the plants, into a glass. This may also very easily be observed by burning a piece of straw in the flame of a candle: abundant white ashes will be left, which continue to retain nearly the form of the straw, and which, if kept in the flame of a candle, melt into an imperfect sort of glass; this is principally silicate of potash.

234. The quantity of this substance which exists in the stems of different plants varies much; some, such as the plants used for polishing, commonly called Dutch rushes, contain even more than hay or straw; and cane contains so much silica, that it appears completely coated with flint.

235. Silica, or silicic acid, combines with lime, magnesia, and alumina, to form silicates, as well as with the alkalies potash and soda; these silicates are for the most

part insoluble in water, and constitute, either pure, mixed, or combined together, an immense variety of different stones; the action of the atmosphere and other natural circumstances combine to effect the gradual decomposition of such compounds.

236. Silica and alumina, which are generally the two principal constituents of soils, differ very greatly in their respective uses. The former is of importance, both chemically and mechanically. Chemically, as forming a soluble compound with alkali, and thus being absorbed by the roots of plants, and conferring strength and stability to their structures; and mechanically, by diminishing the extreme closeness and tenacity of alumina, and thus, by making the soil more porous and open, allowing the passage of air and water through it, and enabling the roots of plants more easily to penetrate it than they could, were it wholly composed of alumina.

237. On the other hand, the use of alumina is principally mechanical, tending to keep the soil moist, from its attraction for water, and likewise being highly useful in absorbing ammonia, both from the air and from all decaying substances evolving it in the vicinity, by virtue of that property which many porous substances, and more especially charcoal, possess, of absorbing or condensing that gas (190); which, as we shall shortly show, is of great importance in the growth of plants.

238. Besides the three earthy bases already spoken of, and a few others of far less importance, as they are very rare, and only to be found in particular places, there are

a numerous series of bases called metallic oxides, several of which are of great importance in the arts, and two of which are almost always present in small quantity in the soil.

239. Most of the common metals, such as iron, lead, and zinc, gradually tarnish, and become rusty when exposed to the air: the reason of this is that they have a strong affinity for oxygen, and under these circumstances they gradually become covered with a film of an oxide, or compound of the metal with oxygen. Many of these metallic oxides are bases, and form with acids a very numerous series of salts.

240. Modern discoveries have shown that both the earths and alkalies are, in fact, the oxides of peculiar and very oxidisable metals (160). Hence the earths, alkalies, and ordinary metallic oxides, are all classed together under the general term base: they combine with acids to form salts; thus gypsum or sulphate of lime is a compound of lime, which is the oxide of a peculiar metal, and sulphuric acid. Green vitriol or sulphate of iron, is a compound of oxide of iron and sulphuric acid; and Cheltenham salts, or sulphate of soda, consists of soda, (the oxide of sodium), and sulphuric acid.

241. To speak correctly, green vitriol should be called sulphate of oxide of iron, but such a system would be very inconvenient; it is therefore customary, when speaking of the salts formed by the oxide of a metal, merely to call them by the name of the metal. Hence,

when chemists speak of sulphate of iron, and carbonate of lead, they always mean salts of the oxides of those metals; the metals themselves, not being bases, could not combine with the acids to form salts.

242. The salts formed by the combination of the different metallic oxides are called just as if they were salts of the metals themselves, because the oxides of the ordinary metals have no special names, like potash, and soda, &c.; thus the sulphate of the oxide of lead, for example, is simply called sulphate of lead. When there are two separate oxides of a metal, both of which form salts with acids, that which contains least oxygen is called a protoxide, and that which contains most, a peroxide; the addition of proto or per to the name of a salt, shows whether it is a salt of the protoxide or of the peroxide; thus the proto-sulphate or per-sulphate, means a sulphate of the protoxide, or peroxide.

243. The most widely diffused and abundant of all the metallic oxides, as well as that which is the most important and valuable in the arts, is the oxide of iron, which exists in different quantities in a great variety of stones, is very common in soils, and is constantly present, though only in small quantity, in the blood of animals, and in the juices of plants.

244. Iron is very rarely indeed found native in its pure metallic state, but is usually met with in the form of an oxide, either pure or combined with carbonic acid, and mixed with alumina and silica. Thus the rich black and red iron ores of Cumberland and other places

are nearly pure oxide of iron, whilst the common clay iron-stones, as they are called, of Staffordshire and Wales, are either carbonate or oxide of iron, mixed with various proportions of alumina and silica.

245. The important art of smelting iron is entirely a chemical operation, and depends mainly upon the fact, that at a high temperature, carbon has a stronger affinity for oxygen than iron has; and hence, when the native oxide of iron is heated with coal or charcoal, it is decomposed, and carbonic acid gas and metallic iron are the results of the process.

246. When those ores are smelted which consist principally of oxide of iron, they are at once heated with carbon; but when the clay iron-stones are used—and they are the ores most commonly employed—they are first submitted to a preparatory process something like the burning of lime, in order to expel the carbonic acid gas which they contain; and when thus converted into oxide of iron, they are mixed with carbon and lime, the use of the latter being to combine with the silica or silicic acid and alumina, and form with them fusible silicates called the slag, which greatly assists in the melting and running together of the newly-reduced iron; and, besides, by covering the metallic iron with a glassy coat, they protect it from further oxidation from the oxygen of the air.

247. Iron is able to form two distinct compounds with oxygen, according to the quantity of that element with which it combines: when it is combined with two-

sevenths of its weight of oxygen, it constitutes a black substance, which is called the protoxide, and when combined with three-sevenths, forms a brownish-red substance, called the peroxide. These oxides are both bases, and each forms a distinct series of salts by combining with acids ; but the salts formed by the protoxide have always a tendency to absorb oxygen from the air, and thus become converted into the salts of the peroxide.

248. The colour of a great many stones and soils is principally caused by the presence of a small quantity of either the peroxide of iron, or of a mixture of both its oxides.

249. The rusting of iron, which proceeds so rapidly when iron is exposed to damp air, is caused by the attraction which the metal has for oxygen. It is very remarkable that iron is unable to combine with the free oxygen always in the air, but is able to take it from water, its compound with hydrogen ; for we find that in dry air, iron remains clean and bright for a long time, but very rapidly rusts when exposed to the joint action of air, carbonic acid gas, and moisture, under which circumstances water is decomposed, and oxide of iron formed.

250. The rust of iron is not a pure oxide, but commonly a mixture of both oxides with a portion of carbonate or compound of the protoxide with carbonic acid.

251. Although iron cannot combine with the free oxygen of the air at ordinary temperatures, yet when

strongly heated it rapidly absorbs oxygen, and then becomes converted into a black scaly oxide; whenever a piece of iron is heated in the fire, a quantity of a brittle, black oxide is formed on its surface, which easily rubs off the iron—and hence this metal is gradually worn away by exposure to fire; it is from this reason that the iron pokers, fire-bars, and other things much exposed to the fire, gradually get thinner and thinner from the constant oxidation of the surface whilst hot, and the removal by rubbing of the brittle coat of oxide thus formed.

252. When a piece of iron is very strongly heated, it at last begins to *burn*, that is to say, the combination of the external part with oxygen goes on so rapidly, and evolves so much heat, that the whole mass of iron is kept sufficiently hot to continue this process of combination, and in consequence the iron glows brightly, gives off abundance of sparks, and runs down in drops of the melted oxide for some time after it has been removed from the fire in which it was heated. In fact, iron, when thus strongly heated, would catch fire and continue to burn like charcoal, if it were not that the crust of oxide formed, protects the metal from further oxidation, and soon stops its combustion.

253. One of the most common and abundant of the ores of iron is called pyrites, which is a compound of iron and sulphur; it is not used in the manufacture of iron, because it is very difficult to separate the sulphur completely from the iron, and the native

oxides and carbonate are far more convenient sources of the metal.

254. Pyrites, or sulphuret of iron, is however a substance of considerable importance in the arts, being one of the sources of sulphur, which is obtained by heating pyrites in an oven, so constructed that the sulphur which is expelled in the state of vapour from the pyrites is cooled and condensed into the solid form in a different part of the oven.

255. Pyrites, when exposed to the air, soon crumbles down, and undergoes a very curious change, in consequence of absorbing and combining with oxygen. Both the iron and the sulphur combine with oxygen, and form oxide of iron and sulphuric acid ; and hence the result of this action is sulphate of iron, or common green vitriol, a salt much used in the arts for a variety of purposes. Pyrites is most abundantly found in the form of variously-shaped balls imbedded in chalk ; to which the common name of "thunderbolt" is very improperly applied ; as the chalk-hills on the sea-side gradually wear away from the action of the sea and weather, these balls of pyrites get exposed to the air, and fall down on the beach, whence they are collected for the use of manufacturers. Many springs of water contain a small quantity of iron, in consequence of which they have a peculiar inky taste ; this is usually derived from the gradual oxidation of sulphuret of iron,—and from the same reason soils also sometimes contain traces of this salt.

256. Sulphuret of iron is likewise very commonly found in coal, being sometimes dispersed throughout it in the form of little yellow shining particles, and sometimes as layers or lumps of the solid sulphuret; its presence in coal is for some purposes highly objectionable; because, whether the coal is burnt in its crude state, or after being converted into coke, a quantity of sulphurous acid gas is always formed by the imperfect combustion of the sulphur; and that nauseous-smelling gas causes serious mischief in several operations in the arts, and consequently in such cases coal free from sulphuret of iron can only be employed. It is the presence of this substance in coal that causes the strong suffocating smell of sulphurous acid sometimes given out by coal and coke fires (134).

257. The oxides of iron are quite insoluble in water, but many of the salts of iron, like the sulphate, are readily soluble in it; the solutions of these salts are all decomposed when alkali is added to them; this combines with the acid, and the oxide of iron is separated as an insoluble powder.

258. The most important of the salts of iron is the sulphate or common green vitriol: it may be formed by acting upon iron by dilute sulphuric acid; when this is done, a large quantity of hydrogen gas is given off, in consequence of the decomposition of a portion of water; the oxygen combines with the iron to form oxide of iron, which unites with the acid to form proto-sulphate of iron, whilst the hydrogen escapes. Green vitriol is, however,

made on a large scale, principally from pyrites, in the manner just described (255).

259. Sulphate of iron, when pure, is a green transparent salt, wholly soluble in water; exposed to the air it becomes brown and earthy-looking, being partially decomposed owing to the absorption of oxygen and formation of peroxide; when strongly heated, it is wholly decomposed, water and sulphuric acid being given off, and oxide of iron left. When pure proto-sulphate of iron is decomposed by an alkali, a grey or black precipitate is formed of the protoxide; after a short time this precipitate becomes red, having absorbed oxygen, and become peroxide.

260. The number of different metals known to chemists is very considerable, amounting in all to 46; but of these the greater number are comparatively rare, and of little importance, not being used for any practical purpose, and consequently chiefly interesting in a scientific point of view. It will therefore be sufficient to consider briefly the leading characters of eight of the most important of them.

261. Gold is found native in a pure and separate state; it has very little affinity for oxygen, never tarnishing or showing any tendency to oxidise in the air either at common temperature or when strongly heated. It is insoluble in acids, except in a mixture of nitric and muriatic acid, which dissolves it; such an acid contains free chlorine, for the oxygen of the nitric acid takes the hydrogen of the muriatic acid, and sets free the chlorine;

hence we learn that the only solvent of gold is, in fact, a solution of chlorine.

262. When a solution of chloride of gold thus obtained, is mixed with a solution of potash or soda, a dark-coloured precipitate falls : this is an oxide of gold ; when heated it parts with the oxygen which it contains, and pure gold is left. The soluble compounds of the metal gold are all very easily decomposed, because the metal has but a very feeble affinity for oxygen, chlorine, &c.

263. Silver, like gold, occurs native in its pure metallic state, but it more commonly is found combined with sulphur, as a sulphuret. It resembles gold in having a feeble affinity for oxygen, so that it does not oxidise either at common temperatures, or when heated, and most of its compounds are easily decomposed, the silver reassuming the metallic state. Silver readily dissolves in nitric or sulphuric acid, and the solutions obtained give oxide of silver when decomposed by an alkali ; the oxide of silver is a salifiable base, and combines with acids to form salts.

264. Silver has a very strong affinity for chlorine, and the chloride of silver is quite insoluble in water ; hence silver cannot be dissolved in muriatic acid, and if muriatic acid, or any solution containing chlorine, either free or in combination, be added to a solution of silver, the whole of the metal will be thrown down as insoluble white chloride. A solution of nitrate of silver is therefore a very useful test to ascertain the presence of chlorine in any solution.

265. Silver has also a strong affinity for sulphur, combining eagerly with it and forming a shining grey brittle substance. The tarnish which we see on old silver is a thin coat of sulphuret, formed by the sulphuretted hydrogen which generally exists in the air of towns. Gold and silver are frequently called noble metals, from their having no tendency to oxidise when exposed to the air.

266. Mercury or quicksilver, likewise, is sometimes found native in the metallic state, but by far most commonly as a sulphuret ; it is obtained from its ore by heating it with a mixture of iron filings and lime ; these substances combine with the sulphur, and the mercury, being a volatile metal, is obtained by a process of distillation.

267. Mercury is fluid at all ordinary temperatures, but by exposure to very intense cold it may be frozen into a brilliant hard solid, looking like silver ; when heated nearly to redness it boils, rises in vapour, and may be distilled, just like water. When mercury is kept for some time at a heat very near its boiling point, it slowly absorbs oxygen, and becomes converted into a red earthy-looking oxide ; mercury is easily oxidised and dissolved by the strong acids ; it forms two oxides, and both of them are salifiable bases,—the protoxide is black, the peroxide red ; when strongly heated, these oxides are decomposed into metallic mercury and oxygen gas.

268. Chlorine acts strongly on mercury, and forms two chlorides corresponding in composition to the two oxides ; the protochloride, or calomel, is a powerful and

valuable medicine,—the perchloride, or corrosive sublimate, a violent poison. The former is insoluble in water, the latter soluble; they are both easily decomposed by alkaline solutions, calomel yielding the black protoxide, and corrosive sublimate the red peroxide of mercury. Sulphur and mercury easily combine, and form a beautiful red compound, vermilion or sulphuret of mercury; it occurs native as cinnabar, the chief ore of the metal.

269. Copper exists naturally in the pure metallic state, but chiefly as a sulphuret, constituting copper pyrites; it is obtained from this ore by roasting, when the sulphur is gradually driven off and an impure oxide of copper left, which is subsequently heated strongly with charcoal to reduce it to the metallic state. Copper has a considerable affinity for oxygen, which it absorbs from the air at common temperatures. Oxide of copper is a black substance readily obtained by heating copper in the air, or by decomposing any of its salts, such as the nitrate, by an alkali.

270. The salts of copper are mostly of a blue or bluish-green colour; they are all decomposed by alkaline solutions, a blue hydrated oxide of copper being precipitated; if ammonia be employed, no precipitate is obtained, or if formed, easily dissolves, because the oxide of copper is soluble in solution of caustic ammonia, forming a very beautiful deep-blue liquid: this property is useful in testing for the presence of copper.

271. Sulphate of copper, blue or Roman vitriol, may be formed directly. It is manufactured on a large scale,

like the sulphate of iron (255); by exposing the roasted sulphuret to the air, it absorbs oxygen and is converted into the sulphate. It is a bright-blue salt, easily soluble in water, and used for several purposes in the arts. It is frequently employed as a steep for seed-corn.

272. Zinc is never found in the metallic state; its ores are calamine, which is a carbonate, and blende, a sulphuret; it is obtained by roasting the ores, which in the one case drives off the carbonic acid, and in the other dissipates the sulphur; the roasted ore is then mixed with charcoal and distilled; the metal is volatile at a very high temperature.

273. When zinc is strongly heated in the air, it burns with a bright flame, and is converted into a white oxide, which may also be obtained by acting on the metal by an acid; the metal easily oxidises and dissolves, forming a salt from which the oxide may be obtained, on the addition of an alkali. Sulphate of zinc, or white vitriol, is a white salt, very easily soluble in water, and made either from the metal and sulphuric acid, or from the native sulphuret.

274. Zinc has a strong affinity for chlorine; by dissolving the metal in muriatic acid a solution of the chloride is obtained. It is very soluble in water, and has been much employed to preserve wood and canvass from decay.

275. Tin occurs native almost entirely as an oxide, from which the metal is obtained pure by merely heating with charcoal. Heated in the air it easily oxidises, and

by the action of acids a protoxide and peroxide may be procured. Peroxide of tin, the same substance which occurs native as tin stone, is artificially made, as a polishing powder, being called "putty powder." Oxide of tin has a remarkable affinity for colouring matter, and hence is much used by dyers in fixing colours. The bisulphuret of tin is of a beautiful golden yellow colour, and is employed for various ornamental purposes in the arts, under the name of mosaic gold.

276. Manganese, like tin, is found only as an oxide; it is a metal in many respects considerably resembling iron, but having a much stronger attraction for oxygen, and consequently obtained in the metallic state with very great difficulty; it forms several oxides, only one of which, however, is a base; some of its salts are employed in dyeing; and the peroxide is much used in the process for obtaining chlorine (151). Manganese is very often found associated with iron in rocks and ores, and not unfrequently exists in minute quantity in soils; it is, comparatively speaking, a rare metal.

277. Lead is obtained almost exclusively from the native sulphuret; it never is found in the pure metallic state. The sulphuret is roasted, and then smelted with small coal or other carbonaceous matter; lead has a strong affinity for oxygen, in consequence of which it tarnishes slowly at common temperatures, and quickly when melted. At a dull red heat, lead is gradually converted into a pale yellow substance, called litharge,—this is a protoxide; if still longer exposed to the air and heat,

it absorbs more oxygen and becomes red lead or minium; besides these two, there is yet a third oxide of lead, which, however, cannot be formed by further heating red lead under the influence of air, but which is easily made by acting on red lead by nitric acid; the lead then acquires a third portion of oxygen and becomes dark brown.

278. Of these three oxides, only one, the protoxide, is a base; the other two oxides, when acted on by acids, part with a portion of their oxygen, and pass into the state of protoxide before they can combine with the acid. The most important of the salts of lead is the carbonate or white lead, a substance better suited than any other which is known for the manufacture of white paint; it is made either by decomposing a soluble salt of lead by an alkaline carbonate, or by exposing lead to the action of the vapour of vinegar and carbonic acid gas.

279. Lead has a strong affinity for sulphur, and in consequence of this most of the salts of lead are decomposed by sulphuretted hydrogen; the blackening of white paint is due to this cause. As the sulphuret of lead is decomposed by chlorine, white paint thus blackened may be cleaned by muriatic acid; this converts the black sulphuret into a white chloride, though it never looks so white as the carbonate did before.

280. Lead is acted on by pure water in a very remarkable way, being oxidised and dissolved with great facility; this is not the case with common water containing salts of lime, &c. (59). Rain water, or very

pure water, kept in leaden cisterns, or passing through leaden pipes, often dissolves so much lead as to become unwholesome or even poisonous; and for the same reason leaden covers to cisterns are equally objectionable, because the water which condenses on the cover, being of course (56) pure, corrodes and dissolves the lead, and dripping down again into the cistern, contaminates the water, which otherwise might have remained pure and wholesome: a great deal of disease is probably caused by want of the knowledge of these facts.

281. Many of the metals, when melted together, combine to form what are called alloys or mixed metals; some of these appear to be regular definite compounds, though others are obviously merely mixtures. The most important of the alloys are gold and copper, and silver and copper, which are harder than gold or silver alone,—these alloys are used for plate, coin, &c.; Zinc and copper, or brass; tin and copper, or bell-metal; tin and iron, or common tin plate, which is often supposed to be merely tin, though it really consists of thin plates of iron, alloyed on the surface with tin, so as to have the strength and stiffness of the iron, together with the freedom from rusting of the tin; and lastly, lead and tin, or pewter, and common solder.

CHAPTER V.

ORGANIC MATTER—THE COMPOSITION OF VEGETABLE AND ANIMAL SUBSTANCES.

282. We have now very briefly described most of those substances which are of importance in studying vegetable chemistry. Before explaining the action which they have on the growth of plants, it will be proper to go a little more into detail respecting the nature of organic matter; that is to say, the various compound substances which constitute the bodies of animals and plants.

283. Most of the substances hitherto described, such as water, ammonia, carbonic acid, common salt, &c., consist wholly of two elements, and are therefore sometimes called *binary compounds*. On the contrary, all animal and vegetable substances consist of three or four elements, and are consequently termed *ternary* or *quaternary* compounds. It has been already stated that plants and animals are composed of carbon, oxygen, hydrogen, and nitrogen (58); it is very important to understand clearly the nature of the compounds formed by these elements.

284. When we endeavour to analyse a plant, that is to say, to ascertain of what it is composed, we find that the greater part of it consists of carbon, oxygen, hydro-

gen, and a small proportion of nitrogen, combined together. When we burn it, or in any other way weaken the affinity which the elements have for each other, they separate, and by combining together, generally form water, carbonic acid gas, and ammonia.

285. When a plant is boiled in water, it is found that part of the plant dissolves in the water, whilst part remains insoluble, and we are unable by long-continued boiling to make the whole of it dissolve in the water. These, then, are two great divisions of vegetable matter—that which is soluble in water, and that which is not. By very simple operations of this kind it is easy to discover that plants are composed of a variety of different substances, readily distinguished from each other by the different properties which they possess. Of those which are usually found in all plants, the most abundant are called lignin, starch, gum, sugar, gluten, and albumen. The four former consist of carbon, oxygen, and hydrogen alone, whilst the two latter contain, in addition to these elements, a portion of nitrogen.

286. Lignin or woody fibre exists in almost all plants; it constitutes the greater part of the stem, bark, and branches of trees, and is present, though in smaller quantity, in the leaves and flowers of trees, shrubs, and succulent plants. It is the most solid constituent of plants; giving strength to those parts in which any quantity of it exists. It may readily be separated from the other matters with which it is associated, by bruising

and long-continued boiling in water and spirit: by these means the softer or more soluble substances may be separated, and pure lignin is left. In the process for preparing flax, the stems of the flax plant are allowed to remain in water for some time; the green, soft parts decay, and at last nothing but the lignin or woody fibre is left.

