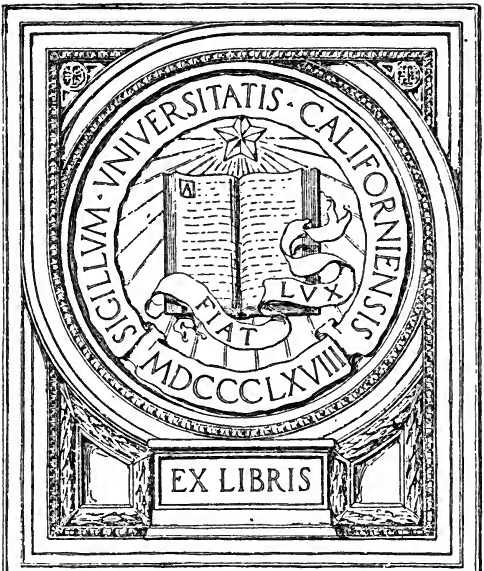
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FELLOW OF THE ROYAL SOCIETY OF SOUTH AFRICA, OF THE INSTITUTE OF CHEMISTRY AND OF THE CHEMICAL SOCIETY, MEMBER OF THE BRITISH AND SOUTH AFRICAN ASSOCIATIONS FOR THE ADVANCEMENT OF SCIENCE, AND OF THE SOCIETY OF CHEMICAL INDUSTRY; LATE CHIEF CHEMIST TO THE TRANSVAAL DEPARTMENT OF AGRICULTURE, FORMERLY LECTURER ON AGRICULTURAL CHEMISTRY AT THE LEEDS UNIVERSITY.

With Illustrations

THIRD EDITION, REVISED

LONDON:
CHARLES GRIFFIN AND COMPANY LTD.
EXETER STREET, STRAND, W.C.2
1920

PREFACE TO THE THIRD EDITION

With the exception of a few corrections and additions, this is a reprint of the last edition. In an elementary book of this kind the introduction of the results of recent work on the constitution and digestion of proteids may safely wait until the main facts and principles are more fully elaborated by the active investigations which are now being made. Doubtless, in the near future, a conception of the whole process of digestion will be reached, clear enough for easy presentment to even elementary students.

Leeds, *October* 1919.

PREFACE TO THE FIRST EDITION

This little volume is based upon the writer's long experience in teaching agricultural students, among whom there are, unfortunately, many who cannot devote the time necessary to acquire sufficient knowledge of pure chemistry to profitably read such works as the author's "Manual of Agricultural Chemistry."*

It is true that any attempt to combine, in one book, instruction in the principles of general chemistry with the somewhat technical information concerning the chemistry of agriculture, must be in many ways a failure, and the author would strongly recommend the user of this work to read some good, modern text-book on the former; or, better perhaps, to ask his teacher to explain, at greater length, the very incomplete and sketchy accounts which are given of the principles of chemistry and of the properties of the elements and compounds important in agriculture.

While fully realising that a satisfactory knowledge of agricultural chemistry cannot be acquired without a previous training in pure chemistry, he is aware that there are many agricultural students and farmers who have, perforce, to do

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* Scott, Greenwood & Son, London.

without this preliminary chemical knowledge, and it is for such that this book is mainly intended.

Since the work is written for the agriculturist rather than for the chemist, few references to chemical literature are given.

The book was prepared while the author was in touch with many of the crops and agricultural practices of South Africa, and it was thought advisable to give some account of the products of tropical and sub-tropical agriculture in addition to the matters relating to ordinary English farming.

In these days of frequent travel and emigration, such inclusions may be of service to many agricultural students who, in the future, may become Colonists, while it may render the book more suited to the needs of the Colonial reader, and to all a comparison of tropical with temperate conditions cannot fail to be useful.

Every writer is apt to give undue prominence to the particular subjects upon which he has himself worked, and perhaps some examples of this weakness may be found in the present volume.

The importance of the composition as well as the amount of the ash constituents of the food of animals, to which reference is made in chap. ix., though perhaps not strongly felt in Europe where diet is varied, is considerable in such countries as South Africa, where the usual food of draught animals is composed almost entirely of cereals.

In chap. iii. a brief account is given of the main causes of the motion of water in a soil, intended to clear away the confusion which is apt to attend the usual "explanation" as to its being due to "capillarity."

Chap. x. deals with the variations in the composition of cows' milk in greater detail, perhaps, than the elementary character of the book justifies; but here again the popular interest at present shown in the subject must be the excuse.

There are, doubtless, other respects in which the work is "out of balance," but for these the reader's indulgence is solicited.

The author hopes that, in spite of this, the book may prove of service to those for whom it is intended.

October 1908.

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CHAPTER I.

INTRODUCTION.

AGRICULTURAL CHEMISTRY concerns itself with the chemical composition of the food of plants and animals and with the chemical changes involved in the processes of life. It has thus to deal with the composition of soil, air and water, of the bodies of plants and animals, of manures and other materials, and with the chemical changes which these substances undergo.