287. Pure lignin is a white tough fibrous substance, composed of an infinite number of very fine threads or fibres perfectly insoluble in water, and not at all altered by keeping in dry air. When heated in the fire it soon turns brown, being partially decomposed; if it be still further heated, it takes fire and burns with a bright flame, the results of its combustion being water and carbonic acid gas. Its composition is—

Carbon	4980
Oxygen	4462
Hydrogen	558
	10,000

288. Starch is almost always found in considerable quantity in all parts of plants. When pure it is a white powder, insoluble in cold water, but readily dissolving in that fluid when boiling hot. There are many different varieties of starch, distinguished from one another by some peculiar property, and which have received various names, according to the plant from which they are obtained. Common wheat-starch, which exists in such large quantities in the seed of wheat, is a good example of the general character of this substance.

289. When grated potatoes are placed on a sieve, under a stream of water, a very large quantity of starch may be washed out. The starch will soon settle to the bottom of the water, the soluble matters of the potato will be dissolved, and at last there will remain on the sieve little else besides the lignin or fibre which the potatoes contained, together with a quantity of starch which cannot be separated from the fibre by mere washing.

290. Potato-flour, arrow-root, tapioca, and sago, are all varieties of starch. They all agree in general chemical characters with wheat-starch, and, like it, consist of carbon, oxygen, and hydrogen, rather less than one half of their weight consisting of oxygen. Starch consists of—

Carbon	4425
Oxygen	4908
Hydrogen	667
	10,000

291. Under the name of Gum are included several substances, which differ considerably in their nature and properties. They all agree in being tasteless, or nearly so ; but some dissolve readily in water, and form a clear transparent solution ; whilst others do not dissolve, but merely soften and swell up in water, forming a gelatinous mass. Gum arabic is a good example of the first kind, whilst common cherry-tree gum belongs to the insoluble variety of gum.

292. A solution of gum in water is called mucilage ;

comparatively a small quantity of gum renders water thick and slimy: such a solution feels sticky to the fingers; it dries slowly, and leaves a small quantity of gum on the surface of any substance over which it has been spread. The juices of many plants are sticky from the quantity of gum which they contain.

293. Gum consists of the same elements as starch, namely, oxygen, hydrogen, and carbon; but it contains a rather larger proportion of oxygen than starch does. Gum consists of—

Carbon	4268
Oxygen	5059
Hydrogen	637
	10,000

294. Associated with gum in many plants, there is found a substance which dissolves easily in water, and like gum, forms a sticky thick solution; it is distinguished readily from gum, however, by possessing a sweet taste, whilst gum is insipid or tasteless; it is called sugar or saccharine matter, under which names a considerable variety of different substances are included.

295. Sugars are divided into two classes: those which are crystallisable, and those which are uncrystallisable: that is to say, those which, when their solution in water is evaporated, are obtained in the form of regular-shaped little grains, like common cane sugar, and those which under these circumstances do not form regular grains, but remain thick viscid liquids, like treacle. The crystal-

lisable sugars are divided into two classes—cane sugar, and grape sugar; these two varieties differ slightly in composition, the latter containing rather more hydrogen and oxygen in proportion to its carbon than cane sugar; they differ very considerably in chemical properties, grape sugar only being capable of undergoing fermentation (309, 313).

296. Sugar exists in a great many vegetables, but it very frequently happens that there are so many other substances present, that the sweet taste of the sugar is quite hidden. It is only in those plants which contain a very large proportion of sugar, or which do not contain any strong-tasted substances, that we are able to recognise sugar by its sweet taste. Most ripe fruits contain a large quantity of sugar; it is likewise found abundantly in the sap of a good many trees, from some of which, such as the sugar maple, it is procured in such quantities as to be extracted as an article of commerce.

297. The composition of sugar is similar to that of starch: the proportions in which its three elements, oxygen, hydrogen, and carbon, are united together are very nearly the same as the composition of starch. The varieties of sugar contain slightly different proportions of these elements; thus the composition of cane sugar is not precisely the same as that of sugar obtained from grapes, beet-root, or other plants. Cane sugar consists of—

Carbon	4499
Oxygen	4860
Hydrogen	641
	10,000

The composition of grape sugar is—

Carbon	3671
Oxygen	5651
Hydrogen	678
	10,000

298. Gluten and albumen in many respects are very similar; they exist in plants in smaller quantities than the three substances already described; but they are nevertheless most important, and of especial interest, as their presence in vegetables is essential to their value as food (367).

299. When the clear juice of any plant is boiled, there usually collects on the surface a thick green scum, which may easily be separated by straining the liquor through linen. This scum consists almost entirely of albumen and gluten, the former being a distinct proximate vegetable principle, the latter a mixture of two distinct principles, fibrin, and gliadine, with oil; they are associated together, and exist in greater or less quantity in almost all plants. In general the seeds of plants contain even a larger relative proportion of these substances, than the plants themselves. A modification of these substances, which is found in many plants, is called legumine or vegetable caseine, because it is almost identical with the peculiar principle of milk called caseine (358).

300. The flour of wheat contains a considerable proportion of gluten; it may be readily separated from flour by tying a portion of thick paste in a piece of linen, and then kneading the paste thus inclosed in linen under a

stream of cold water ; by this process all the starch will gradually be washed out, and at last there will remain in the linen nothing but gluten.

301. Gluten, when thus obtained, is a greyish white, soft, solid substance, elastic and tough, and almost resembling a piece of animal skin in appearance ; it may be dried by carefully warming it till all the water which it contains is evaporated ; and when dry may be preserved for a long time without undergoing any change. By boiling gluten in alcohol it is separated into three substances,—an oil, a tough glue-like substance called gliadine, and vegetable fibrin ; this last-mentioned substance is insoluble in water, soluble in dilute alkaline liquids, very prone to decompose, and apparently identical with animal fibrin in nature and composition.

302. Fibrin, caseine, gliadine, and albumen contain nitrogen ; and all organic substances containing nitrogen have a great tendency to putrefy. Albumen consists of—

Carbon	5501
Hydrogen	723
Nitrogen	1594
Oxygen with Phosphorus and Sulphur	2184
	10,000

Vegetable fibrin contains—

Carbon	5460
Hydrogen	730
Nitrogen	1581
Oxygen with Phosphorus and Sulphur	2229
	10,000

303. It is certainly a very surprising fact that so many different substances should be formed by the combination of the same elements in different proportions. Nothing can well be more dissimilar than oil and sugar, flax and starch; yet it is easily proved that they all consist of the same elements.

304. The knowledge of this might naturally lead one to suppose that, if the whole difference between such substances consists in the relative proportions of carbon, oxygen, and hydrogen which they contain, it might be possible, by some chemical operation, to take away a small portion of carbon or hydrogen, and thus, by altering the relative proportions of the elements, to convert starch into gum, or flax into starch. Now this can really be done; and strange as it may appear, it is nevertheless true, that, by very simple means, it is easy to change gum, starch, and lignin, &c. into each other.

305. When strong sulphuric acid is poured over lignin, it rapidly changes it into gum; after a few minutes the fibrous character of the lignin disappears, and a thick slimy substance is formed; if chalk be then added, to neutralise the acid, a solution of gum is obtained; if the acid is left in contact with the gum it soon begins to char it, and finally completely decomposes it.

306. Starch may also be converted into gum by a very simple process; when starch is heated considerably above the boiling point of water, it is changed into a kind of gum; large quantities of starch are thus made into gum by roasting, and used by the calico-printers under the

name of British gum; by chemists it is called dextrine. The same change may be effected by boiling gelatinous starch with dilute sulphuric acid; it soon loses its gelatinous character, and is converted into gum. Starch also undergoes this change when acted on by diastase (424); a small quantity of this substance, added to a considerable quantity of gelatinous starch, rapidly converts it into gum.

307. If, having converted a portion of lignin into gum by the action of strong sulphuric acid, we add a quantity of water so as to dilute the acid, and then boil the whole together for some hours, the gum will gradually be changed into sugar; by this process, then, we may convert flax, hemp, or woody fibre of any kind, even old rags, for they consist chiefly of lignin, into sugar. When the change is complete the sulphuric acid may be neutralised by the addition of a quantity of chalk; sugar and a little sulphate of lime will then be left in solution. By continuing to boil starch with dilute sulphuric acid in the manner just described, after it has all been converted into gum, sugar is also obtained.

308. Sugar, spirit of wine, and vinegar consist of the same elements: they contain oxygen, carbon, and hydrogen; but the elements are united in different proportions; the properties of these three substances are as opposite as they well can be, and yet the whole difference is in the proportions of their elements. It is well known that when a solution of sugar ferments, it is changed into spirit; it parts with a portion of carbon

and oxygen, and the elements left constitute spirit; hence, during fermentation carbonic acid is given off (92). Again, when spirit and water is exposed to the air and moderate warmth, it soon changes into vinegar; this change is wholly effected by the absorption of a little oxygen from the air.

309. Fermentation is a very singular process, and a knowledge of the effects which it produces enables us to understand many changes which would otherwise appear incomprehensible. Under ordinary circumstances, pure sugar, dry or dissolved in water, may be kept for a long time without its undergoing any change; when, however, it is mixed with a small quantity of certain decomposing matters containing nitrogen, it ferments and is changed into spirit. The substance added does not combine with the sugar or its elements, but, whilst itself decomposing, it causes the sugar also to change.

310. Most varieties of sugar are capable of undergoing fermentation, but it appears that in all cases they previously pass into the state of grape sugar. When a solution containing sugar and ferment is kept for some time at a moderate temperature, the sweet taste of the sugar gradually disappears, much gas is given off, the mixture froths up from the escape of carbonic acid, and when the fermentation is complete, spirit is found in place of sugar. When such a fermented liquor is distilled the spirit passes over before the water, being more volatile; at least the first portions of the liquid which pass over contain the greater part of the spirit.

311. Common spirit of wine is a mixture of alcohol and water ; by repeated distillation with substances which have a strong affinity for water, pure alcohol may be obtained ; it is much lighter than water, and boils at a lower temperature than that liquid. Alcohol consists of carbon, oxygen, and hydrogen, but contains in proportion less carbon, and much less oxygen, than starch or sugar do.

312. The making of bread depends in part on fermentation ; a small quantity of sugar which exists in dough is converted into carbonic acid and spirit, by the action of the yeast or ferment mixed with it ; the carbonic acid thus evolved by dividing the dough, and forming little holes and cavities throughout its mass, renders the bread light and porous.

313. Fermentation, then, is the spontaneous decomposition of a substance, occasioned by the presence of a small quantity of decomposing matter. The yeast, or ferment of beer, possesses the power of inducing the decomposition of sugar and similar substances when mixed with them. Common yeast, and all substances which possess the power of causing fermentation, contain nitrogen ; they are compounds of carbon, oxygen, hydrogen, and nitrogen, and are accordingly very liable to decompose.

314. The various vegetable substances, though so different in properties, are very similar in chemical composition, and may for the most part be readily converted or changed into each other by simple means. They

may, when pure, be preserved unchanged for an unlimited time, if quite dry; but when exposed to air and moisture they sooner or later begin to decompose. Those which consist of carbon, hydrogen, and oxygen alone, are far less prone to decompose than those which contain in addition nitrogen; and these latter, when decaying, possess the singular property of causing substances which do not contain nitrogen to decompose or change likewise.

315. When vegetable substances, such as lignin or sugar, are burnt in the air, water and carbonic acid are produced; precisely the same substances are formed by decay as by combustion. When gluten and albumen are burnt, water, carbonic acid, and ammonia are formed.

316. It is well known that plants possess very various properties: some are noted for their fragrant smell, others for the brilliant colours they produce; some yield oils, others resins, and a great many are valued for their peculiar medicinal qualities: all these various properties are caused by the presence of a certain quantity of some organic substance, some peculiar compound of oxygen, hydrogen, carbon, and nitrogen, which is formed by the plant.

317. The number of these organic substances which have been discovered in plants is very great; it is quite unnecessary to describe or even enumerate them all; it will be sufficient to mention very briefly the most important of them, arranged under three or four heads.

318. Amongst the substances formed by plants is a numerous series of organic acids: substances composed of oxygen, hydrogen, and carbon, which possess acid powers, and combine eagerly with bases to form neutral salts. In general they do not exist in plants in the free state, but are combined with various bases derived from the soil; sometimes they are found in the state of perfectly neutral salts, but more frequently they form acid salts (82), that is to say, there is more acid than the base is able to neutralize; such plants have a sour taste.

319. When the salts of organic acids are burned or strongly heated, the acids are decomposed; in these cases the base, which was previously combined with the organic acid, is found after its destruction combined with carbonic acid in the state of a carbonate.

320. The most important of the organic acids are acetic, citric, tartaric, malic, and oxalic acids. There are few plants which do not contain a small portion of one or other of these acids, either in the free state, or else combined with a base. Unripe fruit contains a considerable quantity of malic and tartaric acids; and the leaves and stems of many plants, such as sorrel and rhubarb, have a strong sour taste from the presence of oxalic and malic acids.

321. Acetic acid, or vinegar, is formed when a mixture of spirit and water, together with some ferment, is exposed to the air; a portion of oxygen is absorbed, and acetic acid is formed. This change takes place when any liquid containing a portion of spirit and some organic

substance, like gluten, is exposed to the air and kept moderately warm; the acetous fermentation, as it is called, then occurs, and vinegar is formed.

322. Another source of acetic acid is the destructive distillation of wood. When wood is burnt, only water and carbonic acid are formed; but when wood is distilled or roasted in close vessels out of the contact of air, it is decomposed, and several new substances are formed by the recombination of its elements; the most important of these substances is vinegar, or, as it is called when thus procured, pyroligneous acid.

323. Acetic acid cannot be obtained perfectly dry. The substance obtained by the above-mentioned processes, is a solution of acetic acid in water; this may be concentrated, but if we attempt to obtain the acid free from any water, it is decomposed. Acetic acid forms numerous salts, some of which are important in the arts, such as sugar of lead, which is an acetate of lead, and pyrolignite of iron, which is an impure acetate of iron; the salts made with the crude wood—vinegar, or pyroligneous acid, are commonly called pyrolignites.

324. Citric acid exists in a free state abundantly in the juice of limes and lemons, and in unripe gooseberries, currants, and other similar fruits; it is easily procured from these sources in white crystals, having an agreeable sour taste, and readily dissolving in water. Citric acid is used in considerable quantity by dyers: none of its salts are of much importance.

325. Tartaric acid is obtained from the juice of grapes,

pine-apples, and several other fruits ; its principal source is wine, from which it is deposited as a super-salt of potash. The bi- or super-tartrate of potash is slightly soluble in water, but almost insoluble in a mixture of spirit and water ; hence, after the fermentation of grape juice and consequent formation of spirit, the bitartrate of potash previously dissolved, is thrown down as a crystalline precipitate, constituting argol, or cream of tartar.

326. Tartaric acid is a white crystalline solid, like citric acid, easily soluble in water, and uniting to bases to form salts called tartrates. It is chiefly used in dyeing and calico printing ; it is also used in medicine.

327. Malic acid occurs associated with citric acid in apples, pears, and in the stems of common rhubarb. It forms salts called malates, but neither the acid nor any of its salts are of much importance ; they are not used for any practical purpose.

328. Oxalic acid exists in considerable quantity in rhubarb, sorrel, and a great many other plants ; it is, however, generally made artificially from sugar. When sugar, starch, lignin, &c. are heated with strong nitric acid, violent action takes place, and the organic substances are decomposed, the whole of their hydrogen being abstracted, and the carbon and oxygen left in those proportions, which form oxalic acid (101). The commonest salts of oxalic acid in plants are oxalate of lime and super-oxalate of potash (344). Oxalic acid is not much used in the arts.

329. The oily substances formed by plants are like-

wise very numerous; they are of two kinds, fixed and volatile; those which when exposed to the air remain without diminishing in bulk, and those which when so exposed evaporate. Olive oil, castor oil, and cocoa-nut oil, belong to the former class, whilst oil of lavender, oil of cloves, and oil of lemons, are volatile oils.

330. All vegetable oils, whether fixed or volatile, contain oxygen, hydrogen, and carbon; they are all combustible, and when burning form water and carbonic acid gas. Oils are found in all parts of plants, but rather more abundantly in the seeds and fruits than in other parts. The seeds of some plants, such as the poppy, linseed, rape, and mustard, contain frequently nearly half their weight of oil.

331. Fixed oils are divided into fat oils and drying oils, the former remain fluid when exposed to the air like olive oil; the latter gradually harden, and dry up into a kind of varnish, like linseed oil. Fat oils are used for soap making, in wool spinning, to burn in lamps, and in diminishing friction; those like cocoa-nut and palm oil, which remain solid at common temperature, are used for the manufacture of candles. Drying oils are employed in preparing paints and varnishes; for this purpose they are usually boiled, which causes them to dry and harden even more rapidly.

332. The odours of plants are for the most part occasioned by the presence of volatile oil, in greater or less quantity. The volatile oils are obtained by distilling the plants which contain them, with water; fixed oils are

procured by pressing the seeds in which they are found, either cold or after a slight roasting ; the former process gives the purest oil.

333. The resins, which are not less numerous than the oils, resemble them in chemical composition and combustibility ; they are formed in large quantity by many plants, and are very frequently seen adhering in large transparent drops to the bark of trees which produce them. Resins frequently look very much like gum, but they may readily be distinguished from gum by the fact that they are quite insoluble in water, whilst gum easily dissolves or softens in that fluid (291). Most of the ordinary resins dissolve in spirit of wine.

334. Colophony, or common resin, is obtained from the wood of pine trees ; the trees are cut down, and burnt ; the heat of this operation melts the resin in the wood, and a large portion escapes burning, being collected as it runs from the burning wood. Most of the resins when fresh from the trees which yield them are fluid, or at least soft, and contain a portion of volatile oil ; this is separated by heat, and then the pure resin is left. Common turpentine consists of resin and oil of turpentine ; it is distilled and the oil of turpentine is thus procured, whilst the resin only is left.

335. There are likewise found a number of gum-resins, as they are called, which have some of the properties of gum, and yet resemble resins ; these are mixtures of gum and resin. They dissolve, though but imperfectly, in both water and spirit of wine.

336. Plants contain an immense variety of different colouring matters, all of which, however, when analyzed, are found to consist of nothing but oxygen, hydrogen, and carbon, or these three with the addition of nitrogen. The nature and properties of these substances are as various as their colours. They are all destroyed by heat, which burns them, like all the other varieties of organic matter. When burnt, the results are water, carbonic acid, and frequently ammonia.

337. Some vegetable colours are tolerably permanent, whilst others are very fugitive, fading in a short time when exposed to air and light, etc. Most vegetable colours are soon bleached by sulphurous acid, and rapidly destroyed by chlorine. The art of the dyer consists in staining wool, linen, and cotton of various colours; some of the colours he employs are metallic, but the greater number are of vegetable origin. Dyes are divided into those which at once permanently stain the fabric to be dyed, such as indigo, and those which require the use of some mordant or substance to fix them. The most important mordants are alumine, oxide of iron, and oxide of tin; these substances have a remarkable attraction for colouring matters, and also for the fibres of cotton, wool, and silk, they consequently assist in staining those materials of various colours.

338. Lastly, there is a number of peculiar vegetable substances, to the presence of which in plants their medicinal properties are in many cases due. Chemists have obtained from various plants a great number of

substances called "active principles," some of which are highly poisonous, whilst others in small quantities are valuable medicines. Amongst this class of substances are the vegetable alkalies, as they are called; these are compounds of oxygen, hydrogen, carbon, and nitrogen, which possess the power of combining with acids and forming neutral salts; they are of course destroyed by heat, and whilst burning give off the usual results of the combustion of organic matter—water, carbonic acid, and ammonia.

339. All plants contain a small quantity of inorganic matter. Besides the lignin, gum, sugar, starch, gluten, and other similar substances which consist of carbon, hydrogen, oxygen, and nitrogen, and which burn in the air when heated, there are always found substances which cannot burn, but which are of an earthy nature; these substances remain as ashes when plants are burnt.

340. The inorganic substances found in plants are by no means numerous; the most common are salts of lime, potash, soda, magnesia, oxide of iron, and silica. These substances are found in the ashes of plants, combined with carbonic, sulphuric, phosphoric, and some other acids.

341. The ashes of plants very frequently contain a considerable quantity of carbonate of potash (157); this salt does not exist in the growing plants, but is formed during their combustion. Potash is found in a very great number of plants, sometimes in combination

with sulphuric acid, or silica, but more commonly united to tartaric, oxalic, or some other organic acid, constituting a tartrate, oxalate, or other salt of potash. When plants are burned, all the organic acids are burned, as well as the lignin and similar substances which they contain; consequently, although in living plants the potash is combined with organic acids to form neutral or even acid salts, yet, as these acids are destroyed when plants are burned, caustic potash is left (157), which, of course, combines with carbonic acid to form carbonate of potash (158).

342. In the same way, carbonate of soda is frequently formed by burning plants which contain salts of soda united to various organic acids.

343. The ashes of many plants contain silica (232), generally in combination with either potash or soda.

344. Lime is almost invariably found in the ashes of all plants, and frequently constitutes a large proportion of the earthy substances present in them. It sometimes exists in combination with sulphuric acid as sulphate of lime (203), but far more commonly united to phosphoric acid, or in the state of phosphate of lime (208). It is likewise very frequently found in considerable quantity in plants, combined with organic acids, particularly as oxalate of lime; hence the ashes of plants commonly contain a portion of carbonate of lime, which is formed in a similar manner to the carbonate of potash already described (158). The quantity of oxalate of lime in some plants is so large, that upon cutting them

through with a knife, multitudes of little crystals of this salt may be seen by means of a common pocket lens.

345. Magnesia is very often found associated with lime, more especially in the state of phosphate of magnesia (219), and as a double phosphate of magnesia and ammonia ; but as this salt is decomposed by heat, the ammonia being volatile, only phosphate of magnesia is found in the ashes.

346. The ashes of most plants contain a trace of oxide of iron ; and occasionally, also, of the oxide of manganese.

347. Animals, like plants, consist almost entirely of four elements, but these are grouped or combined together to form various different compounds. The bodies of all living animals contain a considerable quantity of water; when this is evaporated by heat, there remain certain substances, which may be readily separated from each other in consequence of the different properties which they possess, just in the same way that we can separate the various substances which compose plants (285).