Before commencing the study of agricultural chemistry a student should devote some time to acquiring a knowledge of general chemistry. In this little work it is difficult to impart such knowledge, and the reader should, if he has not already had some training in the science, supplement what he reads here by referring to some good modern text-book of chemistry. This chapter will be devoted to a brief and necessarily very incomplete sketch of the modern theory of chemistry, and of the more characteristic properties of those elements which are of importance in agriculture.

According to present views, all matter (by which is meant everything that possesses weight and which affects our senses) is composed of minute particles, which are incapable of being subdivided and which cannot be destroyed. In view of the electron theory of matter, and of some of the recent discoveries with respect to radium and its conversion into helium, this statement may have to be modified, but so far as the great majority of substances is concerned it may be accepted as true. Thus to the mental vision of the chemist all materials, whether solid, liquid or gaseous, are GRANULAR, inasmuch as they are composed of countless multitudes of these indivisible particles. These particles are known as *atoms* (from two Greek words meaning indivisible), and the theory is known as the ATOMIC THEORY. It is of very ancient origin, but was first applied in its modern sense to chemistry by John Dalton about the beginning of the nineteenth century. There are about eighty-three different kinds of atoms, and a substance containing only one kind is said to be an *element.* The whole earth, so far as is known, is made up of these eighty-three (or thereabouts) elements. The atoms differ in weight, but those of any one element are alike in weight and in all other properties. The properties of any substance reside in its molecules, not in its atoms. Thus, there may be two substances possessed of entirely different properties and yet containing exactly similar atoms, but, in such cases, the molecules are different. For example, ordinary oxygen, consisting of molecules each containing two atoms of the element, is essentially different from ozone, which consists of molecules each containing three atoms of the element. The actual weight of an atom is so small that it is practically impossible to determine it, but the relative weight compared with an atom of another kind can be determined with considerable accuracy. The methods used in the determination of the *atomic weight* of an element cannot here be described. The table on p. 3, giving the names (in alphabetical order) of the elements and their relative atomic weights, may be useful. It is the table published annually by the International Committee on Atomic Weights and gives the figures to be accepted for 1920.

The numbers are calculated on the assumption that the atom of oxygen has a weight represented by 16·000. Formerly it was usual to take as the unit of atomic weight that of hydrogen, but for several reasons it is now preferred to refer the values to the one-sixteenth of the atomic weight of oxygen. After the name of each element in the table is given a *symbol,* consisting of a capital letter with or without another letter. By a symbol is indicated one atom of the element referred to, and thus a symbol has a quantitative as well as a qualitative meaning.

INTERNATIONAL ATOMIC WEIGHTS FOR 1920.

		O = 16			O = 16
Aluminium	Al	27·1	Molybdenum	Mo	96·0
Antimony	Sb	120·2	Neodymium	Nd	144·3
Argon	A	39·9	Neon	Ne	20·2
Arsenic	As	74·96	Nickel	Ni	58·68
Barium	Ba	137·37	Niton	Nt	222·4
Bismuth	Bi	208·0	Nitrogen	N	14·008
Boron	B	10·9	Osmium	Os	190·9
Bromine	Br	79·92	Oxygen	O	16·00
Cadmium	Cd	112·40	Palladium	Pd	106·7
Cæsium	Cs	132·81	Phosphorus	P	31·04
Calcium	Ca	40·07	Platinum	Pt	195·2
Carbon	C	12·00	Potassium	K	39·10
Cerium	Ce	140·25	Praseodymium	Pr	140·9
Chlorine	Cl	35·46	Radium	Ra	226·0
Chromium	Cr	52·0	Rhodium	Rh	102·9
Cobalt	Co	58·97	Rubidium	Rb	85·45
Columbium	Cb	93·1	Ruthenium	Ru	101·7
Copper	Cu	63·57	Samarium	Sa	150·4
Dysprosium	Dy	162·5	Scandium	Sc	44·1
Erbium	Er	167·7	Selenium	Se	79·2
Europium	Eu	152·0	Silicon	Si	28·3
Fluorine	F	19·0	Silver	Ag	107·88
Gadolinium	Gd	157·3	Sodium	Na	23·00
Gallium	Ga	70·1	Strontium	Sr	87·63
Germanium	Ge	72·5	Sulphur	S	32·06
Glucinum	Gl	9·1	Tantalum	Ta	181·5
Gold	Au	197·2	Tellurium	Te	127·5
Helium	He	4·00	Terbium	Tb	159·2
Holmium	Ho	163·5	Thallium	Tl	204·0
Hydrogen	H	1·008	Thorium	Th	232·15
Indium	In	114·8	Thulium	Tm	168·5
Iodine	I	126·92	Tin	Sn	118·7
Iridium	Ir	193·1	Titanium	Ti	48·1
Iron	Fe	55·84	Tungsten	W	184·0
Krypton	Kr	82·92	Uranium	U	238·2
Lanthanum	La	139·0	Vanadium	V	51·0
Lead	Pb	207·20	Xenon	Xe	130·2
Lithium	Li	6·94	Ytterbium	Yb	173·5
Lutecium	Lu	175·0	Yttrium	Yt	89·33
Magnesium	Mg	24·32	Zinc	Zn	65·37
Manganese	Mn	54·93	Zirconium	Zr	90·6
Mercury	Hg	200·6			

When two elements combine together to form a chemical *compound* they do so by the union of a certain number of atoms of one with a certain number of atoms of the other element, and the proportion between these numbers is usually a very simple one, and is always the same for a given compound. To take an example, water is composed of hydrogen and oxygen, and the numbers of atoms are in the proportion of two and one respectively. This can be briefly expressed by the formula H_2O, which conveys the information that a molecule of water consists of two atoms (having a relative weight of 2) of hydrogen and one atom (with a relative weight of 16) of oxygen.