348. The constituents of the bodies of animals may be naturally divided into the organic substances, of which the softer parts of animals are composed, and the earthy or inorganic matters, such as the bones.

349. Animal substances, for the most part, are rather more complicated in their nature than vegetable substances ; they almost all consist of oxygen, hydrogen, carbon, and nitrogen ; in consequence of the presence of

this latter element, they are more liable to decay (302) than those vegetable substances which do not contain it.

350. The principal substances which compose the bodies of animals, and which are therefore called proximate animal principles, are, albumen, caseine, gelatine, fibrin, and fat or oily substances ; besides these, chemists have detected a multitude of other substances ; but these are the most important, or those which constitute the greater bulk of animal matter.

351. There are many varieties of albumen and fibrin, which, in consequence of peculiar properties or slight differences in composition, have received different names ; it is unnecessary to study the nature of all these substances ; we may include them under the general terms albumen and fibrin. Albumen consists of—

Carbon	5484
Hydrogen	709
Nitrogen	1583
Oxygen with Phosphorus and Sulphur	2224
	10,000

352. Albumen is a white solid substance, which swells up and slowly dissolves in water, forming a clear transparent solution. Albumen is separated from its solution in water by the addition of certain acids, and also by the action of heat ; when a clear solution of albumen is boiled, the albumen separates in the form of a white curd or scum ; if the solution contain much albumen the whole becomes solid.

353. This substance exists in many parts of the animal system. The white of egg consists of hardly anything else; when a fresh egg is boiled, the albumen separates as a white curd; it coagulates, or becomes insoluble in water. Albumen occurs, in a state of solution, in blood and many of the liquids and softer parts of animal bodies. It is also found in a dry or solid form. Hair consists of albumen, together with gelatine.

354. Dry albumen may be kept for a long time without undergoing decomposition; but in solution, or when wet, it is very liable to change. Albumen consists of carbon, oxygen, hydrogen, nitrogen, and a small quantity of sulphur and phosphorus; when heated, it burns; and the results of its decay, as well as its combustion, are water, carbonic acid, and ammonia; it leaves a small quantity of white ash, which consists principally of phosphate of lime.

355. Fibrin, when pure, is a white elastic substance, insoluble in water, whether hot or cold, but soluble in acid and alkaline solutions. The muscle or flesh of animals consists principally of fibrin, associated with albumen and gelatine; when dry, fibrin may be easily preserved; but when moist, like albumen and gelatine, it soon begins to decompose. The composition of fibrin is almost identical with that of albumen; they consist of the same elements, united together in nearly the same proportions. Fibrin contains—

Carbon	5456
Hydrogen	690
Nitrogen	1572
Oxygen, with Phosphorus and Sulphur	2282
	10,000

356. Fibrin exists in the bodies of animals in two states, solid, and in solution ; in the former state it occurs in muscle or flesh, in the latter state in the blood ; the soluble fibrin of the blood, however, soon becomes insoluble after it has been taken from the body, and separates as a clot or coagulum. Blood consists of water holding in solution albumen, fibrin, a peculiar red colouring matter, fat, and various inorganic substances, including chlorides of sodium and potassium, carbonates, sulphates, and phosphates of potash, soda, lime, and magnesia, and also a portion of iron.

357. The blood which is sent out from the heart through the arteries, all over the body, differs slightly in chemical nature from the blood which returns through the veins to the heart, undergoing an important change in the course of its circulation : when blood leaves the heart, it is of a bright red colour, and contains oxygen, which has been absorbed in the lungs ; when it returns to the heart, it is black, and contains carbonic acid in place of oxygen (374).

358. Caseine is a substance which very closely resembles albumen in its properties and composition ; it is insoluble in pure water, but dissolves in dilute acid or alkaline liquids, in the latter far more perfectly than in

the former ; it exists in milk, in which it is dissolved by a small quantity of alkali ; the addition of acid to milk, by neutralizing the alkali, causes the separation of the caseine as a curd. Caseine differs from albumen in not being separated from its solutions by boiling ; in chemical composition they are almost identical, the only difference being that caseine contains no phosphorus. Caseine consists of

Carbon	5496
Hydrogen	715
Nitrogen	1580
Oxygen and	2173
Sulphur	36
	10,000

359. Milk, like blood, consists principally of water holding in solution or suspension, organic matter ; milk contains caseine, fatty matter, a peculiar kind of sugar, and small quantities of saline substances, particularly phosphate of lime, and chloride of potassium. When milk is kept at a certain temperature, it soon begins to change, a portion of the caseine turning into a kind of ferment, commences putrefaction ; this induces an imperfect fermentation of the sugar, and converts it into a peculiar acid called lactic acid, and this acid, by combining with the alkali present in the milk, causes the coagulation or separation of the rest of the caseine. The sugar of milk, when pure, cannot undergo the alcoholic fermentation ; but by certain means it may be modified and converted into another kind of sugar, which can

ferment. The Tartars, by causing milk to undergo the alcoholic fermentation, prepare an intoxicating drink which contains spirit.

360. Cream, or the lighter part of milk, consists principally of minute globules, or drops of oil, separated from each other by the solution of caseine, &c., in which they float; being lighter than water, they rise to the surface, when fresh milk is allowed to stand. The operation of churning consists merely in agitating the cream, under the influence of a moderate degree of warmth; the particles of oil then unite and collect together in masses, forming butter. It is difficult to remove the whole of the caseine from butter, but its presence is highly objectionable, from its great proneness to putrefy; by careful and complete washing the greater part may be removed. Salt is generally added, as its presence greatly checks the tendency of the caseine to change, and consequently helps to keep the butter sweet.

361. Cheese varies considerably in composition, according to the mode in which it is prepared. When made from fresh milk, cheese consists of caseine and fatty matter; when made from skimmed milk, it contains little or no fat: in either case, during the pressing and curing of the cheese, it undergoes a peculiar kind of fermentation, which gives rise to several complicated chemical changes in its composition. Cheese is generally made from milk, by the action of rennet, the lining membrane of the stomach of the calf, which has the property of causing the coagulation of the caseine. Cheese which contains butter becomes

soft and viscid when toasted, whilst that which contains none becomes hard, and shrivels up almost like horn.

362. Gelatine, the third great principle of animal matter, is a tough, colourless substance; in cold water, it very slowly softens and dissolves; in boiling water, it dissolves more readily, and forms a solution which becomes a jelly as it cools. The skin, horns, and hoofs of animals consist principally of hard, dry gelatine; and it likewise occurs in many of the softer parts of the body, associated with albumen. Common glue and isinglass consist almost wholly of gelatine; the former is prepared by boiling the clippings of skin, refuse horns, hoofs, and similar matters, in water; a strong solution of gelatine is thus obtained, which, as it cools, becomes a jelly; this, when cut into slices and dried in the air, is the glue of the shops. Gelatine consists of

Carbon	5077
Hydrogen	715
Nitrogen	1832
Oxygen with Sulphur and Phosphorus	2378
	10,000

363. The fat of animals is perfectly similar in nature to vegetable oil; some kinds of fat are solid, others fluid, at common temperature; but they are all fluid when made sufficiently hot; animal oils, like those of vegetable origin, contain no nitrogen,—they consist of carbon, oxygen, and hydrogen, and, when burnt, form carbonic acid

and water; like vegetable oils, also, they form soap when boiled with alkalies.

364. The bones of animals contain a very large proportion of earthy matters; and, indeed, derive their strength and solidity principally from the quantity of those substances which they contain. When bones are burnt, there remains, after the combustion of all the organic matter which they contain, about three quarters of their weight of earthy substances; this is phosphate of lime, together with a small portion of carbonate of lime; bones consist of phosphate and carbonate of lime, cemented together, as it were, with gelatine and a little albumen; they also contain a small quantity of oil. Ivory and the teeth of animals are composed of the same substances as bone. Hoofs and horn likewise contain phosphate and carbonate of lime, but in far less quantity; they consist principally of gelatine (362).

365. The same remarkable similarity of chemical composition which is found amongst vegetable substances is likewise observed amongst those of animal origin; the various proximate elements which constitute the bodies of animals, are, for the most part, almost identical in composition, and, like vegetable substances, they appear more or less convertible into each other. A very slight alteration in the relative proportion of the elements of which they consist causes very great differences in their nature and properties; and in consequence of the very peculiar nature of nitrogen, all substances which contain it are exceedingly liable to change.

366. On comparing together the various substances which constitute animal and vegetable matter, it is observed that lignin, gum, sugar, and starch, are all perfectly distinct in nature and properties from any of the substances usually found in the bodies of animals: a remarkable similarity, however, exists between the fibrin, albumen, caseine, and oily substances of plants, and certain forms of animal matters.

367. The albumen, fibrin, and casein of plants closely resemble the albumen and fibrin of animals; indeed, some of the varieties of these substances may be said to be absolutely identical; they consist of the same elements, and possess the same properties: thus, for example, there is no chemical difference between that variety of albumen which exists in peas, beans, and other leguminous seeds, which is called legumine, and the animal albumen which is found in milk, cheese, &c., and called caseine (358).

368. When albumen, fibrin, or caseine, are acted on by a solution of potash or soda, they soon dissolve, forming a clear solution; when an acid is added to this so as to neutralise the alkali, a precipitate falls, which is precisely the same from whichever of these three substances it is obtained; to this precipitate the name of protein is given. Protein consists of oxygen, hydrogen, carbon and nitrogen, like the substances from which it is obtained, but it contains no sulphur or phosphorus, whilst they always contain a small quantity.

369. The knowledge of this fact, that the fibrin and

albumen, &c., of plants, are identical in composition with some of the most common forms of animal matter, throws great light on the nutrition of animals. It shows that the gluten and albumen of plants used as food may immediately enter into the system of the animal ; whilst gum, starch, sugar, &c., must undergo a change before they can constitute a part of the body of an animal.

370. It has already been stated that vegetable and animal oils consist of the same three elements ; many of these oils contain precisely the same proportions of carbon, oxygen, and hydrogen : hence by some chemists it has been supposed that the oil existing in many vegetables used as food might contribute directly to the formation of fat, without undergoing any change ; though on the other hand many facts might be quoted to show that this view is improbable, and that the fat of animals is formed from starch, gum, and sugar, by a kind of fermentation in the animal system, and that the fatty matters of the food are not directly appropriated by the animals which feed on them.

371. Bearing in mind, then, that the strength of man and animals depends mainly on muscle, and that the formation of muscle is greatly dependent on the amount of organic matter containing nitrogen in their food, it becomes a matter of the first importance to study the mode of increasing the quantity of these matters in food.

372. Some animals feed entirely on vegetable food ; others feed entirely, or in part, on flesh : in either case they derive their nitrogen, or the substances containing

it, from plants. Animals do not appear to have any power of absorbing nitrogen from the air; all the albumen, fibrin, &c., which they contain, is therefore either directly or indirectly obtained from plants.

373. The most important of the chemical functions of animal life may be classed under the two great heads of nutrition, and respiration; and consequently food also may be divided into those kinds which contribute to the one or other of these two objects. The changes which ordinary food undergoes in passing through the stomach of an animal, are briefly these: mechanical division, effected by chewing, &c.; chemical division or digestion, effected in the stomach; chemical transformation, conversion of starch, &c., into animal matters; absorption of azotised matters identical in composition with animal matters, and which are passed directly into the blood; and lastly, separation of useless matters as excrementitious. The chemical office of food is, to supply to the body albumen and fibrin, the elements of blood; in order to counterbalance the waste continually going on in the system, by the constant addition of all those matters which enter into its composition; and secondly, to contribute to the formation of animal matter, by the transformation of starch and other substances of vegetable origin.

374. Respiration has already been described (78) as being, chemically speaking, a mere process of combustion, in which carbon and hydrogen are burned at the expense of the oxygen of the air; this process of combustion is carried on through the medium of the blood,

and goes on in all parts of the body. In the lungs the blood is exposed to the contact of a quantity of atmospheric air; oxygen is absorbed, and carbonic acid given off; the blood thus charged with free oxygen, is sent by the action of the heart to all parts of the body, in the innumerable minute blood-vessels which terminate the arteries; carbon and a portion of hydrogen are taken up, and the oxygen which leaves the heart free, returns to it through the veins, converted into carbonic acid and water: the former is at last given off from the blood, and expired from the lungs, previous to the absorption of a new quantity of fresh oxygen from the air.

375. Two great objects are effected by the circulation of the blood: the one is the removal of carbon and hydrogen, by means of free oxygen, which, by combining with those elements, produces heat, and keeps the body at a uniform temperature; the other is the addition of new matter, to replace that which is removed. The digested food or chyme, as it is called, on passing from the stomach into the smaller intestines, becomes mingled with a portion of bile, a secretion of the liver, consisting of soda and a peculiar fatty acid. In passing through the smaller intestines, the chyme is separated into two portions,—one containing the elements of blood, called chyle, which is absorbed and carried into the blood, the other containing rejected matters, which are passed from the system as excrementitious.

376. The excess of fluid taken into the system with the food, is conveyed away from the body through the

medium of the kidneys, as urine; a secretion which also contains the rejected azotised matters of the blood, in the form of two peculiar substances to which the names of urea and uric acid have been given; these substances consist of carbon, oxygen, hydrogen, and nitrogen, and are very prone to decompose, when mixed with other forms of organic matter. Urea has been made artificially by chemical means, but uric acid has not yet been so obtained: its only source is the animal system. When urine is kept in a moderately warm temperature it soon begins to decompose; when fresh it is generally slightly acid, but after a short time it becomes alkaline from the decomposition of urea and formation of ammonia. The half solid urine of birds and serpents contains a large quantity of uric acid in combination with ammonia. Guano, the excrement of sea fowl, likewise contains a considerable portion of this salt.

CHAPTER VI.

THE FOOD OF PLANTS—ITS NATURE AND SOURCES.

377. HAVING shortly described the elements of vegetable matter, and enumerated the principal compounds of those elements which are found in plants, we may at once proceed to consider the sources of the food of plants; that is to say, the means naturally provided to insure to them a due supply of the various substances necessary to their growth, namely, oxygen, hydrogen, carbon, nitrogen, and the various earthy and saline substances which are always found in plants.

378. There are only two sources whence it is possible for plants to derive these matters, namely, the air and the soil; let us inquire what substances they can obtain in this manner, and how they avail themselves of the food thus offered to them.

379. It has been already stated that the air at all times contains a small quantity of carbonic acid gas (32); it likewise always contains a still more minute proportion of ammonia, which is constantly being formed by decay. Here, then, we see that the air contains the four elements of organic matter; and when, in addition to these facts, we remember that the air is always more or less damp, it is easy to understand that plants can derive from the

air alone the greater part of the substances which they require.

380. Although the air contains so large a proportion of oxygen, and although that substance is in a free state that is to say, not combined with any element, but ready to combine with any substance for which it has an affinity, yet it does not seem that plants derive the oxygen which they contain directly from the air.

381. In the same way, there is no evidence to show that they are able to absorb nitrogen from the air. It might have been supposed that plants would obtain the nitrogen which they require directly from the air, which contains nearly four-fifths of that gas; but there is very good reason to believe that this is not the case, and that plants can only obtain nitrogen, or assimilate it, as chemists say, by absorbing it in combination with some other substance.

382. What has just been said with regard to oxygen and nitrogen, is equally applicable to carbon and hydrogen: the former is a solid substance, and therefore, as one might rightly conclude, plants cannot absorb it in the separate state; when combined with oxygen in the form of carbonic acid gas, and possibly also when in the form of carburetted hydrogen (102), it can be absorbed by plants. Hydrogen has never been found in the air, except in a state of combination; the commonest compounds of hydrogen, and indeed almost the only ones, from which plants could obtain that element, are water and ammonia. It may be laid down as a rule, that plants

can only absorb oxygen, hydrogen, carbon, and nitrogen in a state of combination, and moreover that these compounds, to be absorbed, must be either fluid or gaseous.

383. The soil consists of silica, alumina, lime, magnesia, oxide of iron, small quantities of various alkaline and earthy salts, and a portion of decaying organic matter. It likewise contains water, and the small quantity of ammonia and carbonic acid which the rain has brought down from the air. Plants cannot derive the elements of organic matter from the earthy constituents of the soil, nor from the organic matter which it may contain, unless there is air present; by the action of air these substances decay, and are gradually changed into gases, which plants can absorb.

384. It is commonly supposed that plants derive the whole of their food from the soil; but this is an error: it is a fact well ascertained by chemical experiments that plants derive the greater part of their nourishment from the air, although the soil is equally essential to their growth.

385. The earthy substances contained in plants are principally obtained from the soil: it is true that the air contains exceedingly minute traces of various earthy and saline substances which are suspended in it in the form of dust, and carried about by the winds; but the quantity which plants can derive from this source is comparatively small. The air near the sea-shore, and even to a great distance inland, is frequently loaded with saline particles derived from the sea; after a storm at sea the quantity of salts thus suspended in the air is very considerable.

386. The fact that some solid substances can be thus carried along in the air, in a state of very fine powder, is important, and well worthy of being remembered, as it explains many apparently mysterious phenomena. It is exceedingly difficult to detect the very minute quantity of solid matter contained in the air, but there is no doubt that it often does exist, although we are not aware of its presence.

387. Setting aside the small quantity of earthy matters which plants may derive from the air, it is evident that the great source of the lime, potash, and other similar substances contained in plants, must be the soil: hence the chemical composition of the soil exerts great influence on the plants which are cultivated in it.

388. The soil or earth is essential to the growth of plants in several distinct ways. It enables them to fix themselves firmly, as from its open, porous nature it allows the roots to extend, in various directions, and obtain a secure hold, so that the plant can grow erect into the air without danger of being blown away by the winds. The soil likewise supplies them with substances essential to their growth: such as carbonic acid and ammonia, either generated by the decay of substances which the soil naturally contains, or absorbed from the air; and also yields them the earthy and alkaline salts which they require.

389. As may be supposed, the soil is very variable in composition; its nature is generally a good deal

dependent on the subsoil and stony matters which are buried beneath the surface, many of which are slowly decomposing or crumbling away, and adding to the soil the substances of which they consisted.

390. The origin of all soils appears to be the disintegration or gradual crumbling down of rocks, from the action of frost, and various chemical and mechanical agents; and hence all soils contain innumerable little fragments of different rocks, which are slowly but constantly becoming smaller as the chemical combinations of which they consist are broken up and destroyed.

391. This gradual decomposition of stony particles in the soil is caused by the action of the air. Many of the common rocks are compounds of several different earthy and alkaline substances, in which silica, united to lime, alumina, potash, and soda, forms silicates of those or similar bases.

392. Silicates of this kind, or natural compounds containing silica in combination with several earthy and alkaline bases, are quite insoluble in water, and are scarcely acted on even by the strongest acids; nevertheless they gradually decompose when exposed to the air. Under the joint action of the moisture and carbonic acid in the air, these compounds are disintegrated, carbonate of potash or soda is formed, and in part washed away by the rain, whilst the insoluble earthy bases are left in the form of a very fine powder.

393. The most abundant constituent of soil is commonly silica, which frequently forms nearly nine-tenths

of the whole of its weight; but this is by no means always the case, for in calcareous or limestone countries we frequently find soils containing a very large quantity of lime; whilst others again contain a large proportion of alumina. These differences in the proportion of the earthy components of the soil give rise to the varieties of light or free, and stiff or clayey soils, which are also modified by the presence of a greater or less quantity of organic substances.

394. Soils differ greatly in their mechanical as well as in their chemical nature. The same substances constitute a soil possessing very different properties according as they are in the form of little grains like sand, or in very fine powder. This state of mechanical division is of great importance for several reasons, and most particularly in relation to water. A soil containing a large quantity of alumina is generally known by its stiff, tenacious character, and is remarkable for its great retentive power for water; whilst those consisting principally of silica, and more especially those in which it exists in the form of sand, are generally light and porous soils, and far less retentive of water.

395. Again, a soil containing alkaline silicates in the form of little grains, always contains free alkaline matter in a soluble state, set free by the decomposition of those silicates, and this separation of alkaline matter continues so long as there is any of the solid silicates left; this effect would cease in a short time if all the silicates were very finely powdered; they would soon undergo decomposi-

tion, and the whole of the alkaline salts would then be washed out by the rain.

396. The best soils are those in which the earthy constituents are so proportioned that the light, porous qualities of the one are balanced by the close, retentive properties of the others; for they are then most uniformly suitable to vegetation.

397. The silica and alumina in soils are of course almost wholly free and uncombined with any acid, as the former is not a base, and the latter has hardly any affinity for the weaker acids, such as the carbonic. Small quantities of silica are almost always found in soils, combined with either soda or potash, forming those curious compounds before alluded to, in which the silica seems to play the part of an acid (225); soils never contain more than a very small quantity of these substances; but it is evident that plants, such as grasses, which contain silica, must obtain it from the soil in a soluble form, by gradually absorbing it in combination with alkali, dissolved in water.

398. Silica also exists in soils, in combination with several bases together, such as lime, potash, soda, magnesia, and alumina, constituting the natural rocky silicates just spoken of; the nature and composition of these compounds, as well as their tendency to decompose, varies considerably in different soils.

399. Lime and magnesia, both of which have a powerful affinity for acids, are never present in the soil except in combination with some acid, and this is most commonly

the carbonic; the former substance is also not unfrequently found combined with sulphuric acid, constituting gypsum, or sulphate of lime.

400. The oxides of iron in the soil are usually uncombined, as they have not sufficient attraction for carbonic acid to combine with that gas, which is always present in the air. They in great measure occasion the variations of colour observed among soils; for according as the iron is in the state of protoxide or peroxide, it gives to the soil a black or brownish-red colour.

401. It must not be supposed, however, that the colour of soils is wholly dependent on the iron which they contain, or that the blackness of any particular soil is indicative of the presence of protoxide of iron. The decomposing vegetable substances, which all soils contain in greater or less quantity, are usually of a brown or black colour, and therefore not unfrequently give a very dark colour to soil which only contains a very small portion of iron.