It is important to realise the essential differences between a mechanical mixture and a chemical compound.

From the theoretical aspect this may be stated thus: In a mixture the molecules of the constituents remain intact, and by a sufficiently delicate means might conceivably be detected lying side by side, and each constituent retains its own characteristic properties, so that the mixture has properties intermediate between those of its components. In a compound, on the other hand, all the molecules are alike, and no investigation, however searching, would be able to detect the original components in the compound without destroying its characteristic properties. From the practical aspect it is to be noted that the mixing of the two subjects generally produces no evolution or absorption of heat, and yields a product intermediate in properties between its components, and capable, by merely mechanical means, of being separated into its constituents; whilst with the formation of a compound there is usually much heat evolved, and the product has properties totally unlike those of its constituents. No mechanical means, however delicate, can separate, or even detect the existence of, the constituents.

The following experiment will perhaps help to render the distinction clear. If about 10 grammes of fine copper filings are mixed in a mortar with half their weight of sulphur, a dirty orange powder results. Under the microscope red particles of copper and lemon-yellow fragments of sulphur can be distinguished lying side by side. Moreover, by throwing some of this powder into water the constituents separate out according to their relative specific gravities: the copper particles sink to the bottom, while the lighter sulphur particles rest above the copper; or complete separation may be effected by treating a portion of the mixture with carbon disulphide, when the sulphur is removed in solution and the copper left. On allowing the carbon disulphide to evaporate, the sulphur is recovered in small crystals. In this case a *mere mixture* of sulphur and copper has been made, capable of separation by mechanical means and partaking of the properties of its constituents.

If some of the mixture be heated in a test-tube a chemical union between the copper and sulphur takes place, attended by the production of heat and light, and there results a black substance totally unlike, in all its properties, either of its constituents. If this black substance be ground to powder and examined under the microscope all the particles will be alike black in colour, and neither sulphur nor copper can be detected. If a portion of the mixture be treated with carbon disulphide the substance is not changed in appearance, and the liquid, if filtered off, deposits on evaporation no sulphur (or at most a small trace, due to imperfect mixing or heating of the powder). If the powder be thrown upon water it all sinks together. The substance is evidently neither copper nor sulphur, but by appropriate means it can be shown to contain both. If some of the powder be treated with strong nitric acid a violent action takes place, and a dirty yellow mass floats on the top, the liquid becoming blue in colour. If the liquid be filtered and brought into contact with a bright iron or steel blade or some scrap zinc, a deposit of red metallic copper will be obtained. If the dirty yellow residue be heated in air, it will burn with the blue flame and emit the characteristic odour of burning sulphur. The black substance obtained by heating the mixture of copper and sulphur is a chemical compound called sulphide of copper, and, like almost all compounds, was formed from its constituents with the evolution of heat.

A consideration of the meaning of the term, atom, will clearly show that it cannot be applied to even the smallest conceivable portion of water or other compound substance, since such a portion of matter must contain at least two atoms, and therefore can be further subdivided. Another term, *molecule*, is therefore used for the smallest conceivable portion of a substance which can exist alone. Indeed, even with elementary substances it is usually the case that separate atoms do not exist, but that the molecules of elements contain two or more atoms. Thus, free oxygen exists as molecules, each containing two atoms, and though molecules composed of three atoms of oxygen are known, they are entirely different in their properties from ordinary oxygen, and constitute the substance known as *ozone*. It is only in the case of some few elements that separate atoms exist in the free state. One of the best examples is afforded in the recently discovered element, *argon*. This substance consists entirely of separate atoms, so that in this and similar cases the molecule and the atom are identical. When chemical action takes place no creation or destruction of matter occurs, but new molecules are formed by some rearrangement of the elements present. The chemist endeavours to investigate fully the changes which take place, and in many cases is able to represent the whole of the changes which occur by means of *chemical equations*. To take a simple case, consider the union of hydrogen with oxygen to form water. In hydrogen gas there are only molecules of hydrogen, each molecule represented by the formula H_2, while in oxygen there are only molecules, O_2. When union occurs, two molecules of hydrogen unite with one molecule of oxygen to form two molecules of water. This can be represented thus:

$$2H_2 + O_2 = 2H_2O.$$

A chemical equation is like an algebraical equation, in that there must be the same quantities of each element on each side of the equation; but it is not like an algebraic equation, in that it cannot necessarily be written either way. An equation, to a chemist, is a concise statement of a chemical change, given in addition to information as to its qualitative character, full details of the quantities of the various substances taking part in the reaction. The student, however, must not overlook the fact that before an equation can be relied upon actually to represent a given reaction, a complete and careful experimental investigation of the reaction must have been made. By the beginner particularly, equations must not be used as a means of *predicting* the interaction of two or more substances, but should be regarded as records of facts which have been ascertained by careful experiment.