402. Sulphate of iron is also sometimes present in soils in very small quantity, being formed by the gradual oxidation of sulphuret of iron in the manner previously mentioned (255). A very minute quantity of this salt of iron confers upon the soil peculiar properties which render it appropriate for particular plants; but a slight increase of its amount is attended with bad results, for, unless in very minute quantity, it is poisonous to plants; and hence such soils as contain much sulphate of iron are invariably barren, or incapable of supporting healthy vegetation.

403. The saline matters in the soil are principally the sulphates, muriates, nitrates, and phosphates, of the alkaline and earthy bases. The nature and quantity of these substances vary considerably, but they never constitute more than a very small portion of the soil; their influence upon vegetation is, however, considerable, for certain plants seem to require particular saline substances, and do not grow well in soils not containing them. Thus all kinds of grass and corn contain silica and phosphoric acid: the former substance requires the presence of an alkali, either potash or soda, to render it soluble, and to enable it to enter the roots when it is dissolved in water; whilst the latter is also always associated with a base, which is usually either lime or magnesia. In the same way all plants are found to contain small quantities of similar saline and earthy matters.

404. The relative proportion of the various ingredients of soils vary very greatly. The chief constituent of nearly all soils is generally silica, in the form of sand; and in fact there are comparatively but few good fertile soils in which this is not the case. The sandy matter of most silicious soils consists of nearly pure silica, but in some cases it contains alumina, lime, &c. The following analyses, taken from Dr. Sprengel's book on the composition of soils, will serve as examples of the general nature of ordinary soils; they are samples taken from lands in the north of Germany.

Silica and fine sand	94,998	92,980	96,721
Alumina	610	820	370
Oxides of Iron	1,080	1,666	480
Oxide of Manganese	268	188	trace
Lime, chiefly combined with Silica	141	748	5
Magnesia	208	168	80
Potash	50	65	trace
Soda	44	130	36
Phosphoric Acid	86	246	trace
Sulphuric Acid	41	trace	trace
Chlorine (in common salt)	4	trace	58
Humic Acid	400	764	800
Humus, containing Nitrogen	2,070	2,225	1,450
	100,000	100,000	100,000

405. The nature and quantity of the organic substances in the soil have great influence upon its character and fertility. They act in several ways. By slowly decaying they present a constant source of carbonic acid, and likewise of ammonia, if they contain nitrogen ; whilst, by rendering the soil open and porous, and at the same time augmenting its absorbent powers, they assist in keeping it uniformly moist. They also increase the means which the soil possesses of absorbing and condensing ammonia and carbonic acid from the air

406. It is a remarkable fact, that a mixture of two or three earths, such as lime, silica, and alumina, is better fitted to absorb moisture and gaseous matter, than either of the earths taken singly ; and in the same way, the addition of organic matters to the soil has the effect of increasing this power still further ; and, therefore, as was before said, the best soils are those containing a quantity

of each of the three earths, mixed with a moderate proportion of decaying organic matters.

407. Some soils contain a very large quantity of organic substances, and indeed not unfrequently consist almost wholly of the remains of vegetables: the different varieties of peat are of this character. In such soils we observe the bad effects of the presence of too much organic matter in a soil. It is thus rendered tough, porous, and spongy, so that it is soon saturated with water, or completely dried, by changes of weather. Besides all this, it frequently contains a peculiar acid, produced during the decay of vegetable matter, which is hurtful to the growth of plants.

408. Another use of the organic constituents of the soil is, that they furnish to the plants growing on it the saline substances which they naturally contain, and which not being subject to decay, are gradually washed out by the rains during the decomposition of the organic substances, and are ready to be absorbed by the roots of growing plants.

409. The decay of the vegetable remains in the soil never proceeds so far that the whole of the elements which they contain are converted into carbonic acid and water. The first change which they undergo, when exposed to air and moisture in circumstances favourable to decay, is a diminution of the quantity of oxygen and hydrogen, and likewise, though in smaller relative proportion, of the carbon which they contain.

410. The result of this is a change of colour, some-

what similar to that produced by slightly burning or singeing them by heat: they become more or less brown, according to the degree to which this change has proceeded. Whilst in this state, they constitute what is called HUMUS, the name by which chemists distinguish all kinds of vegetable matter when in a state of decay, and more especially woody fibre, which indeed usually constitutes a very large proportion of the bulk of plants.

411. This process of decomposition proceeds slowly for a considerable time, the relative proportion of the oxygen and hydrogen to the carbon gradually decreasing, carbonic acid and water being all the time formed, until, at last, the humus, consisting of carbon with only a small proportion of oxygen and hydrogen, ceases to undergo any further change; it then is termed mould by chemists.

412. In order to understand this process, which is one of great importance in connection with the growth of plants, it must be remembered that woody fibre and most vegetable substances consist of carbon, oxygen, and hydrogen. Though the elements of these substances are united together in nearly the proportions to form carbon and water, we must nevertheless clearly understand that they are not composed of carbon and water, but that they are distinct compounds of the three elements; and therefore, of course, that the water produced during their decay is not merely set at liberty by a process of decomposition, but is formed by the hydrogen which is given off during decay, entering into combination with oxygen.

413. When woody fibre and similar vegetable substances are exposed to air and moisture, they decay; the chemical affinity which binds their elements together seems to be weakened, and the elements acquire a tendency to form new, and more simple combinations. The oxygen and a portion of the carbon unite and constitute carbonic acid; whilst a portion of the hydrogen combining with oxygen from the air, gives rise to the formation of water.

414. This explains the use of air in facilitating the decay of these substances; for it is evident that if free oxygen be required to combine with the hydrogen, this process cannot go on without a constant supply of fresh air. The rapidity of the decay of vegetable matters in the soil, therefore, depends greatly on the porosity or closeness of the soil, permitting a more or less perfect action of air.

415. In soils containing a large proportion of clay or alumina, the decay of vegetable matter or humus proceeds very slowly, because the close, dense nature of the soil greatly retards the free access of air; though, in other respects, such soils are decidedly favourable to decay, inasmuch as they remain long moist, and a certain degree of moisture is essential to decay.

416. It is necessary to acquire a clear conception of the nature of what is called humus, and the office which it performs in the nutrition of plants. It was formerly supposed that plants derived their carbon from the organic matter of the soil, that the brown decaying substances called humus were directly absorbed by plants,

and their carbon appropriated: it is now known that this is not the case. The real use of humus is, that it constantly generates carbonic acid.

417. When water is poured on humus or decaying vegetable matter, very little of it is dissolved, and the water acquires a pale yellow colour: if, however, the water contains potash or soda, either caustic or in the state of carbonate, it dissolves far more humus, and acquires a deep brown colour: the cause of this is, that the alkalies facilitate the decay of that substance. Under the influence of the alkalies, a peculiar acid is formed, which has accordingly been termed the humic. The brown solution obtained under these circumstances contains humic acid in combination with potash or soda.

418. It has been supposed that this acid might be formed by the action of alkalies on the humus or decaying matters which the soil contains, and that the humates, or compounds of humic acid, thus formed, being absorbed by plants, might supply them with carbon. There is, however, no proof whatever that this really is the case; on the contrary, as has already been stated, there is every reason to believe that decaying vegetable matters merely yield carbon to growing plants, by generating carbonic acid gas.

419. The food of plants, then, is carbonic acid gas, water, and ammonia, partly derived from the air, and partly from the soil; and certain earthy and saline substances, derived almost wholly from the soil. Let us consider the circumstances under which plants are able

to absorb and assimilate these substances, and what other conditions are requisite to their growth.

420. The important influence which water has on the changes which vegetable substances are liable to undergo has already been alluded to, when speaking of albumen, fibrin, and the other similar substances which enter into the composition of seeds. All these substances, which, under the joint action of air and moisture, are so liable to undergo various changes, become comparatively fixed and unchangeable, when well dried and protected from the action of water. During the germination of seeds, a great change takes place in the nature of the substances composing them. Carbonic acid is formed by the combination of a portion of the carbon which they contain with the oxygen of the air. The conditions requisite to the germination of seeds are, therefore, moisture, a certain degree of heat, and the presence of air.

421. Light appears to be prejudicial, and, therefore, darkness may be said to be also necessary to the perfect germination of seeds; and these conditions are all secured by a good soil. The office performed by moisture is, in the first place, principally mechanical, serving to soften and swell up the dry matters composing the seed, and, by assisting in the introduction of air, to facilitate the changes requisite to germination: it likewise acts chemically, its presence being essential to the conversion of starch into gum and sugar. It is also possible that water may sometimes be decomposed during germination, its oxygen combining with carbon to form carbonic acid.

422. When seeds germinate in a confined portion of air, we find that the air does not increase in bulk at all; the nitrogen is not at all affected, but the oxygen is found to have combined with a quantity of carbon, and to be converted into carbonic acid, and, in consequence, the insipid and comparatively insoluble starch contained in the seeds, has changed into more easily soluble, sweet, and mucilaginous or gummy substances, fit for the nourishment of the embryo plant, before its roots and leaves are sufficiently developed to enable it to derive support from the different sources of food presented to it.

423. When the access of air is prevented, whilst at the same time seeds are exposed to moisture, they are unable to undergo this change; germination, or the growth of the embryo, cannot take place, and the seeds decay; a portion of the water is decomposed, and the oxygen and hydrogen which it contained unite with the elements of the vegetable matter, and form carbonic acid, ammonia, carburetted hydrogen, and other substances.

424. The first chemical change which takes place in a germinating seed is the change of a portion of its azotised constituents into diastase (306), a substance which does not exist previously in seeds, but is formed by the process of germination; the azotised matter converted into diastase immediately begins to act as a kind of ferment, causing the starch and gum of the seed to pass into the state of sugar, a change that cannot be effected without the presence of free oxygen, which removes the excess of carbon. During the earliest stage of germination, a small

portion of vinegar or acetic acid is formed ; alkalies tend to assist germination, because they combine with and neutralise this acid.

425. The chemical changes attendant on the process of germination are very different from those which go on during the growth of a complete plant. Before the formation of leaves, and in the very earliest stages of its growth, a plant requires only warmth, moisture, and the presence of air ; but subsequently, it requires, in addition to these, carbonic acid and light.

426. It is the oxygen of the air alone which is essential to the germination of seeds, for the nitrogen being unable to combine with carbon, under ordinary circumstances, is quite useless in diminishing the quantity of that substance contained in the seeds : its presence in the air is, however, very useful, serving to dilute the oxygen and to prevent its acting too rapidly. Seeds are found to germinate very quickly in pure oxygen gas, but the plants produced are weak and unhealthy.

427. The germination of seeds may be readily effected in water, although they are for the most part unable to grow and vegetate under that fluid. The change which under ordinary conditions is effected in seeds by the oxygen of the atmosphere is, under these circumstances, caused by the oxygen of the small quantity of common air always dissolved or held in solution by water. In no case can a seed germinate unless free oxygen is present, or some other means exist by which a portion of the carbon in the seed can be removed, so as to

cause the change in the constituents of the seed before described.

428. In the process of malting, or converting raw grain into malt, the object to be attained is to change a large portion of the starch which the barley contains into gum and sugar. This is effected by steeping the grain in cold water, and then heaping it up together on the floor of the malt-house ; it is thus placed in the most favourable conditions for germination, and consequently the chemical changes attendant on that process immediately commence. The seeds lose carbon, and at the same time convert the oxygen of the air into carbonic acid ; the embryo or young plant begins to increase in size, and the grain becomes warm from the heat evolved by the chemical action. In malting barley about 20 per cent. of starch is changed into sugar and gum.

429. If this were suffered to continue, the sugar and gum formed would be consumed by the growing young plant, and the malt would then become useless. When, therefore, the process has proceeded to a certain extent, it is stopped by the gradual application of heat, which, by driving off the water and drying the grain, destroys the conditions requisite for the further growth of the young plant, and preserves the grain in the state most proper for the uses of the brewer and distiller.

430. There are several chemical means by which germination may be accelerated, but in general very little benefit is derived from such processes. Thus, for example, substances which have a strong affinity for

hydrogen assist germination, because they tend to decompose water, and set free oxygen. For this reason solutions containing free chlorine are found to cause seeds to germinate more rapidly than they would otherwise do.

431. When seeds are sown in the earth, they are placed in a situation where they are protected from the action of light, and exposed to the influence of air and moisture; and provided they are not too cold, that is, above the freezing point of water, they will germinate and produce plants. Below that temperature seeds cannot germinate, because, as has been already said, the action of water is in the first instance to soften the seed, and this it cannot effect when so cold as to assume the solid form itself. If buried too deep in the soil, the free access of air to the seeds will be retarded, or even perhaps wholly prevented, and under these circumstances of course they cannot grow.

432. The nature of the soil too is of considerable importance: very clayey soils allow a less perfect action of air than those which are of a more porous and open structure, and in the former, therefore, the process of germination proceeds more slowly.

433. In the next stage of the growth of plants, or when they have leaves, they begin to absorb carbon from the air instead of parting with it; and this they do by decomposing the carbonic acid always present in the air, a power which they possess when exposed to the influence of light.

434. The effects of light in increasing chemical affinity

are highly curious, and but very imperfectly understood: there are a good many substances which, although they have an affinity for each other, cannot combine in the dark. In the same way, that peculiar chemical change which goes on when plants grow, cannot proceed well in the dark; the decomposition of carbonic acid and water, and the combination of their elements in order to form lignin or starch, &c., goes on very imperfectly without light.

435. The effect of Light, in causing chemical combination and decomposition, is quite independent of its brightness or illuminating power. The rays of light which reach the earth from the sun, possess three distinct classes of properties; those which give light, those which give heat, and those which cause chemical action. In passing through different substances it is found that one or other of these properties is lost; the heating rays, for example, passing through, whilst those which give light are stopped.

436. Chemical action is caused in the cells of the leaves by the agency of these chemical rays of light, which enable the vital power as it is called, to form organic matter; hence it is frequently said that Light stimulates vegetation. Chemical action is also augmented by Heat, which, though it cannot alone effect those changes usually produced by light, considerably assists them, and is therefore classed with light as a stimulus. Electricity also, that marvellous power, in many respects so similar to light and heat; the effects of which we frequently see in lightning and thunder storms, is believed

to exert great influence on vegetation ; but though there certainly appears great probability of the truth of this, it is as yet not proved by direct and unexceptionable experiments.

437. When the young plants appear above the surface of the ground, their mode of growth is changed : they then require air and light, and being no longer preserved by the soil from the action of light, are immediately able to effect the decomposition of carbonic acid.

438. The roots of a plant require little more than moisture. The water which they obtain from the soil contains those saline and gaseous matters which the plants want, whilst the leaves require in addition to these matters the influence of light ; and all these they obtain by growing up into the air.

439. When plants are shaded from the light, or covered up, either artificially or by the leaves of surrounding plants, the action of light is impeded, and they are unable to effect the proper decomposition of carbonic acid. Every one knows that under these circumstances, plants become unhealthy and send up long weak shoots, endeavouring to reach the light, and to place their leaves in a situation where they will be exposed to its influence.

440. The existence of most plants may be divided into four periods: firstly, germination, or the development of the young plant from the embryo ; secondly, the growth of the plant to maturity ; thirdly, blossoming, and the formation of seed or reproductive parts ; and,

fourthly, decay, or a cessation of vitality, and consequent decomposition of the organic structure.

441. In each of these four periods different chemical changes are going on, and therefore different conditions are requisite for the perfection of those various processes. In the commencement, water, air, a certain degree of warmth, and the absence of light, appear nearly all that is required for the growth of the embryo, which obtains food from the matters stored up in the seed, until it has so far increased in size as to have acquired roots and young leaves, and in other respects has become fitted to derive nourishment from external sources.

442. During the growth of the perfect plant, it is observed, that in addition to water and a certain degree of warmth, carbonic acid, ammonia, and certain earthy and saline substances, are required; whilst light, which in the first stage of its growth appears prejudicial, is now required to assist in those complicated chemical changes which are going on, when the compound organic substances, such as woody fibre, gum, starch, gluten, &c., are formed in the organs of the plant by the combination of the elements of water, carbonic acid, and ammonia.

443. Hence during the day, or whilst plants are exposed to the influence of light, the carbonic acid absorbed by them is decomposed, the carbon alone being retained in their structure, whilst the oxygen is given off.

444. During the night, or when light is withdrawn, this process of decomposing carbonic acid and acquiring carbon goes on very slowly, and accordingly some of the

carbonic acid then absorbed by the roots is given off again unchanged, by other parts of the surface of the plants, in place of undergoing decomposition. For plants are at all times receiving from the soil carbonic acid, which must necessarily enter their system with the water they absorb from the soil through their roots; but they can only derive nourishment from it when, in consequence of the influence of light, they are able to effect its decomposition, and so, by retaining the carbon, to increase the quantity of organic matter which they contain.

445. In the third stage of the existence of a plant, or during the formation of seed, the same general conditions are required which are necessary during the second ; for the formation of seeds and fruit is governed by very nearly the same laws which regulate the production of leaves and woody fibre. Those causes which are most influential in maintaining the healthy growth of the leaves, such as temperature, a due supply of food, and more especially light, are likewise the most important in the growth and perfection of the seed.

446. The principal chemical use of the leaves is to assist in the formation of the organic substances existing in plants, which they do by exposing the crude juices to the action of light, and thus effecting those peculiar changes dependent on the combination of carbon, nitrogen, hydrogen, and oxygen, under the influence of light, on which the growth and increase of plants depend.

447. The organic substances thus formed in the leaves are either stored up in the stem of the plant, or in other

ways appropriated to its increase and perfection ; and in most cases but little of them remains in the leaves. The office of the fruit or seed-vessel is different ; for though, like the leaves, it is able to assist in the production of organic matter, the substances so formed are retained and stored up in itself, and the fruit or seed-vessel not only returns nothing to the plant on which it grows, but in addition attracts to itself a large portion of the vegetable matter formed, by the combination of carbon, oxygen, and hydrogen, under the influence of light, in the leaves.

448. Thus, whilst the leaves are continually adding new matter to a plant, the fruit, on the other hand, by absorbing that matter, checks the growth. Hence, also, the practice of pruning fruit-trees with a view to improve the fruit; the young fruit thus gets an additional supply of organic matter, which would otherwise have gone to the formation of fresh leaves had not the branches been removed.

449. It must not, however, be supposed that the formation of flowers and seeds is similar to the formation of woody fibre, or leaves ; very different changes take place, but the same general conditions are required by plants in both cases.

450. Flowers do not, like leaves, possess the power of decomposing carbonic acid under the influence of light ; on the contrary, flowers appear at all times to give out carbonic acid. From this it is evident that they must consist principally of substances containing in proportion less carbon than the ordinary proximate principles, such

as gum and lignin. There is a common belief that plants in blossom deteriorate the air, and, therefore, that their presence in bed-rooms is highly objectionable. It is true that flowers generate carbonic acid ; but it is probable that the evil effects occasionally produced by flowers in sleeping-rooms are occasioned by a minute quantity of a volatile oil, (332) to the formation of which the smell of flowers is to be attributed.

451. When fruits are first formed, they act very like leaves ; they absorb food from the air, and under the influence of light form organic matter, whilst at the same time they collect and appropriate much of the organic matter generated by the surrounding leaves. At this period of their growth fruits have very little taste, and in composition they somewhat resemble leaves ; when they have attained a certain size they undergo a new change, and ripen, during which they acquire a sweet, or slightly acid taste.

452. In the first stage of the ripening of fruit, acid matter is generated, in consequence, apparently, of the conversion of some of the tasteless constituents of the fruit into malic, tartaric, and other organic acids. During the second period of ripening, the greater part of these acids are converted into sugar, and a portion of colouring matter is at the same time formed. The formation of sugar and colouring matter takes place quite independent of the plant ; for fruits may be ripened after removal from the plant which produced them.

453. In the first period of vegetation, when a seed

has been placed in the conditions requisite to germination, the embryo plant has no power of obtaining food for itself, either from the air or the soil; it is entirely dependent on the seed for a supply of those matters which are necessary to its growth. A seed, then, is a magazine or store of food, prepared for the use of the young plant, and accordingly a large quantity of the matters secreted by a plant are necessarily employed in the formation of seed.

454. There is a great distinction between organic and organised matter. The former term signifies, as has already been explained, sugar, starch, or similar compounds; whilst by the latter name is meant the cellular and fibrous parts of plants. The chemist may by artificial means readily make some forms of organic matter, and convert them into others; but he cannot make organised matter: the latter is a product of vital action, and has never been formed by artificial means.

455. The first change effected by plants is to convert carbonic acid and water, under the influence of light, into starch and similar forms of organic matter; the second operation is to form these substances into the various cells and tubes which compose the structure of plants. The former is a purely chemical operation; the latter requires something more, namely, the exertion of vital power.

456. The embryo of a seed possesses vitality, but has no power, at first, of assimilating the elements of organic matter directly from the air; it is, therefore, able to

convert starch, gluten, and the other proximate principles into organised matter, and consequently grows and increases in size, by feeding on the store of organic matter provided for its use in the seed.

457. The means provided to insure the reproduction of plants are very various. In some plants seed only is formed; whilst in others we observe tubers or collections of food, prepared and preserved in underground receptacles, for the nourishment of the young plants of the next season.

458. Many plants, such as wheat, barley, beans, &c., form seeds which consist merely of an embryo, or growing body, surrounded with a supply of organic food, sufficient for the use of the young plant, until it has grown large enough to feed itself. The seeds of other plants are more complete, being surrounded with an additional quantity of organic matter, which, by decaying, insures to the roots and leaves of the young plant a due supply of gaseous food as soon as it is able to feed itself by those organs.

459. The seeds of all plants which bear fruit are of this kind. When a peach, for example, falls from the tree which produced it, the soft pulpy matter of the fruit soon decomposes, and by the time that the seed begins to germinate, the fruit is wholly converted into humus: hence the roots of the young plant are placed in a soil rich in carbonic acid, as soon as it is possible for them to absorb it.

460. During the whole existence of a plant, from the

formation of its first leaves till its death, it is constantly absorbing moisture from the soil through the roots, and as constantly parting with it by the leaves. The water thus collected from the soil contains carbonic acid, ammonia, and such saline matters as are present in the soil. If the leaves of the plant are exposed to the action of light, the carbonic acid and ammonia are decomposed, together with a portion of the water, and organic matter is formed.

461. During the night, or in the absence of light, this change takes place but imperfectly; and hence, then, the water absorbed by the roots, which is still given off by the leaves, carries with it a considerable portion of the gaseous matter collected from the soil.

462. The exact office in the nutrition of plants, performed by the saline substances they absorb, is as yet but imperfectly known. Some plants appear to require particular substances, and it is known that certain substances cannot be formed by plants unless the soil contains particular saline matters. All plants contain more or less lime, as well as other bases, such as potash and soda; these, of course, are never in the pure state, but combined either with organic or inorganic acids, or else with chlorine. Albumen, gluten, casein, and fibrin, are always found to contain a small quantity of certain phosphates, particularly those of lime and magnesia; hence these substances appear to be essential to the formation of those principles in plants.

463. It is not known whether plants have any power

of selection by their roots; that is to say, whether they are able to absorb from the soil only those substances which they require, or whether they absorb all the soluble matters present in it. To a certain extent they seem to have some power of selection, but at the same time they are very frequently injured by the absorption of poisonous matters from the soil.

464. The quantity of these inorganic matters found in plants is various at different periods of their growth. In general, young plants contain a larger proportion than old ones, and as seeds contain a supply of all that young plants require, a quantity of these salts is necessary for the ripening of seed: hence plants require a large supply of inorganic matter from the soil during the third period of their existence, or during the formation of seed.

465. These are, in very general terms, the conditions requisite to the growth of plants; but there are many special conditions appropriate to particular species, and many important circumstances, which must not be overlooked in studying the chemistry of vegetation. The differences of climate, and their influence on the growth of plants, are not less remarkable than those of the soil itself; and indeed the very same soil would possess a very different degree of fertility in different climates.

466. In the hot, moist regions of the tropics, plants grow with far more rapidity, and vegetation is more vigorous, than in temperate regions. In tropical countries, decay proceeds far more rapidly than it does in

our own country; carbonic acid and ammonia, the food of plants, are produced in greater quantity than here; whilst, from the greater power of the sun, plants are able to assimilate more of those substances than they can in colder countries.

467. The same circumstances which are favourable to the putrefaction of organic matters, are likewise those which facilitate the decomposition of inorganic compounds in the soil (392). Consequently, in warm tropical climates, a more copious supply of the requisite earthy matters is continually being set free, ready to be absorbed by the plants; proportionate, in fact, to the augmented vigour of the vegetation.

468. Hence, in endeavouring to introduce into one country the plants of another, it is necessary to consider the conditions under which they naturally grow; and care must be taken to imitate as closely as possible those conditions, not merely as regards soil, but likewise in respect to temperature, moisture, and light. These, however, are practical matters into which it is unnecessary here to enter.

469. In the last stage of the existence of a plant, or when, either from excessive cold, disease, or merely old age, the vitality becomes extinct, all that curious series of changes by which organic matters are generated under the influence of light in the cells of plants, ceases; decay commences, the organic compounds of the plant begin to decompose, and their elements re-arrange themselves into simpler forms. The greater part of the hydrogen

combines with oxygen, and is gradually given off in the state of water; the nitrogen and hydrogen combine, and form ammonia; whilst the carbon is slowly dissipated in the air in the state of carbonic acid, and at last little remains besides mould, or charcoal in combination with a small quantity of oxygen and hydrogen (411), and the insoluble earthy matters which the plant may have contained.

470. A plant dies, when at the end of the season, it has passed through the various stages of its existence, fulfilled the office for which it was created, and formed seeds or reproductive particles, which will insure a fresh growth of the same kind of plant next year; after this, vitality gradually declines in energy, the formation of fresh organic matter ceases, and that already formed begins to decompose.

471. Disease is occasioned by many causes, but independent of numerous minor sources, such as the attacks of insects, &c.; the most important are deficiency of light, deficiency of vital energy, and deficiency of heat; either of these alone, or a combination of them, induces disease in plants, and often leads to death, by enabling the elements of organic matter to commence those changes which constitute decay and decomposition.

472. As has already been observed, plants are constantly employed in preserving the purity of the atmosphere: they feed on the foul or vitiated air produced by respiration, combustion, and decay; and their vigour and luxuriance are always in proportion to the impurity

of the air. It must however be clearly understood, that there is a limit to the quantity of carbonic acid plants are able to decompose: an excess would kill them; whilst if there were none of it in the air, they could not live. The vegetation of the whole globe is just enough to keep the air in a uniform state of purity (77, 94).

CHAPTER VII.

ARTIFICIAL SOURCES OF THE FOOD OF PLANTS.—ACTION OF MANURES.

473. WHEN we remember that, although plants derive a large portion of their nourishment from the air, yet at the same time they absorb considerable quantities of saline matters from the soil, it is evident that all plants must more or less impoverish the soil, by taking away that which causes its fertility.

474. The natural vegetation of any country enriches rather than deteriorates the soil, because nothing is carried away from its surface; the plants which grow on it, return to the soil, during their decay, all the earthy and saline substances which they had absorbed from it during their growth, whilst they add to it a considerable quantity of the carbon they had collected from the air.

475. Very different, however, is the condition of cultivated lands; on them large crops are raised year after year, which are removed and carried away to a distance, to form the food of men and animals. Such land is gradually impoverished, because with the crops a large quantity of inorganic matter, necessary to the fertility of the land, is removed. It remains for us to inquire, what are the best means of restoring these matters to

the soil; and likewise, in how far is it possible to increase the fertility of the soil, by augmenting the natural quantity of any of its constituents.

476. In practice there are three courses adopted to maintain the fertility of the soil, namely, fallowing, a rotation of crops, and the application of manure.

477. In order to comprehend the effect produced by fallowing, it is necessary to remember the mode in which soil is formed. As has already been stated, soils consist principally of small fragments of different rocks and stones, which, from a variety of causes, have gradually crumbled down to powder. The sand or fine particles of stone in the soil are constantly decomposing (392) and adding to the soil, potash, soda, and very finely-divided earthy matters; it is from sources of this kind that most of the saline substances present in the soil are derived.

478. The soluble salts formed in this manner are dissolved by the rains, and in great part washed away from the surface; a portion, however, always remains in the soil, and is absorbed by plants. When a crop of some plant requiring, for example, a large quantity of potash, is raised in such a soil, it often happens that the crop takes away nearly all the soluble potash the soil contains; and in consequence, it would be impossible to raise a second crop of that plant on the same soil, as there would not be potash enough in it.

479. If, however, the soil is left for some time fallow, if no crop at all is raised on it, the soil has time to renew

itself; by the action of the air, the further decomposition of the silicates and other similar stony compounds in the soil, is effected, and a fresh supply of potash is provided.

480. The same end is obtained by a system of rotation. In place of sowing a second crop of the plant which requires so much potash, some other plant is taken, which does not require potash, but which requires other substances that the soil contains.

481. In both these cases we restore, by the slow effects of the air, those substances which we remove with the first crop. In manuring, we at once add to the soil that which the plants require.

482. Generally speaking, wheat cannot be grown on the same land year after year, and accordingly various systems of rotation are adopted. It is evident, however, that as soon as we know what are the substances required by wheat and other crops, we shall at once know how to restore to the soil those substances which each crop removes, and thus be enabled to obtain crops of the same plant, for any number of years in succession, from the same soil. The labours of chemists are, however, hardly far enough advanced for this, at present.

483. The period of time over which the rotation is made to extend, varies greatly in different countries and in different soils. The ordinary period in England is four or five years, but it is sometimes extended to nine, or even more. In the ordinary four or five course system, wheat is only grown once in four or five years, manure

being given only once, at the commencement of the course, when a crop of turnips being grown, is fed off by sheep; the land thus receiving a rich dressing of sheep's dung.

484. With respect to the natural sources of saline matters in the soil, it must be observed that although their nature and quantity are in great measure influenced by the composition of the subsoil and stony substratum, yet it frequently happens that from want of mixture the soil is deficient in some of those very substances which the subsoil is rich in; and in consequence the soil becomes considerably improved by mixture, or by spreading over the surface some of the decomposing stones dug from below.

485. We are apt to think that a soil must of necessity contain portions of those substances which enter into the composition of the substratum; but this is by no means always the case. Thus the surface-soil of a chalk district is not unfrequently nearly wholly destitute of calcareous or chalky matters; and soils in such situations are, therefore, often improved by spreading lime over the surface.

486. It is consequently of high importance to know the nature and composition of the subsoil, as well as the surface soil; for by a judicious use of the former, the soil itself may frequently be very much improved, and probably some saving effected in the quantity of manure required for the land.

487. The system of subsoil ploughing, so successfully practised in many parts of the country, is connected with this subject, and depends mainly upon the advantages

derived from admixture of the subsoil with the surface. In this operation a plough is employed to break up and pulverise the soil to a considerable depth below the surface, without bringing the soil so disturbed up to the top; by this process the permeability of the soil to air is greatly increased, and in consequence, the subsoil is soon brought into a fit state to be mixed with the ordinary soil, by the use of a suitable plough.

488. Part of the benefit derived from this operation is doubtless due to the greater openness conferred upon the soil, which permits a more perfect access of air and moisture, and allows the roots of the growing plants more easily to penetrate through it; but at the same time, advantage is also derived from the greater supply of saline and soluble earthy matters which are thus made available for the use of the plants.

489. A very great variety of different substances is included under the general name of manure. Some of the substances added to the soil act principally in a mechanical way, improving its texture; others are chiefly valuable as sources of carbonic acid and ammonia; whilst many are useful as supplying saline and earthy matters in which the soil may be deficient. It would be easy to divide all manures into these three classes; but it is more convenient to divide them simply into the organic and the inorganic, because many manures act in all these three ways at once, improving the texture of the soil, and supplying carbonic acid, ammonia, and saline matters.

490. The Chinese, who are very economical of their

manure, apply it in small quantities at several distinct periods to their plants, when they judge it to be wanted; it may in fact be said that they manure their plants whilst in Europe it is the custom to manure the soil; this must of necessity be the case, where labour costs less than manure.

491. Organic manures may in general terms be described as consisting of any kind of organic matter in a state of decay or putrefaction. Setting out with the knowledge that organic matter consists of carbon, oxygen, hydrogen, and nitrogen, it is not difficult to understand the changes produced by its decomposition.

492. The complicated changes which organic matters undergo in decomposing, are generally divided into four separate classes, namely Fermentation, or the formation of new compound substances, by the partial decomposition of a compound; the change being induced or commenced in consequence of the presence of some other decomposing matter:—Putrefaction, or the complete decomposition of organic matter and its conversion into different inorganic compounds, such as water, ammonia, carbonic acid, sulphuretted hydrogen, &c.:—Decay, a slow process of oxidation, almost analogous to combustion, differing from putrefaction in being dependent on the presence of free oxygen or air. This change is always accompanied by the evolution of heat:—Mouldering, a change intermediate between putrefaction and decay, taking place in organic matters exposed to the action of water, but not to that of air.

493. Organic manures consist of mixtures of various organic substances in a state of putrefaction or decay. The more changeable substances at once enter into putrefaction, sometimes communicating their own state to those which are less changeable, sometimes only inducing decay in them ; thus for example, urine soon putrefies by itself, and if mixed with straw it gradually causes the latter to heat and decay.

494. Whilst describing the different varieties of organic matter, attention has constantly been drawn to the results produced by their putrefaction. It has been repeatedly stated that the substances formed by the putrefaction of organic matter are water, carbonic acid, and ammonia. The nature and rapidity of the change is, however, greatly modified by circumstances.

495. Organic matter containing nitrogen changes far more rapidly than that not containing this element (302). It might have been supposed that under such circumstances the nitrogen would be given off in a free and uncombined state ; it is therefore remarkable to find that, at the moment of escaping from one compound, it enters into combination with another element. This fact is important, and deserves a little further consideration, for it is found that at the moment of separation substances have a peculiar tendency to enter into fresh combinations.

496. Substances in this state, or whilst being set at liberty by the decomposition of compounds which previously contained them, are said to be in the *nascent*

state. It is always found that substances which have an affinity for each other, but under ordinary circumstances cannot combine, are able to do so when in the nascent state.

497. All attempts have failed to cause the combination of a mixture of hydrogen and nitrogen gases ; but when these two substances are in the nascent state they combine readily, and ammonia is formed.

498. The rapidity with which animal substances decay or putrefy depends on moisture, warmth, and air. It has been stated that substances of this kind may be preserved a long time if dry ; water is necessary to their putrefaction. It is well known that meat may be preserved fresh a long time if frozen, or kept at a temperature below the freezing point of water, whilst, on the other hand, if kept in a warm place, it soon begins to change.

499. The decomposition of animal matter may likewise be accelerated by the mixture of potash, soda, or lime, &c., with it, and under these circumstances nitric acid is formed (127), though all the ammonia formed at the same time is lost (123). It appears that the mixture of these bases assists in the formation of the acid, in consequence of the strong affinity which they have for it, and that therefore they increase the natural tendency which nitrogen has to separate from the carbon, oxygen, and hydrogen with which it is united in organic matter.

500. Whilst animal matters are putrefying, they commonly emit a very offensive smell : now, as neither water, carbonic acid, ammonia, nor nitric acid can cause this, it

is evident that some other substance must at the same time be formed. The fact is, that the nauseous odour given off under these circumstances is occasioned by the formation of sulphuretted hydrogen (143).

501. Sulphur and hydrogen, though hardly able to combine with each other under common circumstances when brought together, unite readily when the hydrogen is in that peculiar nascent state above adverted to. Thus, when organic substances containing small quantities of sulphates decay, a portion of the hydrogen, whilst set at liberty, combines with some of the sulphur contained in the sulphates, and sulphuretted hydrogen gas is formed.

502. This gas is evolved in considerable quantity during the decomposition of nearly all animal substances, and likewise those vegetables, such as cabbage, &c., which contain both nitrogen and sulphur; though its odour is not unfrequently almost overpowered by the strong pungent smell of the ammonia evolved at the same time.

503. When such decomposing substances are exposed to the air, the sulphuretted hydrogen gas formed is dissipated, and carried away in the atmosphere; but at the same time a large quantity of the ammonia also formed is lost, and this is of course highly objectionable. The value of these kinds of manure depends in great part on the quantity of nitrogen which they are able to supply to the plants; and everything tending to assist in retaining that substance in the soil, and rendering it available to the growth of plants, is advantageous; whilst, on the other hand, everything increasing its loss, or dissipation

in the air, lessens the value of the manure, and renders its application of less service.

504. Animal manures, to a slight degree, modify the mechanical texture of the soil; though from their great proneness to decompose, the effects of this kind which they produce are comparatively transitory. Their principal value consists in the ammonia and carbonic acid, or nitric acid, which they yield, and the earthy and saline compounds which they contain. In addition to this, they are also of value by facilitating the decomposition of vegetable substances employed as manure (493).

505. As perhaps the most useful part of these kinds of manure is the volatile substances formed during their decay, great care should be taken to suffer as little as possible to escape and be lost. It is probable that the best method of preserving the greater part of these matters is to dissolve it in water. The employment of liquid manure is gradually coming more and more into use, and the prejudices against its application are vanishing, as the beneficial results produced by its use become known.

506. Organic manure is of comparatively little value in a chemical point of view until it has undergone decomposition; plants do not seem able to absorb and appropriate organic matter; hence, in all cases, whether applied fresh or decomposed, it must undergo decay or putrefaction, before it can constitute food for plants. It appears further, that plants cannot absorb solid matter; it is consequently also requisite that these matters should

be soluble in water, or capable of entering into the organs of plants in a fluid state. When water is added to organic manure in a state of decomposition, putrefaction is assisted, the escape of gases is diminished, and the useful part of the manure obtained in that form best suited to the wants of growing plants.

507. When plants are growing very vigorously, and are abundantly supplied with manure, it appears that they sometimes do absorb a small quantity of organic matter together with the inorganic products of putrefaction. Vegetables forced with abundance of strong animal manure, such as pigs' dung, are frequently found to have acquired a bad taste, from the presence of a minute quantity of the manure, which they have absorbed undecomposed.

508. The greatest attention should be paid to the modes of collecting, preserving, and economising animal manure. There can be no doubt that a very large quantity of manure is constantly wasted under the old systems of using it, and the least consideration will convince any one of this.

509. The food of plants consists principally of certain volatile or gaseous substances, produced, amongst other ways, by the decomposition of organic matter; we add organic matters to the soil, to supply plants with more food than they could otherwise obtain. If, then, previous to using these substances as manure, they are exposed for some time to the air, sun, and rain, a considerable portion of the volatile products of decay will be lost; and yet this is constantly done.

509. Manure should be carefully collected — none should be neglected or suffered to go to waste ; it should be preserved in proper receptacles, sheltered from the sun and rain, so that the volatile products of its decay may neither be lost by the heat of the former, nor washed away by the latter ; and lastly, by the action of water it should be softened, and as much as possible reduced to a fluid state, so that it may be easily and uniformly applied to the land. The formation of liquid manure tanks deserves the most serious attention of the farmer.

510. In the application of these kinds of manure, it has to be remembered that although carbonic acid and ammonia are the principal food of plants, yet that there are limits to the quantity of these substances they can absorb, and that too great a supply of such food is not only useless, but objectionable, and even highly injurious. It is useless to give a plant abundance of carbonic acid and ammonia, if we do not at the same time give it those earthy and saline substances which it requires (339). Even if both are supplied to plants, it is impossible for them to absorb more than a limited quantity. Excess does harm.

511. As animal matter is either directly or indirectly formed from vegetable substances, it is natural to expect that animal substances must contain, in addition to the four elements of organic matter (349), the same earthy substances which plants contain, and this is really the fact (364). The phosphate and carbonate of lime of the bones is obtained from plants, and the alkaline and other

salts found in the various parts of the animal body are derived from a similar source.

512. The knowledge of this fact necessarily leads to the conclusion that all animal matter must be valuable as manure. The flesh and softer parts of animals, as well as the bones and other solids of the body, are composed of the same substances, both inorganic and organic, as plants; and during their decay yield them up again in a fit state to be absorbed by plants.

513. The vegetable substances which constitute the food of animals contain more earthy and saline matters than animals require, and they are accordingly passed from the body as excrementitious. The food of animals in great part goes to supply the waste, occasioned by respiration. In this process carbonic acid is formed by the oxidation of carbon in the body by the oxygen of the air; hence in the air expired from the lungs it is found that the oxygen is more or less combined with carbon, and converted into carbonic acid (78, 374). The heat evolved by the combination of this carbon with oxygen keeps up the warmth of the body. The waste of organic matter in the body thus occasioned, is supplied by food, the organic part of which supplies that consumed by respiration; but as the greater part of the inorganic substances contained in food are not required for this purpose, the excess is voided in the solid and fluid excrements.

514. There are few things of greater value as manures, than these offensive and apparently useless substances,

which consist of a mixture of organic and inorganic matters; the former, in consequence of the nitrogen they always contain, ready to decompose and furnish carbonic acid and ammonia; the latter, those very substances which we require to add to the soil, those very substances which are removed with crops. In consequence of the volatile nature of the products of their decomposition, every means must be employed to prevent their loss.

515. When animal substances are left for some time exposed to the air, they undergo decomposition, and there at last remains nothing but the more fixed substances which they contained, together with a quantity of salts of ammonia, formed during the decomposition of the easily putrefiable matters. This residue is a valuable manure, though in forming it a very large portion of the ammonia produced, is lost by evaporation. The guano or huano of South America, which has of late excited so much attention, is the remains of the excrements of sea-fowl, which has partly undergone this change (533).

516. There are other modes besides that already adverted to (190), whereby the loss of ammonia may be prevented. Both ammonia and its carbonate are volatile, and though by the addition of water it is easy to retard their escape, it cannot be entirely prevented. It has therefore been proposed to add to liquid manure a small quantity of some acid, which shall combine with the ammonia to form a neutral salt, and so prevent further loss from volatility. The trials which have hitherto been made appear perfectly satisfactory, and the

only question is — which is the best method of thus neutralising or fixing it ?

517. The simplest method of fixing ammonia is to add to the manure a small quantity of a weak solution of any acid ; but we may also fix it by the addition of any salt containing an acid united to a base by a less affinity than the acid has for ammonia : when this is done, the salt is decomposed, the base is set free, and the acid combines with the ammonia.

518. Ammonia may be fixed by the addition of a small quantity of sulphuric, nitric, muriatic, phosphoric, or any other acid. Sulphuric is, generally speaking, the cheapest, and therefore the most convenient to employ ; the quantity to be added of course depends on the quantity of ammonia in the manure ; when enough acid has been used, all smell (182, 184) of ammonia disappears. A slight excess of acid does no harm, as it is certain to become neutralised by the bases always present in the soil.

519. It not unfrequently happens that from local circumstances a large supply of some other acid liquors may be obtained, more particularly in the vicinity of manufactories ; all such substances may be used with advantage. The comparative value of the different salts of ammonia is as yet unknown ; perhaps the best acid, if it could be procured cheap enough, would be the phosphoric. Phosphate of ammonia forms a most valuable manure.

520. Various salts have been proposed for the purpose of fixing ammonia ; amongst these the best appear

to be gypsum or sulphate of lime (203), and copperas or green vitriol, the sulphate of iron (258). When either of these salts is mixed with solutions containing ammonia in the state of a carbonate, both are decomposed, sulphate of ammonia is formed (188), and carbonate of lime or oxide of iron is left, as an insoluble powder. For several reasons acid is preferable to fix ammonia; it is more easily used, and requires far less care and attention in mixing with the solution containing ammonia.

521. Animal substances must have undergone decomposition before they can serve as the food of plants. It has already been stated that plants appear only able to absorb nitrogen in a state of combination (381); no form of organic matter is suitable to the nourishment of a healthy plant. It is the office of the leaves to convert carbonic acid, ammonia, and water, into organic matter, and hence organic matter must be resolved by decomposition into these substances, before it can be absorbed by plants.

522. There are some plants, however, which seem to be exceptions to this rule, and which appear able to feed on organic substances. Certain fungi and parasitical plants, or those which grow upon others, probably feed by directly absorbing organic matter. The small fungi which constitute the various forms of mouldiness are of this description; they flourish in the dark, and grow on any kind of dead organised matter. All plants which have leaves and require the influence of light, feed on gaseous matter, and never on organic compounds.