Before giving a brief description of the elements which are of importance in agriculture it may be advisable to explain the meaning of some of the commoner terms used in chemistry As these explanations cannot claim to be other than fragmentary and disconnected, no attempt at a logical arrangement is made. For convenience in reference an alphabetical order has been adopted.

Acid:—a substance generally possessing a sour taste and the property of changing vegetable blues, *e.g.*, blue litmus, to red, and containing one or more atoms of hydrogen, which can be replaced by a metal. As types of acids, sulphuric acid, H_2SO_4, nitric acid, HNO_3, hydrochloric acid, HCl, acetic acid, $HC_2H_3O_2$, may be mentioned. By replacement of the hydrogen of these substances by a metal, *e.g.*, sodium, the salts sodium sulphate, Na_2SO_4, sodium nitrate, $NaNO_3$, sodium chloride, $NaCl$, and sodium acetate, $NaC_2H_3O_2$, are obtained. The possession of the sour taste and the power of changing vegetable blues to red is indicated by saying that the substance has an acid reaction, but is not a proof that it is an acid; *e.g.*, copper sulphate, $CuSO_4$, has an acid reaction, yet it is a true salt.

Alkali:—a. substance opposed in its properties to an acid, capable of neutralising and destroying the characteristics of an acid, forming, in doing so, a salt and water. The most important alkalies are soda, $NaOH$, potash, KOH, and lime, CaO or CaH_2O_2. Ammonia, NH_3, or in solution $(NH_4)OH$, also acts as an alkali. A substance is said to have an alkaline reaction if it turns certain vegetable colours—*e.g.*, litmus—which have been reddened by an acid, back to blue again.

Base:—a substance, generally an oxide or hydroxide of a metal, which can partially or wholly neutralise the acidity of an acid, forming thereby a salt and water. The alkalies are bases soluble in water, but many bases are insoluble.

Basicity of an acid is the number of atoms of replaceable hydrogen present in a molecule of the acid. Thus the basicity of nitric acid, HNO_3, or hydrochloric acid, HCl, is 1; or these acids are said to be *monobasic.* Sulphuric acid, H_2SO_4, has a basicity of 2, or is *dibasic;* phosphoric acid, H_3PO_4, of 3, or is *tribasic*, and so on. Monobasic acids can only form one kind of salt with a metal, since the hydrogen must be wholly replaced, if replaced at all. Thus there can only be one sodium nitrate —the substance $NaNO_3$. Dibasic acids, or acids of higher basicity, can, however, form more than one salt with a metal. Thus the sodium salt of sulphuric acid might be $NaHSO_4$ or Na_2SO_4, according to whether one or both the atoms of hydrogen in the acid have been replaced by sodium. The former salt belongs to a class called the acid salts, and would be more correctly named sodium hydrogen sulphate.

Destructive Distillation:—the change produced when a substance, generally a carbonaceous compound, is submitted to a high temperature with exclusion of air, and when gases and vapours are emitted, the original substance being permanently destroyed by the process. A good example is afforded in the preparation of gas from coal. In most cases a black residue, consisting largely of carbon, is left behind.

Endothermic and Exothermic Compounds.—By an exothermic compound is understood a substance in whose formation heat was evolved—*e.g.*, carbon dioxide. Most compounds are exothermic. An endothermic compound, on the other hand, is one in whose formation heat or energy was absorbed. Consequently exothermic compounds are stable and require some power to decompose them, while endothermic compounds are unstable and give out heat or energy when they decompose; they are often explosive. A chemical change evolving heat is described as an exothermic reaction, while one in which heat or other form of energy is absorbed is called an endothermic reaction.

Organic Matter is, strictly speaking, matter which has been produced by organisms—*i.e.*, animals or plants—but the term is used in a wider sense in chemistry for any compound of carbon, whether produced by life-processes or artificially. Almost all forms of organic matter, when strongly heated out of contact with air, blacken, owing to the liberation of carbon; with free access of air combustion occurs, and carbon dioxide and other products are formed.

Oxidation and Reduction.—By oxidation, literally speaking, is meant union with oxygen, but in a chemical sense the term is given a wider significance, *viz.*, combination with more oxygen or with some substance playing the part of oxygen. Thus the conversion of a ferrous compound, *e.g.*, ferrous chloride, $FeCl_2$, into a ferric compound, ferric chloride, $FeCl_3$, is often called by chemists a process of oxidation, though no oxygen may be concerned in it.

Reduction is used in exactly the opposite sense. A substance which brings about oxidation of others is called an "oxidising agent," while one which removes oxygen or anything which plays the part of oxygen is called a "reducing agent." Common oxidising agents are air, nitric acid and nitrates, chlorates, chlorine, &c.; common reducing agents are easily oxidisable metals, *e.g.*, zinc, partially oxidised substances such as sulphurous acid, H_2SO_3, many forms of decaying organic matter (especially when under water), &c.