523. Liquid manure, consisting chiefly of urine and other waste animal manures diluted with water, is never so valuable in its fresh state, as it becomes after a time when the organic matter is chiefly converted into carbonic acid, water, ammonia, &c. The time required for this change varies from four to eight weeks, or even more, according to the season of the year; putrefaction being much more rapid in hot than in cold weather.

524. The substances containing nitrogen are those which first begin to undergo putrefaction, and accordingly ammonia is one of the earliest products of the putrefaction of liquid manure; at this time much of the ammonia is in the caustic state, and hence it is not so fit for manure as it is subsequently, when combined with carbonic acid in the completely putrefied liquid. In conquence of the great volatility of caustic ammonia, much of it is lost by evaporation, in the early stage of putrefaction; it is for this reason that close tanks for liquid manure are so much recommended, and that the addition of fixers is found so advantageous.

525. Amongst the principal animal substances employed as manures are urine, and dung of all kinds, the flesh and blood of dead animals, fat and oily matters, hair, wool, skin, and lastly horns, hoofs, and bones. These substances are all more or less valuable, as yielding to the soil a large quantity of the substances which constitute the food of plants; they putrefy, and their elements form new combinations with great rapidity. Those which change most readily of course yield ammonia

and carbonic acid most rapidly, and these constitute the most powerful manures : those which decompose more slowly are less powerful, but more lasting in their effects.

526. Urine, dung, and the decomposing carcases of all animals are excellent manure ; they are for many purposes considered to be too strong, and means are adopted to diminish their power. These manures evolve, during their rapid decay, a very large quantity of ammonia, carbonic acid, &c., far more in fact than plants require or can absorb. The excess is hurtful and must be prevented.

527. There are two ways by which this may be effected ; the one is to mix strong manure with a considerable quantity of some substance far less prone to decomposition, so as to dilute it, or check its putrefaction ; the other, and certainly infinitely the worst way, is to expose it to the air for some time, and not to use it until a great part of the ammonia evolved by its decomposition is dissipated, or combined with acids ; acids remains is then sufficiently mild to be used with safety.

528. In order to preserve as much as possible the valuable parts of these manures, they should be mixed with a certain quantity of vegetable refuse matters, such as sawdust, weeds, &c. This addition tends to check their too rapid decomposition, and prevents the great loss which ensues when manure decays too rapidly and becomes hot from the effects of its own decomposition ; and at the same time the vegetable matters added are

gradually brought into a state of decay, which renders them also a most valuable addition to the soil. Farm-yard dung is a mixture of this kind.

529. The extremely offensive odour of nightsoil is a great obstacle to its collection and use as manure. In its fluid state the expense of conveying it to any distance is of course great, and accordingly various plans have been adopted to reduce it to the solid form, both to diminish cost of conveyance, and also to admit of its being used with the drill; in these, however, a portion of the volatile constituents is generally lost, though what remains is undoubtedly a valuable manure. In the manufacture of some of the best of these "disinfected nightsoils," charcoal powder, burnt clay, and other similar porous substances, are used to absorb the gases evolved (190).

530. The most economical mode of using nightsoil is, probably, to allow it to putrefy, diluted with water, and mixed with a considerable quantity of vegetable matter; and to employ it as liquid manure. Of course this cannot be done when it is intended subsequently to carry it to a distance.

531. The dung of different animals varies considerably in its value as manure, depending in great part on the substances which constitute their food; that of those which live on animal food, being of course richer in nitrogen than that of vegetable feeders. The value of those kinds used as manure are in the following order:—Pig's dung, nightsoil, sheep and rabbit's dung, horse

dung, and cow dung; the first being that of most value.

532. In manuring land, by feeding off with sheep, not only does the land receive a large quantity of valuable manure from the dung, urine, and perspiration of the animals, but it likewise has its mechanical texture materially modified by the constant treading of the sheep.

533. Guano, the residue of the putrefaction of the excrement of sea fowl, consists chiefly of various salts of ammonia, inorganic compounds, and undecomposed organic matters, analogous in nature to horn and wool (538). The salts of ammonia dissolve easily in water, and are at once absorbed by plants, whilst the undecomposed organic matter, gradually undergoing decomposition, continues for some time to yield a regular supply of ammonia. In guano there exists all the chemical elements of an excellent manure; but of course it does not produce the same mechanical effect on the soil which yard dung does.

534. In using guano as liquid manure, it must be remembered that the solution formed by pouring water over it only contains the ammonia and about one quarter of the phosphates; the rest of the phosphates, and the organic matter, being nearly insoluble in water; hence the residue is nearly as valuable a manure as that which is dissolved, and in order to derive the whole benefit from the manure, the insoluble part must, by agitation or other means, be kept suspended in the liquid whilst it is being spread over the ground.

535. Analogous in nature and value to these substances

are dead fish, and the refuse matters left in curing and preserving fish ; sugar refiners' waste, which is a mixture of charcoal, blood, and various organic matters containing nitrogen, which exist in crude sugar ; and wool soap, an abundant refuse from the wool mills, consisting of putrid urine, in which the wool is boiled to remove the grease which it naturally contains, and which is consequently rich in ammonia.

536. Strong animal manures are doubly valuable, for not only do they contain abundance of those matters which constitute the food of plants, but they also assist in rendering useful, materials which would without them be of far less service. Whether these manures are employed in the liquid or in the solid form, some means should be adopted to retain the ammonia, either by the addition of acids, or by some other method.

537. These remarks are far less applicable to animal manures, such as fatty substances, horn, wool, bones, &c., which change but slowly. These substances for the most part act slowly and gradually, and in a very different manner from the softer parts of animals. In general the strength or value of animal manures is in proportion to the quantity of nitrogen which they contain ; those which contain much of that element decompose rapidly, and evolve a considerable quantity of ammonia ; whilst those containing little or no nitrogen change slowly, and, though valuable, and perhaps more lasting in their effects as manures, are far less powerful for the time.

538. Woollen rags, hair, feathers, clippings of horn and skin, greaves, the refuse of the tallow melters, the refuse of glue manufactories, and similar matters, form valuable manures; because, though they do not decompose so rapidly as other animal manures, they slowly and gradually decompose, and continue to give out ammonia, &c., for a very long time.

539. The substances of this sort employed as manures are very numerous; including as they do the refuse of all those processes of the arts in which animal matters are used, their value in all cases chiefly depends on their slowly decomposing, and affording a continual source of ammonia, &c.

540. Although oil or fat of all kinds contains no nitrogen, and therefore exhibits very little tendency to change when pure, yet when mixed with earth, the large surface which is exposed to the air assists in its decomposition, particularly if other animal matter also is present; and it accordingly forms a valuable constituent of mixed manures. The dregs of oil, waste blubber, and all refuse oils, are excellent manures; soap likewise, in which oil or fat is combined with alkali, is used with advantage whenever it can be obtained at a moderate price. The waste soap of the wool factories has already been mentioned as of great value (535).

541. The water which runs to waste from many manufactories in which soap is employed, might be used with great advantage for manure; it often holds in solution a considerable quantity of valuable matter, and might be

well employed in the formation of liquid manure. The drainage water of towns generally containing, as it does, urine, refuse from the kitchens, soap, &c., is an excellent component of manure; the most valuable substances which it contains, exist in a state of solution; the mud which falls to the bottom when it is left to stand at rest, is comparatively speaking of little value in a chemical point of view.

542. The last animal manure which it is necessary to speak of is bones, though as their chief value consists in the inorganic matters which they contain, they might almost be classed amongst the inorganic manures. Bones consist of earthy matters (364), together with a quantity of gelatine and fat; the value of bones as a manure consists in their mechanical effect on the texture of the soil, the earthy substances which they supply (583), the ammonia given out during the decay of the gelatine or glue, and the carbonic acid and hydrogen supplied by the fat.

543. The quantity of putrefiable matter in bones is small in proportion to their whole weight, and its decomposition is retarded by the large quantity of earthy matter they contain; hence bones form a good and lasting manure. Boiled bones form a better manure than raw or green bones. This appears to be occasioned by the removal of fat during boiling; the fat which bone contains retards the decomposition of the gelatine, and probably also renders the phosphate of lime less soluble than it is when the oil is removed.

544. In stating that boiled bones form a better manure than raw or unboiled ones, it is of course evident that the operation of boiling cannot in any way increase the absolute quantity of manure which they can supply, but merely renders them more rapid in their action, as they become less lasting in their effects, in exact proportion to the rapidity of their action when first used.

545. As phosphate of lime is insoluble in pure water, and but slightly soluble in water containing carbonic acid, and as the most valuable component of bone is phosphate of lime, we should be led to expect that they would form a lasting manure, producing a beneficial effect so long as any of the phosphate of lime remains unabsorbed. As the quantity of this substance which plants are able to obtain from bone in one season is comparatively small, it has been proposed to mix with bones some substance which shall render the phosphate of lime more soluble.

546. The cheapest and most convenient substance for this purpose is sulphuric acid or oil of vitriol (140); this forms with bones a compound called "superphosphate of lime," one of the most valuable of the artificial manures yet proposed. Crushed bones, either burnt or not, the former, however, being preferable, are mixed in a leaden vessel with sulphuric acid; after a short time the acid is found to have completely decomposed the bones and reduced them to the state of a moist solid, which however may be easily rubbed to powder, and used in any way as manure, either alone or mixed with dry soil, or other manures.

547. The effect thus produced by the sulphuric acid is very simple; burnt bones consist of phosphate and carbonate of lime, the latter in a far smaller proportion than the former; when sulphuric acid is poured over burnt bones the carbonate of lime is wholly decomposed, being converted into gypsum or sulphate of lime (211); the phosphate of lime is partly decomposed, the sulphuric acid takes from it the greater part of the lime forming gypsum, whilst the rest of the lime being still combined with the phosphoric acid, constitutes a very sour and easily soluble salt, a biphosphate or superphosphate of lime.

548. As the most valuable part of this manure is soluble in water, it may easily be used as a liquid, being dissolved in water. Whether used dry or in solution it is most advantageous to use with it some manure containing ammonia, such as yard dung, guano, or any of the strong animal manures.

549. It is frequently the custom to mix a considerable quantity of earth or soil with putrefying animal manure. This to some extent is a good practice; the earth added prevents too rapid putrefaction, and retains some of the products of decomposition; a considerable quantity of ammonia, which would otherwise be lost, is absorbed by the soil (190). The addition of burnt clay or charcoal is useful for a similar reason.

550. The use of lime, on the other hand, is decidedly objectionable; it increases the rapidity of decomposition, and tends to the formation of a portion of nitric acid, but its use causes the loss of a large quantity of ammonia, in

consequence of its power of decomposing all the salts of ammonia (123), combining with the acid which they contain, and expelling the ammonia in the state of gas. The addition of lime greatly accelerates putrefaction, and renders it a far less noisome process, as the lime absorbs the sulphuretted hydrogen evolved (143), which would otherwise escape into the air.

551. Wood ashes mixed with putrefying animal matters act in a similar manner to lime ; the alkali which they generally contain accelerates decomposition, but occasions loss of ammonia.

552. A good deal of what has been said respecting animal manures is equally applicable to those of vegetable origin ; but in general the decay of vegetable manures is far less rapid than that of animal substances, and they are more valuable for their mechanical effects, and the carbonic acid and saline matters which they supply ; whilst, in addition to these, animal manures yield ammonia, the substance which is indispensable to the formation of gluten, albumen, fibrin and casein, the most important of the constituents of vegetables (371).

553. The use of decaying vegetable matters has already been described whilst speaking of the nature of humus, and the organic constituents of the soil (405). A moderate quantity is very desirable, but too much is decidedly hurtful. A soil containing a very large quantity of humus or decaying vegetable matter is always full of carbonic acid ; seeds do not germinate well in such a soil ; and the excess of carbonic acid is even hurtful to plants themselves.

554. The principal vegetable substances employed as manure are straw of all kinds, leaves, saw-dust, bran, oil-cake, sea-weed, and green manures, or crops which are merely sown to be ploughed in, and thus afford food to a second crop, of some more valuable plant.

555. All these manures when mixed with soil slowly decay, and yield carbonic acid and small quantities of saline and earthy matters. They are most advantageously used when employed in combination with some kind of animal manure; this is the case in farm-yard manure. Straw alone decays but slowly, but when mixed with the dung and urine of cattle it soon begins to change, and in a short time the whole is brought into a state of decomposition.

556. In this case a sort of putrid fermentation is caused; the animal manure decomposes rapidly, and causes a similar change to take place in the vegetable substances with which it is mixed (493); decomposition proceeds rapidly, heat is evolved, and if the bulk of the mixture is large, this action becomes so energetic that the value of the manure is seriously injured by the high temperature to which it is thus exposed.

557. The decay of vegetable manures may also be facilitated by the addition of lime; for the objection which applies to the mixture of lime with animal manures is not applicable to the ordinary vegetable manures. The latter for the most part contain but little nitrogen, their value principally depending on their mechanical action, and on the formation of carbonic acid.

558. Vegetable manures decay more or less rapidly in proportion to the quantity of nitrogen which they contain ; green manures contain a notable quantity of gluten and albumen, and accordingly decompose rapidly, whilst sawdust, which consists principally of woody fibre, and contains hardly any nitrogen, decomposes slowly. Sawdust is therefore a most excellent substance to mix with the excrement of animals, and other strong animal manures.

559. Wood sawdust is valuable as manure in proportion to the facility with which it decomposes, and the inorganic matters which it contains ; that obtained from young trees decomposes with more facility than the sawdust of old wood. The wood of those trees which contain much resin decays less rapidly than other woods, and is therefore not so valuable as a constituent of mixed manures (528). Those woods which when burnt yield a large quantity of ashes rich in alkaline salts (157), are useful additions in the state of sawdust to manures rich in ammonia.

560. There are a few manures of vegetable origin, which contain a considerable quantity of nitrogen, and which consequently approach very near in nature to those formed of animal substances : such, for example, is yeast or barm ; this consists of matter rich in nitrogen in a state of incipient putrefaction (313), and is a very strong manure. so also is oilcake, the residue left after expressing the oil from seeds like linseed, which are rich in oil ; it contains much gluten and albumen, and is for that reason a strong and valuable manure.

561. Green manures, as they are called, always contain enough nitrogen to insure their own decomposition, though it goes on far slower than does that of animal manures; the value of green manure is shown, in the ploughing up of an old pasture; and even more strongly in the case of those crops which are sown, merely to be ploughed in, when they have formed a considerable quantity of organic matter.

562. Some plants decompose with far more readiness than others; for the most part, water plants, both sea and land, decay less easily than land plants; they notwithstanding are useful manures. Seaweed employed alone, decays but slowly; it is however valuable for its mechanical effects, and likewise for the alkali which it contains; it may be used with great advantage together with strong animal manures (528).

563. Green manures, which contain but little nitrogen, may also be used very advantageously together with urine and similar animal substances, which soon bring them into a state of decomposition. In using weeds, &c. for this purpose any seeds which they may contain are nearly sure to be destroyed, which might otherwise render the soil very foul. A similar effect is also produced by steeping these matters in the ammoniacal liquor of the gas-works (183, 593); the whole of the vegetable matter is soon reduced to a pasty decomposing mass, which is a very good manure.

564. The dry and less changeable kinds of vegetable matter are chiefly valuable for their mechanical effects,

the influence which they exert upon evaporation, and the inorganic matters which they contain ; they likewise may, however, be brought into a state of decomposition by the addition of animal matters (528).

565. The number of inorganic substances employed as manures is very great, and their use is naturally much dependent on the nature of the soil. In many cases great benefit is derived from mixing soils ; either mixing a portion of the subsoil with the surface-soil (383), or by adding to the soil, earth brought from a distance, and possessing a different nature and composition.

566. The earthy matters thus added to the soil can hardly be called manures, although in truth they considerably resemble manures in the mode in which they act. By draining, deep ploughing, mixing, and by the use of mineral manures, either the mechanical texture of the soil is improved, or substances are added to it in which it was previously deficient.

567. It is almost unnecessary to say anything respecting the importance of draining, and the change which it produces in too retentive soils, and in soils which from their position are naturally wet and swampy. The facts which have previously been stated, show that too much moisture in a soil is hurtful, preventing the free circulation of air throughout it, and in several ways interfering with the healthy growth of plants ; this is remedied by draining.

568. By draining, and subsoil ploughing, the access of air is facilitated, and the decomposition of silicates and

similar stony compounds in the earth is assisted. In mixing, or by adding mineral manures, we increase the quantity of certain inorganic components of the soil.

569. Amongst the modes of fertilizing the soil and augmenting the growth of crops, the subject of irrigation must not be omitted. The effects produced by flooding grass land are well known; they depend on several distinct causes. Very dry parched land is of course improved by irrigation, when from the heat of the climate the greater part of the natural moisture of the soil is evaporated; under such circumstances, the artificial application of water is necessary for the successful cultivation of plants, and accordingly it is a constant part of the agriculture of tropical countries, in the cultivation of rice and similar crops.

570. Water is of service in temperate climates as a solvent of saline matters, as assisting the decay of organic matters in consequence of the air which it holds in solution, as bringing saline substances which are useful to plants, and as affording a supply of organic matter capable of affording ammonia, nitric acid, &c., by its subsequent decomposition.

571. In flooding land, the saline substances contained throughout the soil, and formed by the decomposing agency of the atmosphere (392), are dissolved, and consequently brought into a condition fit for absorption by growing plants; but quite independent of this, almost all water contains a considerable quantity of inorganic matter (59), which in many cases is a valuable addition to the

soil. In those cases where drainage water is allowed to mix with that employed for irrigation, of course the organic matters and saline substances which the former contains, produce their effect in addition to that of the latter. The benefit is produced almost entirely by the liquid, and the substances which it holds in solution ; the fine mud which it leaves on the surface of the ground is of comparatively but little value.

572. Road-drift and the scrapings of ditches, are often used as manures with very beneficial results ; their value of course depends in great part on their composition, and the nature of the soil to which they are applied ; the scrapings from roads made of stone such as whinstone, are far more valuable than those made of silicious grit or sandstone. This difference depends entirely on the alkaline matters, &c. which the former contains ; but besides this, road scrapings are often rich in animal matters, derived from the dung and urine of cattle. Road-drift is seldom used alone, but forms an excellent addition to more concentrated manures, such as alkaline salts, guano, super-phosphate of lime, &c.

573. The fine mud deposited in stagnant waters, and on the banks of many rivers, is of value as manure, though by no means so valuable a substance as is frequently supposed ; its composition varies considerably, and sometimes, particularly in the vicinity of large towns, it contains a considerable quantity of animal matter, phosphoric acid and ammonia ; but, generally speaking, the most valuable part of the manure is carried away by the water (541). Even

in those cases when it is rich in animal matters, its weight and the heavy expense of carrying it to any distance, very seriously interfere with its use.

574. The mode in which many inorganic matters act is very imperfectly understood, and must of necessity remain so until the office performed by saline and earthy substances in the nutrition of plants is explained. It is, however, certain that the addition of an earthy substance to the soil is of no use, if the soil already contains abundance of that particular compound; and consequently that the applicability of any such manure is wholly dependent on the nature and composition of the soil.

575. When reading accounts of experiments with various inorganic manures, it must always be borne in mind that on one soil salts of potash, on another nitrate of soda, and on a third phosphate of lime, may be the best manure, because the soils may happen to be deficient in those substances.

576. Plants almost invariably contain salts of the alkalies, and lime, or magnesia; sometimes combined with organic acids, sometimes with sulphuric, muriatic, or phosphoric acid. Phosphates of lime and magnesia, in particular, are very commonly met with in plants. It will be proper to enumerate briefly the artificial sources of these inorganic substances, and to consider the best method of supplying them to the soil.

577. Lime is a very common ingredient in plants, and is also found in almost all fertile soils; the addition of lime or calcareous matter, therefore, to soils which are

destitute of it, or contain but very little, invariably improves them. Lime is added to the soil pure, in the form of quick and slaked lime, as a carbonate in the various forms of chalk, limestone, marl, shell-sand, as a sulphate in gypsum and plaster-stone, and as a phosphate in bones and the various organic manures already referred to.

578. When quick lime is spread over the surface of land, other effects are produced besides the mere addition of carbonate of lime. The quick lime soon absorbs moisture, and crumbles to powder, it then gradually absorbs carbonic acid from the air, and returns to the state of carbonate (201). The chalk which is thus formed is in a state of very fine powder, and becomes more thoroughly mixed with the soil than it could be by ordinary means; but at the same time the quick lime has greatly assisted in promoting the decomposition of inorganic and organic matters in the soil, and caused the formation of a considerable quantity of nitrate of lime, a salt of some value as a manure.

579. Caustic lime possesses the power of gradually effecting the decomposition of earthy and alkaline silicates in the soil, combining with alumina and silica, and setting free the potash which they contain; consequently one of the most important of the chemical effects produced by the action of lime upon the soil, is that of rendering useful a portion of the potash which it previously contained in an insoluble, and therefore useless state.

580. There is great difference in the value of different

kinds of lime for this purpose. All limestones which consist merely of carbonate of lime yield pure caustic lime when burnt (90), but many limestones contain a portion of carbonate of magnesia, and these when burnt yield a mixture of caustic lime and magnesia. Such lime is in general objectionable as manure. It is probable that the tendency which magnesia has to remain caustic for a long time, absorbing carbonic acid but slowly from the air, is the cause of this (214). Limestones which contain much alumina and oxide of iron do not burn into good lime because the lime and clay partly unite and form a kind of slag.

581. Chalk, shell-sand, and indeed shells themselves, which consist of carbonate of lime and a small quantity of animal matter, are useful additions to all soils which contain but little lime. Quick or caustic lime is especially useful in soils rich in humus. Soils of this kind generally contain a small quantity of acid, which greatly interferes with their fertility; this acid is neutralized by the addition of lime. Both lime and likewise its carbonate are valuable additions to soils containing sulphate of iron (258, 402). That salt, which appears to be hurtful to vegetation, is decomposed by lime; gypsum is formed, whilst the iron is converted into oxide or carbonate.