Putrefaction:—a process of decomposition, sometimes accompanied by oxidation, of carbonaceous matter, produced by the life-processes of bacteria, yeasts, moulds, &c., and resulting in the production of evil-smelling gases or vapours. When oxidation by the air occurs, heat is evolved.

Valency.—Elements differ in their power of combining with other elements. Thus chlorine can only combine with hydrogen atom for atom, or one atom of chlorine is chemically equivalent to one atom of hydrogen, as is seen in the compound HCl; oxygen has usually twice the combining power of hydrogen, or one atom of oxygen is chemically equivalent to two atoms of hydrogen, as seen in the compound H_2O; nitrogen is possessed of even greater value in combination: one atom of it can combine with three atoms of hydrogen, as NH_3; lastly, carbon forms a compound CH_4, showing that one atom of carbon is equivalent to four of hydrogen. The number of atoms of hydrogen which one atom of a given element can combine with or replace is called the *valency* of the element. The valency of chlorine is 1, that of oxygen 2, that of nitrogen 3, and that of carbon 4. Or chlorine is said to be *monovalent*, oxygen *divalent*, nitrogen *trivalent*, and carbon *tetravalent*. The valency of an element varies in different compounds, and generally those compounds of an element in which it has one particular valency possess many properties in common, but quite distinct from the properties which it has in another class of compounds in which its valency is higher or lower. Thus divalent iron, which occurs in all *ferrous* compounds, gives quite a distinct set of reactions from trivalent iron, which occurs in all *ferric* compounds.

Volatile:—capable of being converted from a liquid or solid into a vapour or gas by heat. The term is somewhat loosely used in two senses:

(1) (the proper use) When a substance on heating is converted into a vapour or gas without undergoing any chemical change. In this case, on cooling, the gas or vapour is transformed again into the original solid or liquid—*e.g.*, camphor, water.

(2) When a substance, on being heated, is converted into gas

or vapour, and at the same time a chemical change, either decomposition or oxidation, takes place. In this case the body is permanently altered, and on cooling, the gas or vapour does not yield the original substance.

Of the eighty-three elements in the list on p. 3, by far the larger proportion play little or no part in the ordinary processes of plant and animal life. Indeed, a considerable number are found in only extremely small quantities. From the standpoint of the agriculturist, therefore, they possess little interest. The bodies of animals and plants are mainly built up of compounds of the following elements:

Oxygen.
Hydrogen.
Carbon.
Nitrogen.
Sulphur.
Phosphorus.
Calcium.
Potassium.
Sodium.
Magnesium.
Iron.
Chlorine
Silicon.

A short account of these elements will now be given.

Oxygen is the most abundant and most important of the elements. It forms about half the weight of the solid crust of the earth, eight-ninths of the water, and nearly one-fourth of the atmosphere. In the first and second instances the oxygen is in a combined state; in the atmosphere it exists as the free element, merely mixed with the other constituents.

Oxygen can be prepared in many ways. One of the most usual laboratory methods is by the action of heat on potassium chlorate, a substance having the composition expressed by the formula $KClO_3$. The proportions of the elements present in this substance are thus one atom of potassium, with a relative weight of 39, one atom of chlorine, weighing 35·46, and three atoms of oxygen, each weighing 16, so that in $39 + 35{\cdot}46 + 48$, *i.e.*, 122·46 parts by weight of the salt, there are 48 parts of oxygen. The final action of heat upon potassium chlorate is to expel all the oxygen and to leave a residue of potassium chloride, KCl. The reaction is therefore represented by the equation

$$2KClO_3 = 2KCl + 3O_2.$$

The operation can be conducted in a hard glass flask or retort, and the gas collected over water, in which it is only sparingly soluble. If manganese dioxide, MnO_2, be mixed with the potassium chlorate the latter yields its oxygen at a much lower temperature, and without fusion. A curious fact is that in such a case the potassium chlorate is alone affected, the manganese dioxide remaining unchanged at the end of the operation. Oxygen compressed into steel cylinders is now an article of commerce. Most of the oxygen so supplied is prepared from the air by a process known as Brin's. This is based upon the behaviour of barium monoxide, BaO, when heated in air. Under proper conditions oxygen is absorbed and barium dioxide or peroxide, BaO_2, is formed, the other constituents of the air passing away unchanged. By the action of a higher temperature or lower pressure the barium dioxide decomposes into the monoxide and free oxygen. The barium monoxide is then again ready to absorb a fresh portion of oxygen from the air, and so the process can go on almost indefinitely. The reactions involved may be thus represented :—

$$(1)\ 2BaO + \underset{\substack{| \\ \text{from the air}}}{O_2} = 2BaO_2$$

$$(2)\ 2BaO_2 = 2BaO + O_2$$

the equations in this case being simply reversed. The apparatus employed on the large scale is ingenious and somewhat complicated.

Oxygen is a colourless, odourless gas, very slightly soluble in water, 100 volumes of water under ordinary conditions dissolving about 4 volumes of the gas. It shows a great tendency to combine with other substances, and the act of union is usually attended with the production of much heat. Burning or combustion is nearly always due to the heat produced by the combination of the substance burnt with the oxygen of the air. It is found, therefore, that any substance which will burn in air (containing its 21 per cent. of free oxygen) will do so with increased brilliancy in pure oxygen. The temperature attained and the intensity of the light emitted are always greater in the latter case, though the total quantity of heat evolved by the union of a definite weight of a substance with oxygen is constant, and independent of the circumstances under which the union takes place.

Quantity of heat is measured by the weight of water which it can raise in temperature through 1° C. It is therefore possible to determine the amount of heat which is evolved by the union of the unit weight (1 pound or 1 gramme) of a substance with oxygen, and this value will be true under whatever circumstances the union may take place. The number which expresses the number of units of mass (pounds or grammes) of water which are raised in temperature through 1° C. by the union of the unit mass (one pound or gramme) of a substance with oxygen is called the *heat of combustion*, or the *calorific power* of the substance. The following table gives the calorific power of a number of important substances:

Charcoal	8080	Fat of butter	9216
Hydrogen	34460	Olive oil	9400
Wood	2800	Grape sugar	3750
Average coal	7500	Cane sugar	3955
Coke	7050	Milk sugar	3952
Albumin	5900	Malt sugar	3949
Casein	5860	Cellulose	4185
Urea	2542	Starch	4182
Fat of sheep	9494		

In ordinary cases of burning, the evolution of heat is readily evident, but in some cases of slow combination with oxygen the heat is evolved so slowly that conduction and convection carry it away almost as rapidly as it is produced, and very slight or no elevation of temperature is apparent. In some cases, however, of slow oxidation, when the escape of heat is hindered from any cause, the temperature rises so as to be perceptible, or even dangerous. Under particularly favourable conditions the rise of temperature may be sufficient to start rapid combination with oxygen, and flame then results. Such cases of "spontaneous combustion," as they are called, not infrequently occur. Among the chief causes may be mentioned absorption of oxygen by drying oils, *e.g.*, linseed or cotton-seed oil, especially when spread on cotton waste, as in mills; fermentative changes in vegetable matter, *e.g.*, hay, tobacco; slow oxidation of certain minerals, *e.g.*, iron pyrites in coal.

Hydrogen is also very abundant in nature, though, because of its low atomic weight (1·008), the proportion by weight present on the earth's surface is small. Its most abundant compound is water, H_2O. It can readily be obtained from water by the removal of the oxygen by the aid of metals. Some will set hydrogen free at the ordinary temperature on contact with water, *e.g.*, potassium or sodium, the reaction being

$$Na_2 + 2H_2O = 2NaOH + H_2,$$

only half the hydrogen being thus evolved. Other metals liberate hydrogen from the water at about the boiling-point, *e.g.*, magnesium:

$$Mg + 2H_2O = MgH_2O_2 + H_2;$$

while others require a red heat, *e.g.*, iron. The reaction in the last case is

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2.$$

A more convenient method of preparing hydrogen is by the action of a dilute acid upon a metal, *e.g.*, dilute sulphuric acid upon zinc:

$$Zn + H_2SO_4 = \underset{\text{Zinc sulphate.}}{ZnSO_4} + H_2.$$

The reaction commences at the ordinary temperature, and the gas can be collected over water.

The characteristic properties of hydrogen are its lightness and the high temperature produced by its union with oxygen. The former led to its employment for filling balloons, and though now the more easily obtained coal-gas is generally employed for the purpose, it is not nearly so efficient, and only about half of it is hydrogen, the remaining half being made up of heavier gases. Although the flame of hydrogen burning in air or oxygen is intensely hot and can be used to melt refractory substances, *e.g.*, silica and platinum, it possesses practically no illuminating powers. When mixed with air or oxygen and heated to a high temperature, *e.g.*, by contact with a flame or electric spark, hydrogen, like all inflammable gases, explodes violently. With hydrogen and air the temperature required to start the explosion is about 650° C., and any mixture containing from 5 to 80 per cent. of hydrogen is explosive. Free hydrogen is very rarely found in any quantity in nature, though certain fermentative changes to which vegetable matter is liable, produce it, and it has been found in the gases escaping from volcanoes. In a state of combination, however, it occurs in a very large number of compounds, particularly when combined with carbon, oxygen and nitrogen.

Carbon is the element most closely associated with plant and animal life. It forms a large portion of the solid matter of all living beings, and the chemical processes of animal and plant life are mainly those in which carbon plays an important part. It exists in the combined state in many minerals, *e.g.*, the carbonates of calcium, magnesium, iron, zinc and lead, and also in a small but important constituent of the air, carbon dioxide. The element occurs in three distinct forms: the diamond, graphite or plumbago, and the amorphous forms as charcoal, lampblack, &c. These *allotropic* forms as they are called, though identical in composition (being elementary carbon), are possessed of very different physical properties. Thus the diamond is crystalline, transparent, and about three and a half times as heavy as an equal bulk of water; graphite is crystalline, opaque, and about two and a half times as heavy as water; while amorphous carbon is, of course, non-crystalline, opaque, and (when its pores are filled with water) about one and a half times as heavy as water. The black colour which is produced when animal or vegetable substances are strongly heated without access of air ("charring") is due to the separation of free carbon from the various carbonaceous compounds present; indeed, the charring of a substance when it is heated can usually be taken as an indication that it contains *organic* or carbonaceous matter. Chemically, carbon is remarkable for its power of uniting in a vast number of different proportions with hydrogen and with hydrogen and oxygen. Of such compounds thousands are known, and their study comprises that branch of science known as *organic chemistry*, which, though of comparatively recent origin, has already attained vast dimensions.