582. Sulphate of lime, or gypsum, is likewise a very useful addition to all soils which do not naturally contain it. It is partly useful as supplying lime and sulphuric acid, and partly as serving to fix ammonia from the air (520), and thus yielding plants more of that substance than they could otherwise obtain. Gypsum is sometimes

employed after being burnt, and sometimes unburnt; the only use of the burning is that it renders it very easily crushed, the gypsum in fact falling to powder when burnt. This operation is rather roasting than burning, because, if too strongly heated, it loses its property of again absorbing water.

583. Phosphate of lime is found native as a mineral in Spain and other countries; it would certainly form a valuable manure for poor soils. As phosphate of lime is found in nearly all plants, all substances containing it are useful as manures (545). The native phosphate of lime has as yet hardly come into use at all as a manure, in consequence of the expense of collecting and carrying it to any distance. Phosphate of lime exists abundantly in bones (364), and in smaller quantity in all organic manures, and in the ashes of plants. A minute quantity of phosphate of lime is found in many rocks, and in particular kinds of chalk and marl, which are consequently valuable additions to the soil.

584. There are no mineral manures which contain phosphate of magnesia; it exists in many soils, and in a good many organic manures. Bran contains a considerable quantity of this salt. Magnesia, in its pure and caustic state, appears to be hurtful to plants, but some of its salts are useful; thus, sulphate of magnesia, or Epsom salts, has been found a valuable manure for potatoes, &c.

585. Ashes of all kinds constitute an important class of manures. They are of value for the charcoal,

lime, phosphoric acid, and alkaline salts which they contain. The ashes of organic substances, such as the ashes of wood and vegetable matters, consist principally of those substances which plants require. Kelp, or the ashes of sea-weed, consists of similar saline compounds, generally containing more alkaline salts than the common ashes of land plants. Soap-maker's ash, which consists of the insoluble part of wood ash, contains a considerable quantity of phosphate of lime, and is consequently a valuable manure (597).

586. The ashes of turf, peat, and weeds consist of pretty nearly the same substances as the ashes of trees and other plants: they therefore constitute valuable manures. The good effects which have been produced by paring and burning, are in great part due to the charcoal and saline matters which are spread over the soil, in the form of ashes. The earth which adheres to the roots and plants burnt in this process acquires considerable power of condensing ammonia from the air (190).

587. Burnt clay, or clay which has been strongly heated, has its mechanical properties also greatly altered, and acquires the property of absorbing ammonia in large quantity. When dry burnt clay, which has been exposed to the air for some time, is moistened or breathed upon, it gives out a very perceptible smell of ammonia.

588. The ashes of coal are of less value as manure than most other ashes; they do not contain alkali or phosphoric acid, but consist of silica, alumina, oxide of iron, and a small quantity of sulphate of lime. Their

chief value appears to consist in the charcoal and sulphate of lime which they contain.

589. Although charcoal has been spoken of as undergoing no change whatever under ordinary circumstances (69), and as having no tendency to oxidise or form carbonic acid when exposed to the air, yet in some conditions when exposed to moisture, warmth, and air, the more porous kinds of charcoal do slowly and gradually form carbonic acid; and this action appears to go on more rapidly, when charcoal is mixed with humus (410) and other decaying organic matters.

590. Waste charcoal of all kinds is useful as manure, particularly in close and retentive soils; hence it is often the custom to burn or char sawdust, brushwood, and dry vegetable rubbish: a mixture of ashes and charcoal is thus obtained, which is more valuable than that which is left when such matters are entirely burnt to ashes. For various purposes in the arts, such as the manufacture of gunpowder, that charcoal is best which contains the least quantity of inorganic matter, but for manure it is just the reverse.

591. In connexion with ashes, soot and the refuse of gas-works may be mentioned, although very different in their nature. Soot consists principally of finely-divided charcoal or carbon, but it contains a considerable quantity of salts of ammonia; hence it is a powerful and valuable manure. If a little quicklime is mixed with soot, the salts of ammonia will be decomposed, and the strong pungent smell of ammonia becomes evident.

For this reason, lime and soot should not be used together as manure: the objection of course does not apply to the use of chalk and soot.

592. Soot contains a good deal of the ammonia obtained during the combustion of coal, but, in consequence of its volatility, a considerable portion is lost. In the process for making gas, where coal is roasted in close iron vessels, all the ammonia is saved, and is condensed by means of cold water. The gas is made to bubble through a quantity of water: this condenses the ammonia, and constitutes what is termed gas liquor, or the ammoniacal liquor of the gas-works. It is a solution of ammonia, partly caustic, and partly combined with carbonic acid and sulphuretted hydrogen (144).

593. Ammoniacal liquor is a strong and excellent manure, resembling in some respects the manures formed by the decay of animal substances. As obtained from the gas-works it is almost always too strong to be used as a manure for grass-lands or crops, and must be diluted with four or six times its bulk of water. Gas liquor may also be conveniently used, mixed with green vegetable manures, the decomposition of which it greatly facilitates (563).

594. In consequence of the volatility and caustic nature of free ammonia, it is found advisable for most purposes to fix the ammonia of gas liquor. This may either be done with an acid, or with gypsum, or sulphate of iron (518, 520): a cheap acid like the sulphuric is, generally speaking, the most convenient. Gas liquor

resembles putrid urine, inasmuch as it is very rich in ammonia ; but it differs from it in not containing the fixed alkaline and earthy salts which that manure does.

595. As the strength of gas liquor mainly depends on the salts of ammonia which it contains, and as the relative quantity of these salts varies considerably, it is difficult to state the exact quantity of any acid necessary to neutralise the ammonia ; the average quantity of strong sulphuric acid requisite for this purpose is from 20 to 25 lbs. for every 100 gallons of gas liquor ; a little excess of acid hardly ever does any harm, as it immediately becomes neutralised by lime, &c., in the soil.

596. Potash and soda, as has been several times stated, are very commonly found in plants, and consequently are important constituents of manure ; they both exist in most soils though present but in small quantity, and are generally combined with silica and other earthy substances ; these compounds are slowly and gradually decomposed by the carbonic acid of the air (392) ; their decomposition may be artificially assisted by the action of lime (579) ; the principal salts of the fixed alkalies used as manures are the carbonates, muriates, nitrates and sulphates.

597. The ashes of some plants contain a very large quantity of carbonate of potash : in fact the potash of commerce, the chief source of the alkali, is the ash of plants ; whilst kelp, the ash of sea plants, consists chiefly of carbonate of soda. Both potashes and kelp are good manures in moderate quantity, but their value depends as

much on the earthy phosphates which they contain, as on their alkaline salts.

598. Muriate of potash or chloride of potassium is sometimes used as a dressing for grass land. The petre salt of the nitre refiners contains a large quantity of this salt. It used formerly to be obtained in large quantities by the soap-boilers, who mixed salt with their potash soap; the salt was decomposed and a hard soda soap and chloride of potassium in solution were the results. The soapmakers' spent lees were considered a valuable manure for grass land, and were believed to destroy moss.

599. Muriate of soda or chloride of sodium (common salt), is frequently recommended as a valuable manure; and in many soils, particularly those containing little chlorine, it produces very marked effects, when applied in moderation. It is by many stated, that cattle thrive better on plants which have been manured with a small quantity of common salt, than on those not so manured. Common salt is not unfrequently added to dung with a view of facilitating its putrefaction; it is very improbable that any such effect should be produced by salt, which in fact is more likely to retard decomposition.

600. Common salt is sometimes recommended to be added to liquid manure for the purpose of fixing ammonia, because by particular processes, and by employing very strong solutions, carbonate of ammonia and common salt may be made mutually to decompose each other; under all ordinary circumstances, however, the two salts have no action on each other, and it is quite useless

to add common salt to animal manures as a fixer for ammonia.

601. Salt is of course of no use as a manure on land near the sea-coast, or exposed to winds loaded with the salt of sea spray. On other land it is frequently employed, either alone, or mixed with earth and lime; when used in the latter manner it is common to make a compost, by mixing salt, earth and lime, some time before it is required, and allowing the mixture to remain some time, sheltered from the rain, the whole being occasionally turned: such a mixture contains a portion of carbonate of soda.

602. When solutions of chloride of calcium (207) and carbonate of soda are mixed together they are both decomposed, chloride of sodium (common salt) and carbonate of lime (chalk) being produced. From this fact it is evident that under ordinary circumstances chalk and common salt cannot decompose each other; nevertheless, when chalk or lime is mixed with salt and moist earth a considerable quantity of carbonate of soda and muriate of lime are produced, an effect which does not take place if a mixture of the two salts is thrown into a quantity of water.

603. A mixture or compost of lime and salt is a good manure: it contains carbonate of soda and chloride of calcium, both of which are useful to plants. It is possible that salt when applied to land is always more or less decomposed in this manner, and that according to the extent to which this takes place, salt produces a more or less beneficial effect.

604. Common salt is a necessary addition to the soil in the cultivation of marine plants, or such as naturally grow near the sea shore. It is also frequently used to kill insects. For all these purposes the most impure salt may be used : the impurities for the most part rather increase the value of the substance as manure (218).

605. Nitrate of potash has long been used as a manure, being found to produce beneficial effects on most soils, in quantities from one to three hundred weight per acre. The exact nature of the chemical effect produced by alkaline nitrates on plants is not accurately known ; but as both nitric acid and fixed alkali are separately valuable as manure, or at least are found to assist vegetation, we might reasonably expect that the nitrates should be good manures ; it must always be remembered, however, that though they contain both nitrogen and alkali, they cannot well be used alone on ordinary soils, and are best employed in conjunction with some other substance containing phosphoric acid.

606. A great many rich and fertile soils are found to contain a small quantity of nitrate of potash, soda, or lime, which appears to produce nearly the same effect as the salts of ammonia, rendering vegetation vigorous and dark-coloured. The way in which these salts are formed will be easily understood when we remember, that whenever substances containing nitrogen decay in the neighbourhood of lime or alkaline salts, a portion of nitric acid is formed (127, 550). Under these circumstances, the ammonia which would otherwise be produced, is oxi-

dised, and nitric acid and water are formed in place of ammonia; the acid combines with the alkali, and nitrate of potash or soda results. These salts are frequently found in mixtures of decomposing organic manures; they are formed in the same way in the soil itself.

607. The effects produced on different plants by alkaline nitrates are very various, some being far more beneficial than others. Some plants, such as the sunflower, tobacco, lettuce, and many others, always contain more or less of these salts. Others do not contain them, but when supplied with nitrates, are subsequently found to contain the base, without the acid. The soda, potash, or lime, is combined with some organic acid, whilst the nitric acid has disappeared. It is probable that in these cases the nitrogen of the acid is assimilated by the plant, or that it assists in the formation of gluten and albumen.

608. Nitrates can have but very little value as manures on the soils which naturally contain salts of nitric acid, or which, in consequence of the substances they contain, are constantly forming nitrates. On soils neither containing nitrates nor other alkaline salts, they appear to produce very beneficial results. It has been found that wheat manured with alkaline nitrates contains more gluten and albumen than that grown in land not so manured.

609. These remarks apply equally to nitrate of soda and nitrate of potash; at least similar effects are produced by the two salts, as far as regards the increased formation

of gluten and albumen. Nitrate of soda contains weight for weight more nitrogen than does the nitrate of potash. It is not known in how far soda is able to replace potash, or whether it is indifferent which of the two alkalies is supplied to plants.

610. Silicates of potash and soda have also been proposed and partially employed as manures. These salts are easily made by melting together sand and carbonate of potash or soda (228); it was supposed that they would be particularly valuable for corn and grass crops, as these plants contain a considerable quantity of silica, but the result of trials hitherto made with these compounds, has been such as to render it probable that the silica which they contained produced much less effect than the alkali.

CHAPTER VIII.

COMPOSITION OF PARTICULAR CROPS AND MANURES.

611. Plants differ considerably from each other in chemical composition ; not only do various plants consist of different proportions of the proximate elements which compose them, but also the same plant is found to contain variable proportions of these substances, depending on the peculiarities of soil, situation, mode of cultivation, manure, and the weather, or season when they were grown. In the following pages a brief account is given of the average mean composition of some of the principal crops.

612. The first point to be ascertained is the relative proportion of water, organic matter and inorganic matter in different plants ; this is done by very carefully drying a weighed portion : the loss which it sustains indicates the quantity of water ; the dry matter is then burnt, the weight of the ashes, shows the proportion of inorganic matter. The chemical composition of the organic matter, as well as the inorganic constituents, requires a separate analysis.

613. The average composition of Wheat, grain and straw, is—

	GRAIN.	STRAW.
Organic matter	835	688
Inorganic matter . . .	20	52
Water	145	260
	1000	1000

According to Boussingault the ultimate composition is—

	GRAIN.	STRAW.
Carbon	461	448
Oxygen	434	389
Hydrogen	58	53
Nitrogen	23	4
Inorganic matter . . .	24	70
	1000	1000

614. The proportion of bran and flour obtained from wheat varies very considerably, namely from about 18 to 40 per cent.; in practice, however, the bran always contains a considerable quantity of starch, soluble matters, &c.; in the following analyses the term bran is used to denote the insoluble fibrous husk alone.

	Hermbstädt.		Vauquelin.	
WHEAT.	NO MANURE.	MANURE, URINE.	FRENCH W.	ODESSA W.
Starch . . .	666	399	715	565
Gluten . .	96	351	110	145
Albumen . .	7	14		
Sugar	19	14	47	85
Gum	18	16	33	49
Fixed oil . . .	10	10	—	—
Soluble phosphates	3	9	—	—
Bran	140	142	—	23
Water . . .	42	42	100	120
	1000	1000	1000	1000

615. The inorganic substances contained in wheat

(613) are also found to vary greatly in composition and proportion from different sorts of wheat. According to the experiments of Sprengel, 100,000 parts of dry wheat contain 1177 parts of inorganic matter ; the same quantity of wheat straw contains 3518 parts of earthy matters. These consist of the following substances :—

	GRAIN.	STRAW.
Potash	225	20
Soda	240	29
Lime	96	240
Magnesia	690	32
Alumina	26	90
Silica	400	2870
Sulphuric acid	50	37
Phosphoric acid	40	170
Chlorine	10	30
	1777	3518

616. With these data it is easy to calculate roughly the amount of the various substances abstracted from a soil by a crop of wheat. A crop yielding 5 qrs. per acre would consist of about 23 cwt. of grain, 4 tons of straw, and 30 cwt. of stubble and roots, the latter of course remaining in the soil, and would according to the above analyses remove in the grain 86 lbs. of alkali and 10 lbs. of phosphoric acid, whilst the straw would contain 44 lbs. of alkali and 92 lbs. of phosphoric acid.

617. The composition of Barley is about—

	GRAIN.
Organic matter	825
Inorganic matter	25
Water	150
	1000

The proportion of the proximate elements of barley, according to the experiments of Hermbstädt, is—

BARLEY.	NO MANURE.	MANURE, URINE.
Starch	625	596
Gluten	29	59
Albumen	1	5
Sugar	50	44
Gum	47	44
Fixed oil	1	4
Soluble phosphates	1	7
Husk	136	136
Water	108	103
	1000	1000

618. In the process of malting barley (428) a large quantity of starch which the grain naturally contains, is converted into sugar and gum. The following analyses by Prout show the relative proportions of these substances which he found in the raw, and in the malted grain. By Hordein is meant a peculiar kind of starch which exists together with common starch in barley. Hordein is insoluble in hot water, whilst common starch is readily soluble (288).

	BARLEY.	MALT.
Starch	320	560
Hordein	550	120
Gluten	30	10
Sugar	50	150
Gum	40	150
Resin	10	10
	1000	1000

619. According to the experiments of Sprengel 100,000

parts of dry Barley contain 2349, and 100,000 parts of straw 5242 parts of inorganic matter, consisting of—

	GRAIN.	STRAW.
Potash	278	180
Soda	290	48
Lime	106	554
Magnesia	180	76
Oxide of iron	trace	14
Oxide of manganese	—	20
Alumina	25	146
Silica	1182	3856
Sulphuric acid	59	118
Phosphoric acid	210	160
Chlorine	19	70
	2349	5242

620. Oats consist on the average of—

Organic matter	872
Inorganic matter	28
Water	100
	1000

According to Boussingault the grain of oats is composed of

Carbon	503
Oxygen	371
Hydrogen	63
Nitrogen	22
Inorganic matter	40
	1000

621. The proportion of the proximate elements of oats are (Hermbstädt)—

	NO MANURE.	MANURE, URINE.
Starch	600	531
Gluten	19	44
Albumen	2	5

	NO MANURE.	MANURE, URINE.
Sugar	64	50
Gum	70	57
Fixed oil	3	4
Soluble phosphates	1	6
Husk	120	170
Water	108	130

622. According to Sprengel 100,000 parts of dry Oats contain 2580, and 100,000 parts of straw 5740 parts of inorganic matter, consisting of—

	GRAIN.	STRAW.
Potash	150	870
Soda	132	2
Lime	86	152
Magnesia	67	22
Alumina	14	6
Oxide of iron	40	2
Oxide of manganese	—	2
Silica	1976	4588
Sulphuric acid	35	79
Phosphoric acid	70	12
Chlorine	10	5
	2580	5740

623. Rye consists on the average of—

Organic matter	889
Inorganic matter	11
Water	100
	1000

According to Boussingault, the grain of rye consists of—

Carbon	463
Oxygen	442
Hydrogen	53
Nitrogen	16
Inorganic matter	23
	1000

624. The proportion of the proximate elements of rye is (Hermbstädt)—

	NO MANURE.	MANURE, URINE.
Starch	563	502
Gluten	86	120
Albumen	26	35
Sugar	47	33
Gum	54	46
Fixed oil	9	11
Soluble phosphates	13	42
Husk	101	108
Water	100	101
	1000	1000

625. According to the experiments of Sprengel, 100,000 parts of the grain of rye contain 1040, and 100,000 parts of the straw contain 2793 parts of inorganic matter, consisting of—

	GRAIN.	STRAW.
Potash	532	32
Soda		11
Lime	122	178
Magnesia	44	12
Alumina	24	25
Oxide of iron	42	
Oxide of manganese	34	—
Silica	164	2297
Sulphuric acid	23	170
Phosphoric acid	46	51
Chlorine	9	17
	1040	2793

626. The grain of Maize or Indian corn consists of about—

Organic matter	857
Inorganic matter	13
Water	130
	1000

According to the experiments of Payen, dry maize contains—

Starch	712
Gluten Albumen	123
Fixed oil	90
Gum	4
Woody matter	59
Inorganic matter	12
	1000

627. Sprengel found in 100,000 parts of maize grain 1312 parts of inorganic matter, and in 100,000 parts of maize straw 3985 parts of inorganic matter, consisting of—

	GRAIN.	STRAW.
Potash	200	189
Soda	250	4
Lime	35	652
Magnesia	128	236
Alumina	16	6
Oxide of iron	traces	4
Oxide of manganese	—	20
Silica	434	2708
Sulphuric acid	17	106
Phosphoric acid	224	54
Chlorine	8	6
	1312	3985

628. The grain of Rice consists of about—

Organic matter	856
Inorganic matter	4
Water	140
	1000

According to the analysis of Braconot, rice contains—

	CAROLINA.	PIEDMONT.
Starch	851	838
Gluten Albumen	36	36
Sugar	3	0½
Gum	—	—
Fixed oil	1$\frac{3}{10}$	2½
Earthy phosphates	4	4
Husk	48	48
Water	50	70
	1000	1000

The more recent experiments of Payen and Boussingault, however, indicate a larger proportion of albumen and gluten as existing in rice; these chemists found 75 in place of 30 of those substances.