Nitrogen is much less abundant in nature than the elements already described. A peculiarity of its occurrence is the fact that it appears to be present only in the outermost portion of the earth, the greater portion being free in the air. No true minerals containing it, except those which owe their origin directly to plant or animal life, *e.g.*, coal and Chili saltpetre, are known. All living matter, however, contains it as an essential constituent.

It can readily be obtained from its compound with hydrogen, ammonia, by removing the hydrogen either by means of oxygen or chlorine. Its properties are chiefly of a negative character, for it shows little tendency to combine with other elements. Although in the free state it is so inert, the nitrogen compounds are as a rule, possessed of great chemical activity, and many of them are very important substances. Many powerful drugs and poisons contain nitrogen, *e.g.*, quinine, $C_{20}H_{24}N_2O_2$, strychnine, $C_{21}H_{22}N_2O$, prussic acid, HCN; while most explosives, *e.g.*, nitroglycerine, $C_3H_5N_3O_9$, gun-cotton, $C_6H_7N_3O_{11}$, and many others, are also nitrogen compounds. It is an essential ingredient in the food of both animals and plants. To the former it must be supplied in combination with carbon hydrogen, oxygen and other elements in the complex compounds known as albuminoids, while plants require it chiefly in the form of nitrates. Only under very special conditions can some species of plants obtain the nitrogen they require from the free nitrogen of the air. As will be seen in subsequent chapters, although plants are surrounded with air, which contains about three-quarters of its weight of nitrogen, *combined* nitrogen is one of the essential and most valuable constituents of manures. A large portion of the nitrogen in the food consumed by men and animals is eliminated in the form of urea and other compounds in the excreta. Unfortunately these are in many cases sent down the sewers into the rivers, which are thereby polluted, and finally are discharged into the sea. The valuable combined nitrogen is thus wasted so far as its utilisation in agriculture is concerned.

Sulphur is found both free and combined in nature. The free element is found in volcanic districts, particularly in Sicily; while in the combined state it occurs as sulphuretted hydrogen, H_2S, in many mineral waters; as sulphides of many metals, *e.g.*, of iron, as *iron pyrites*, FeS_2, of lead, as *galena*, PbS, of zinc, as *blende*, ZnS; and also as sulphates of certain metals, *e.g.*, of calcium, as *gypsum* or *selenite*, $CaSO_4.2H_2O$, and *anhydrite*, $CaSO_4$ and of barium, as *barytes* or *heavy spar*, $BaSO_4$. Calcium sulphate is very widely distributed, and being soluble in water is to be found in most spring and river waters.

Sulphur can be obtained by the partial oxidation of sulphuretted hydrogen:

$$2H_2S + O_2 = 2H_2O + 2S.$$

In this way large quantities of sulphur are now obtained, the sulphuretted hydrogen being produced from bye-products in the manufacture of "soda ash" (sodium carbonate) from common salt.

Sulphur ("brimstone") is a yellow, brittle substance which is very inflammable. It burns in air with a pale blue flame and forms the suffocating gas, sulphur dioxide, SO_2, while small quantities of sulphur trioxide, SO_3, are also produced. The latter by its union with the water vapour always present in the air, forms sulphuric acid, H_2SO_4. Sulphur, like carbon, is capable of existing in three modifications, possessing different physical properties. Unoxidised or partially oxidised sulphur compounds are very injurious to plants, while sulphates are not only harmless, but necessary. Sulphur is present in the albuminoids of both animals and plants, and when putrefaction of these substances occurs is often liberated as sulphuretted hydrogen. This substance is perceptible by its disagreeable odour as one of the chief products of the decay of albumin in eggs.

Phosphorus always occurs in a state of combination. Phosphorus compounds, chiefly phosphates, are very widely distributed, but in small proportion, in the rocks of the earth. Deposits of calcium phosphate, $Ca_3P_2O_8$, occur in certain localities, and are highly prized for manurial purposes. All fertile soils contain small quantities of phosphates, which are taken up by plants, and through plants find their way into animals, where they accumulate in the bones or other hard-parts (*e.g.*, teeth and shells). The element itself is somewhat difficult to obtain, because of its strong affinity for oxygen. It is prepared by the action of carbon upon metaphosphoric acid at a very high temperature, the chief reaction being—

$$4HPO_3 + 12C = 12CO + 2H_2 + P_4.$$

Phosphorus, as usually prepared, is a yellowish, waxy substance which has the power of emitting a faint light when exposed to air. This property was the origin of its name, which is derived from the Greek and means "the light-bearer." The emission of light is due to slow oxidation, and although the glow occurs at low temperatures, heat is evolved, and often raises the temperature to a point high enough to start rapid combustion (about 60° C.), and actually to set fire to the phosphorus. Phosphorus burns in air with a dazzling white light, evolving dense clouds of phosphorus pentoxide, P_2O_5, which readily dissolve in water, forming phosphoric acid, H_3PO_4. Phosphorus is a violent poison. It is largely used in the manufacture of lucifer matches, and occasionally as a rat-poison. From an agricultural standpoint its chief importance lies in the use of its compounds, the phosphates, as manures, and its occurrence in association with fats and albuminoids in feeding stuffs and in the bodies of animals.