629. The dry grain of Buckwheat consists of, according to Zenneck—

Starch	523
Gluten	107
Sugar and gum	83
Fixed oil	4
Husk	269
Inorganic matter	14
	1000

630. From the experiments of Sprengel, it appears

that 100,000 parts of the seed of buckwheat contain 1354 parts of inorganic matter; 100,000 parts of the dry straw contain 3203 parts, consisting of—

	SEED.	STRAW.
Potash	204	332
Soda	330	62
Lime	156	704
Magnesia	183	1292
Alumina	26	26
Oxide of iron	8	15
Oxide of manganese	44	32
Silica	144	140
Chlorine	15	95
Sulphuric acid	47	217
Phosphoric acid	170	288
	1354	3203

631. The proportion of starch, &c., in seeds which contain much Oil, is, of course, considerably less than in the grains hitherto described. The following is an analysis of Linseed by L. Meyer :—

Starch	15
Gluten	29
Albumen	28
Azotised matter	151
Gum	61
Sugar, &c.	109
Colouring matter	25
Resin	25
Wax	1
Fixed oil	113
Husk	443
	1000

632. In this analysis the quantity of oil is considerably

below the usual average (634). The large quantity of azotised matter which exists in linseed explains the value of oil-cake, both in fattening cattle and as a manure (560). From the experiments of Sprengel, it appears that 100,000 parts of linseed contain 2340 parts of inorganic matter, and 100,000 parts of the stem contain 1456 parts of inorganic matter, consisting of:—

	SEED.	STALKS.
Potash Soda	438	510
Lime	630	230
Magnesia	234	480
Alumina	2	2
Oxide of iron	trace	10
Oxide of manganese	—	—
Silica	120	20
Chlorine	12	20
Sulphuric acid	24	66
Phosphoric acid	880	118
	2340	1456

633. Hemp-seed contains, according to Bucholz—

Albumen	247
Gum	90
Sugar	16
Resin	16
Woody fibre	50
Fixed oil	191
Husk	383
Loss in analysis	7
	1000

634. The proportion of oil yielded by different seeds varies greatly with the year, climate, soil, &c.; the

following table shows the average proportion of oil obtained from 100 parts of some of the most important oil seeds:—

Linseed	22	Almond	30 to 40
Poppy	47 to 50	Beech nut	15 to 17
Walnut	40 to 70	Colza	39
Hemp	25	Rocket	18
Rape	33	White mustard	36
Castor	50 to 60	Black ditto	18
Grape seed	11	Earth nut	45
Sunflower	15	Gold of Pleasure	27

635. Common field Beans, according to an analysis by Einhof, consist of (299)—

Starch	501
Albumen and legumine	117
Sugar Gum	82
Husk	100
Water	156
Salts and loss	44
	1000

636. Kidney beans were found by Braconot to consist of—

Starch	430
Legumine	182
Albumen	54
Sugar	2
Gum	15
Fixed oil	7
Husk	70
Water	230
Salts and loss	10
	1000

637. According to the experiments of Sprengel, 100,000 parts of common beans contain 2136, and 100,000 parts of bean straw contain 3121 parts of inorganic matter, consisting of—

	SEED.	STRAW.
Potash	415	1656
Soda	816	50
Lime	165	624
Magnesia	158	209
Alumina	34	10
Oxide of iron	—	7
Oxide of manganese	—	5
Silica	126	220
Sulphuric acid	89	34
Phosphoric acid	292	226
Chlorine	41	80
	2136	3121

638. The composition of ripe Peas according to Braconot is—

Water	125
Husk	83
Albumen and legumine	264
Starch	436
Sugar	20
Gum	40
Fixed oil	12
Salts and loss	20
	1000

639. Peas consist of about 854 parts organic, 26 inorganic matter, and 120 parts water. According to Sprengel, 100,000 parts of peas contain 2464, and 100,000 parts of pea straw contain 4971 parts of inorganic matter, consisting of:—

	SEED.	STRAW.
Potash	810	235
Soda	739	—
Lime	58	2730
Magnesia	136	342
Alumina	20	60
Oxide of Iron	10	20
Oxide of Manganese	—	7
Silica	410	996
Sulphuric acid	53	337
Phosphoric acid	190	240
Chlorine	38	4
	2464	4971

640. Lentils, according to analyses of Einhof, consist of—

Starch	282
Albumen and legumine	331
Gum	51
Sugar	27
Husk	161
Water	140
Salts and loss	8
	1000

641. In the preceding analysis of lentils no mention is made of fixed oil; the following analysis, quoted by Boussingault, is therefore probably more correct:—

Starch	400
Legumine	220
Gum	70
Sugar	15
Fibrous matter	120
Fixed oil	25
Inorganic matter	25
Water and loss	125
	1000

642. According to Sprengel 100,000 parts of Lentils contain 1528, and 100,000 parts of Lentil straw contain 3899 parts of inorganic matter, consisting of :—

	SEED.	STRAW.
Potash	736	420
Soda	118	33
Lime	57	2040
Magnesia	85	119
Alumina	12	34
Oxide of iron	52	
Oxide of manganese	traces	traces
Silica	180	686
Sulphuric acid	94	38
Phosphoric acid	140	480
Chlorine	54	49
	1528	3899

643. Common Vetch, according to an incomplete (?) analysis, by Crome, is stated to contain :—

Starch	26
Albumen	19
Gum, &c.	76
Woody fibre	104
Water	775
	1000

644. According to Sprengel 100,000 parts of Vetch seed contain 5191, and 100,000 parts of Vetch straw contain 2290 parts of inorganic matter, consisting of :—

	GRAIN.	STRAW.
Potash	897	1810
Soda	622	52
Lime	160	1955
Magnesia	142	324
Alumina	22	15
Oxide of iron	9	9
Oxide of manganese	5	8
Silica	200	442
Sulphuric acid	50	122
Phosphoric acid	140	280
Chlorine	43	84
	2290	5191

645. A great number of different analyses of Potatoes have been published, as the varieties of the tuber are found to contain very different proportions of starch, azotised matter, &c. The ultimate composition of dry Potato is (Boussingault):—

Carbon	440
Oxygen	447
Hydrogen	58
Nitrogen	15
Inorganic matter	40
	1000

646. According to the experiments of Einhof and Lampadius the composition of Potatoes is :—

	RED.	KIDNEY.	SWEET.	PERUVIAN.	BREAD-FRUIT.
Starch	150	91	151	150	138
Albumen, &c.	14	8	8	19	20
Gum, &c.	41	—	—	19	28
Starchy fibre	70	88	82	52	69
Water	750	813	743	760	745
	1000	1000	1000	1000	1000

The composition of good Potatoes varies from about 10 to 25 starch, 3 to 8 fibre, 2 to 4 gum, 1 to 2 azotised matters (albumen &c.) and 70 to 80 parts of water per cent.

647. According to Sprengel 100,000 parts of dry Potato tuber contain 2653 parts; and 100,000 of Potato haulm, 4786 parts of inorganic matter, consisting of :—

	TUBERS.	HAULM.
Potash	1291	138
Soda	748	0 (?)
Lime	106	2928
Magnesia	104	488
Alumina	16	52
Oxide of iron	9	58
Oxide of manganese	trace	44
Silica	27	801
Sulphuric acid	174	245
Phosphoric acid	128	32
Chlorine	50	0 (?)
	2653	4786

648. The Batatas or sweet Potato of the West India Islands, contains, according to O. Henry :—

Starch	133
Albumen	9
Sugar	33
Cellular matter	68
Fixed oil	11
Malic acid, and salts	14
Water	732
	1000

649. The ultimate composition of the tubers and

stem of the Jerusalem Artichoke, according to Boussingault, is :—

	TUBER.	STEM.
Carbon	433	457
Oxygen	433	457
Hydrogen	58	54
Nitrogen	16	4
Inorganic matter	60	28
	1000	1000

650. The tubers, according to the analysis of Braconot, contain a peculiar variety of starch, to which the name of Inulin is given ; the tubers were found to contain :—

Starch (Inulin)	30
Albumen	10
Sugar, uncrystallizable	148
Gum	12
Fixed oil	1
Woody fibre	12
Inorganic matter	27
Water	770
	1000

651. The bulbs of the Oxalis crenata were found by Payen to contain :—

Starch	25
Albumen	15
Gum, &c.	55
Woody fibre	44
Water	861
	1000

652. Common Cabbage consists of about 62 parts of organic matter, 7 of inorganic matter, and 931 parts of water. According to Sprengel 100,000 parts of dry

Cabbage contain 7546 parts of inorganic matter, consisting of:—

Potash	2370
Soda	1154
Lime	1747
Magnesia	22
Alumine	17
Oxide of iron	8
Silica	210
Sulphuric acid	959
Phosphoric acid	785
Chlorine	274
	7546

653. The composition of Turnips and Swedes is very similar; they consist of the same proximate elements united in nearly the same proportions. The following table shows the composition of three varieties according to Hermbstädt:—

	SWEDE.	WHITE.	CABBAGE.
Starch and fibre	53	72	60
Albumen	20	25	25
Sugar	90	80	90
Gum	30	25	35
Inorganic matter	5	15	5
Water	800	790	780
Loss	2	3	5
	1000	1000	1000

654. Dry Turnip, according to Boussingault, consists of:

Carbon	429
Oxygen	423
Hydrogen	55
Nitrogen	17
Inorganic matter	76
	1000

655. According to the same chemist, 100,000 parts of dry Turnip contain 6226 parts of inorganic matter, consisting of :—

Potash	2610
Soda	317
Lime	844
Magnesia	333
Alumina and oxide of iron	93
Silica	496
Sulphuric acid	844
Phosphoric acid	465
Chlorine	224
	6226

656. Common Beet, and Mangel-wurzel also, are very similar in composition. The following table shows the composition of four varieties:—

	ORGANIC MATTER.	INORGANIC MATTER.	WATER.
Red mangel-wurzel	88	11	901
Castelnaudary beet	139	11	850
White sugar beet	120	11	869
Bassano beet	115	12	873

According to Boussingault Field Beet consists of :—

Carbon	428
Oxygen	434
Hydrogen	58
Nitrogen	17
Inorganic matter	63
	1000

657. According to the experiments of Sprengel, 100,000 parts of dry Beet-root contain 5986 parts of inorganic

matter, and 100,000 parts of the dry leaves contain 15,439 parts, consisting of:—

	ROOT.	LEAVES.
Potash	1481	5600
Soda	3178	3290
Lime	285	2316
Magnesia	139	839
Alumina	20	130
Oxide of iron	58	50
Oxide of manganese	50	60
Silica	105	425
Chlorine	380	1064
Sulphuric acid	123	975
Phosphoric acid	167	690
	5986	15,439

658. The Carrot, according to Hermbstädt and Einhof, contains:—

	EINHOF.	HERMBSTADT.
Starch	3	—
Fibre	46	90
Albumen	9	11
Gum	—	18
Sugar	81	78
Volatile oil	—	.4
Water	861	799
	1000	1000

659. According to Sprengel 100,000 parts of dry Carrot contain 5090 parts of inorganic matter. 100,000 parts of the leaves contain 10,420 parts, consisting of:—

	ROOT.	LEAVES.
Potash	2718	3236
Soda	709	921
Lime	505	5050
Magnesia	295	398
Alumina	30	78
Oxide of iron	25	15
Oxide of manganese	46	0
Silica	105	454
Chlorine	54	223
Sulphuric acid	208	1082
Phosphoric acid	395	963
	5090	10,420

660. The Parsnip consists of :—

Organic matter	195
Inorganic matter	12
Water	793
	1000

According to Crome it contains :—

Starch	18
Albumen	21
Gum	61
Sugar	55
Fibre	51
Volatile oil	trace
Water	794
	1000

661. From the experiments of Sprengel it appears that 100,000 parts of dry Parsnip roots contain 4643 parts of inorganic matter ; 100,000 parts of the dry leaves contain 15,661 parts, consisting of :—

	ROOT.	LEAVES.
Potash	2310	3207
Soda	780	2448
Lime	520	4160
Magnesia	300	473
Alumina	26	132
Oxide of iron	5	9
Oxide of manganese	—	—
Silica	180	1400
Chlorine	198	950
Sulphuric acid	213	1198
Phosphoric acid	111	1784
	4643	15,661

662. Clover, according to the analysis of Boussingault, consists of :—

Carbon	474
Oxygen	378
Hydrogen	50
Nitrogen	21
Inorganic matter	77
	1000

663. The composition of white and red Clover, as given by Crome, is :—

	WHITE.	RED.
Starch	10	14
Albumen	15	20
Gum	34	35
Sugar	15	21
Woody fibre	115	139
Wax and resin	2	1
Earthy matter	8	10
Water	800	760
	1000	1000

664. According to Sprengel, 100,000 parts of white Clover in the fresh state contain 1735 parts of inorganic matter, consisting of :—

Potash	590
Soda	110
Lime	446
Magnesia	58
Alumina	36
Oxide of iron	12
Oxide of manganese	—
Silica	280
Chlorine	40
Sulphuric acid	67
Phosphoric acid	96
	1735

665. The composition of Lucern, according to Crome, is :—

Starch	22
Albumen	19
Gum	44
Sugar	8
Woody fibre	143
Wax and resin	6
Earthy matter	8
Water	750
	1000

666. According to Sprengel, 100,000 parts of fresh Lucern contain 2580 parts of inorganic matter, consisting of :—

Potash	362
Soda	166
Lime	1304
Magnesia	94
Alumina	8
Oxide of iron	7
Oxide of manganese	—
Silica	90
Chlorine	86
Sulphuric acid	109
Phosphoric acid	353
	2580

667. According to Sprengel, 100,000 parts of fresh Saintfoin or Esparcette contain 1671 parts of inorganic matter, consisting of :—

Potash	494
Soda	105
Lime	527
Magnesia	69
Alumina	16
Oxide of iron	traces
Oxide of manganese	—
Silica	120
Chlorine	38
Sulphuric acid	82
Phosphoric acid	220
	1671

668. Hay. According to the experiments of Boussingault, 10,000 parts of good meadow Hay contain 547 parts of inorganic matter, consisting of :—

Potash	130
Soda	10
Lime	107
Magnesia	43
Oxide of iron	5
Silica	189
Sulphuric acid	16
Phosphoric acid	32
Chlorine	15
	547

669. As has been several times stated, the exact relative proportions of these different constituents of plants varies very considerably, depending on soil, climate, manure, &c. Thus, for example, mangel-wurzel root contains from 9 to 11 parts of inorganic matter in every thousand parts, or abstracting the water, from 87 to 150 parts in the dry root; hence it is easy to see that a crop of 25 tons may in truth take more inorganic matter out of the land than one of 30 tons; and that the mere weight of the crop is no proof of the extent to which it has exhausted the soil.

670. This effect is quite independent of the mere quantity of water in the crop, because the same result is shown when we ascertain the relation which exists between the inorganic matter and the dry organic matter which the plants contain; in different crops of mangel-wurzel it is found that the quantity of dry organic matter which is formed for every hundred parts of inorganic matter absorbed from the soil, varies from 568 to 1045.

671. It is consequently evident that, in order to raise the most profitable crops, we must endeavour to

obtain the largest possible quantity of useful vegetable matter, with the smallest relative proportion of inorganic matter. This is a subject of the greatest practical importance, and one well worthy of the attention of scientific agriculturists.

672. Having now briefly stated the average composition of some of the most important plants cultivated as crops, it may be useful to enter shortly into the composition of the most common substances employed as manure, in order more fully to show the relation which exists between plants and the manures employed in their cultivation. Of the simple animal manures the most important are dung, urine, and bones.

673. The dung of sheep (according to Zierl) consists of 291 parts dry organic matter, 30 parts inorganic matter, and 679 parts water. The earthy matters consist of about half silica, a quarter carbonate and phosphate of lime, and the remainder alkaline salts. The urine of the sheep consists of 28 parts organic matter, 12 parts inorganic matter, and 960 parts water, containing a portion of ammonia; because even in fresh urine a portion of the azotised matter which it contains is generally beginning to decompose and form ammonia.

674. Fresh cow dung (according to Boussingault) consists of 124 parts dry organic matter, 17 parts inorganic matter, and 859 parts water. The inorganic matter contains two-thirds of silica, nearly one-third of earthy phosphates, and a small quantity of alkaline salts. Cows' urine consists of 53 parts dry organic matter,

21 parts inorganic matter, and 926 parts water (Sprengel).

675. The composition of cows' urine, and the nature of the changes which it undergoes when suffered to putrefy, either alone or diluted with water, are shown in the following table (Sprengel):—

	FRESH.	PUTREFIED. ALONE.	PUTREFIED. WITH WATER.
Urea	4000	1000	600
Albumen	10	—	—
Mucus	190	40	30
Benzoic acid	90	250	120
Lactic acid	516	500	500
Carbonic acid	5256	16	1533
Ammonia	205	487	1622
Potash	664	664	664
Soda	554	554	554
Silica	36	5	8
Alumina	2	—	—
Oxide of iron	4	1	—
Oxide of manganese	1	—	—
Lime	65	2	8
Magnesia	36	22	30
Chlorine	272	272	272
Sulphuric acid	405	388	332
Phosphoric acid	70	26	46
Acetic acid, or vinegar	—	1	20
Sulphuretted hydrogen	—	1	30
Insoluble earthy phosphates and Carbonates	—	180	150
Water	92,624	95,442	93,481
	100,000	100,000	100,000

676. Fresh horse dung consists of 284 parts dry organic matter, 18 parts inorganic matter, and 698 parts

water. Of the inorganic matter about one-ninth is carbonate and phosphate of lime, one-twelfth alkaline salts, and the remainder silica (Zierl). Horses' urine consists of 27 parts dry organic matter, 33 parts inorganic matter, and 940 parts water.

677. Fresh pigs' dung, consisting of the excrement and urine together, contains 93 parts dry organic matter, 87 parts inorganic matter, and 820 parts water. Pigs' urine contains 56 parts dry organic matter, 18 parts inorganic matter, and 926 parts water (Sprengel). The inorganic matters consist chiefly of alkaline salts.

678. Human excrement (according to Berzelius) contains 227 parts dry organic matter, 100 parts of inorganic matter, and 733 parts water. Its constituents are :—

Albumen	8
Extractive	27
Mucus, fat, resin	140
Bile	9
Vegetable remains	70
Soluble salts	12
Water	733
	1000

679. The inorganic matter contained in 1000 parts consequently weighs 150, and contains 100 parts earthy phosphates, 12 parts carbonate of soda, 8 parts sulphate and phosphate of soda, and sulphate of potash.

680. Human urine (according to Berzelius) consists of 49 parts dry organic matter, 7 parts salts of ammonia, 11 parts inorganic matter, and 933 parts water. Its composition in detail is :—

Urea	3010
Mucus	32
Lactic acid, lactate of ammonia, animal matter insoluble in alcohol	1714
Chloride of sodium	445
Sulphate of potash	371
Sulphate of soda	316
Phosphate of soda	294
Phosphate of ammonia	165
Muriate of ammonia	150
Earthy phosphates	100
Uric acid	100
Silica	3
Water	93,300
	100,000

681. The composition of bones varies considerably in the proportion of the constituents, though all bones consist chiefly of phosphate and carbonate of lime, together with gelatine and a portion of fat. Sheep's bones consist of:—

Phosphate of lime	700
Carbonate of lime	50
Organic matter and water	250
	1000

682. The bones of oxen and cows (according to Berzelius) contain:—

Phosphate of lime	555
Phosphate of magnesia	29
Soda and chloride of sodium	34
Carbonate of lime	39
Fluoride of calcium	10
Organic matter	33
Water	300
	1000

683. The bones of horses contain a rather larger proportion of phosphate of lime. They consist of:—

Phosphate of lime	670
Soda and chloride of sodium	30
Organic matter and water	300
	1000

684. The bones of pigs contain 520 parts of phosphate of lime, 10 parts carbonate of lime, and 470 parts organic matter and water; those of calves, 540 phosphate of lime, and 460 animal matter and water. The bones of fishes, generally speaking, contain less earthy matter than those of land animals. The bones of the cod fish contain 480 phosphate of lime, 55 carbonate of lime, 20 phosphate of magnesia, 6 salts of soda, and 440 organic matter and water.

685. The composition of farm-yard dung, and all mixtures of animal and vegetable manures, is very variable. The following analysis of Boussingault may be considered as expressing very nearly the average composition of good yard dung:—

	FRESH.	DRY.
Carbon	74	358
Hydrogen	9	42
Oxygen	53	258
Nitrogen	4	20
Inorganic matter	67	322
Water	793	—
	1000	1000

686. The composition of the inorganic part of such manure, like that of the organic, varies considerably.

The following shows the composition of 10,000 parts of the inorganic matter in yard dung (Richardson) :—

Potash	322
Soda	273
Lime	34
Magnesia	26
Sulphuric acid	327
Chlorine	315
Soluble silica	2705
Phosphate of lime	711
Phosphate of magnesia	226
Phosphate of iron	468
Phosphate of manganese	trace
Phosphate of alumina (?)	trace
Carbonate of lime	934
Carbonate of magnesia	163
Sand	3099
Alkali and loss	397
	10,000

687. The putrified dung of birds has of late years been much employed as manure, under the name of guano. The composition of this substance varies greatly, according to the extent to which decomposition has proceeded, and the degree to which it has been exposed to the atmosphere. The following table shows three different analyses of guano :—

	BERTELS.	OELLACHER.	URE.
Urate of ammonia	32	122	147
Oxalate of ammonia	134	177	32
Oxalate of lime	164	13	10
Phosphate of ammonia	64	60	143
Phosphate of ammonia and magnesia	42	116	45
Phosphate of lime	100	202	220
Muriate of ammonia	65	22	30
Chloride of sodium	1	4	—
Carbonate of ammonia	—	8	10
Carbonate of lime	—	16	—
Sulphate of potash	42	40	60
Sulphate of soda	11	49	—
Sulphate of ammonia	—	—	20
Phosphate of soda	53	—	—
Humate of ammonia	—	11	—
Wax and resin	6	7	—
Sand. Insoluble residue	58	17	12
Alumina	1	—	—
Water	227	43	85
Organic matter		83	185
	1000	1000	1000

688. The value of guano as manure depends on the ammonia which it contains, or the presence of matter capable of forming ammonia by its slow putrefaction, and on the presence of phosphoric acid. No manure is more subject to fraudulent adulteration than guano. One of the most common modes of doing this is by

the addition of earth or brickdust. The presence of these substances may be roughly ascertained in guano by burning a portion. The ashes left by pure guano are white, or nearly so; while, if soil or brickdust has been added, the oxide of iron, which they always contain, will give the ashes more or less a red-brown colour.

689. The composition of wood ashes varies very considerably, according to the wood from which it is obtained. The composition of three kinds of wood-ash, as given by Sprengel, is:—

	OAK.	BEECH.	SCOTCH FIR.
Potash	162	221	22
Soda	67	33	22
Lime	174	250	232
Magnesia	14	50	50
Alumina	81	23	170
Oxide of iron		38	
Oxide of manganese		38	
Silica	269	55	66
Chlorine	24	19	23
Sulphuric acid	34	77	22
Phosphoric acid	19	56	28
Carbonic acid	155	140	365
	1000	1000	1000

690. In the process for making potash or pearlash (157), the greater part of the soluble salts contained in the wood-ashes is washed out; the remainder is a valuable manure, and often contains a considerable quantity of phosphoric acid. The refuse ash from soap factories consists of the same matters. The following table exhibits the composition of three kinds of "lixiviated ashes," according to Berthier:—

	OAK.	BEECH.	SCOTCH FIR.
Lime	548	426	423
Magnesia	6	70	105
Oxide of iron	—	15	1
Oxide of manganese	—	45	4
Silica	38	58	46
Phosphoric acid	8	57	10
Carbonic acid	396	329	360
Charcoal	—	—	48
	996	1000	1000

691. The ashes of peat, as might be expected, contain less alkaline salts than those of wood; they usually contain a considerable quantity of gypsum (203, 528). The following table shows the composition of three sorts of Dutch ashes analysed by Sprengel :—

	BEST.	MIDDLING.	INFERIOR.
Potash	2	2	1
Soda	10	39	4
Lime	136	86	61
Magnesia	49	16	39
Alumina	45	35	41
Oxide of iron	66	54	41
Oxide of manganese	10	43	2
Silica	471	559	704
Chlorine	12	30	5
Sulphuric acid	72	64	34
Phosphoric acid	20	8	13
Carbonic acid	41	64	55
Charcoal	66	—	—
	1000	1000	1000

692. Kelp, the ashes of sea weeds (176, 585), resembles wood ashes in containing a large quantity of

alkaline salts; but it contains little or no phosphoric acid. The following analyses are by Dr. Ure:—

	RONA.	HEISKER.
Carbonate of soda Sulphuret of sodium	55	85
Sulphate of soda	190	80
Chlorides of sodium and potassium	375	365
Carbonate of lime	100	240
Sulphate of lime	95	—
Alumina and oxide of iron	100	90
Silica	—	80
Sulphur and loss	85	60
	1000	1000

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