Calcium is very abundant in nature, always occurring in a combined state. Calcium carbonate, $CaCO_3$, is found in enormous quantities in chalk, limestone and marble; the sulphate is very abundant as gypsum or selenite, $CaSO_4 . 2H_2O$; and the silicate is found as a constituent of many minerals. The element itself is an easily oxidisable metal, difficult to prepare, and of little importance. Its oxide, CaO, is the important substance *quicklime.* Calcium is an essential constituent of plant food, but in soil its compounds fulfil other more important functions, which will be described hereafter.

Potassium occurs in many minerals. Most silicates contain it in smaller or larger amount, and in some, *e.g.*, *orthoclase*, $Al_2O_3.K_2O.6SiO_2$, and *mica*, $K_2O.3Al_2O_3.4SiO_2$, potassium is an essential ingredient. It also occurs in sea-water, from which sea-weeds accumulate large quantities of potassium compounds. The huge saline deposits at Stassfurt furnish a large proportion of the potassium required in the arts and for manurial purposes. The character of these deposits will be described later.

The element can be prepared by the action of carbon at a very high temperature upon the carbonate or hydroxide of potassium. It is a bright, lustrous metal, very soft, and so susceptible to oxidation that it has to be kept from contact with air or moisture; this is often effected by means of naphtha, a hydrocarbon. By contact with water it yields potassium hydroxide and liberates hydrogen:

$$K_2 + 2H_2O = 2KOH + H_2.$$

The heat evolved by this reaction is so great that the metal melts to a globule, which floats on the surface of the water with a hissing sound; the hydrogen is ignited, and burns with a flame coloured violet by the vapour of the potassium.

Potassium compounds are of great importance in agriculture and essential constituents of all fertile soils. They appear to be closely associated with the growth and increase of plants, and are always found in greatest abundance in the twigs, young leaves, and other rapidly growing portions. In the plant the potassium is in combination with various acids, nitric, hydrochloric, and very often with organic acids—*e.g.*, oxalic, $H_2C_2O_4$, citric, $H_3C_6H_5O_7$, tartaric, $H_2C_4H_4O_6$, and malic, $H_2C_4H_4O_5$. In the ash of plants, however, it generally occurs as carbonate, and this is the chief constituent in the ash of the twigs and leaves of trees. Potassium salts are very soluble in water, but are absorbed and retained by certain constituents of the soil, so that their loss by drainage from soil is little to be feared.

Sodium is very widely distributed in nature, and is a constituent of many silicates. In the form of chloride, $NaCl$, it is very plentiful as *rock-salt* and as the largest saline ingredient in sea-water. The element is prepared by the action of carbon upon the carbonate or hydroxide, or by electrolysis of common salt. Its properties resemble those of potassium. Sodium compounds are very largely used in the arts, and the preparation of sodium carbonate is one of the largest and most important of the chemical industries.

Sodium is found in the ashes of most plants, but, except in the case of certain species, does not appear to be essential to their welfare. A striking difference between sodium and potassium compounds, which are so much alike in most of their properties, is in their behaviour towards the soil when applied in solution. The potassium salts are retained by the clay and organic matter in an insoluble form, but the sodium salts are easily washed out by water and escape into the drains.

Magnesium is widely met with in nature as carbonate and silicate. The metal itself is a bright, silvery substance, very light, and capable of burning in air or oxygen with an intense and dazzling white light. Magnesia, MgO, magnesium, carbonate, $MgCO_3$, and Epsom salts, $MgSO_4.7H_2O$, are the compounds most commonly used in the arts.

Magnesium is found in the ash of plants, and appears to be essential, but as it is rare to find a soil deficient in magnesium it is of little practical importance from an agricultural standpoint.

Iron occurs in a large number of compounds. *Hæmatite*, Fe_2O_3, *magnetite*, Fe_3O_4, and *spathic iron ore*, $FeCO_3$, are abundant minerals, valued as ores of iron. The element occurs in two states of oxidation, as ferrous or divalent iron, and as ferric or trivalent iron. The former forms salts which are white or green in colour; the latter, compounds which are red and yellow. Ferrous compounds are often present in rocks or minerals deep underground, but when they are brought to the surface they combine with the oxygen of the air to form ferric compounds. The change of state of the iron is indicated by a change in colour in the rock or mineral, often from green or grey to red or yellow. Only ferric compounds should occur in good soils. Iron is essential to plants, but a small quantity is all that is required, and in most soils more than this is present.

Chlorine is very abundant, especially in combination with sodium, as *rock-salt*, in the sea and in spring-water. Other compounds of chlorine also occur as minerals. The element is usually obtained by oxidising hydrochloric acid, HCl, when the hydrogen is removed to form water and the chlorine evolved. Many substances may be used to bring about this oxidation. Black oxide of manganese, MnO_2, is often used. When this substance is heated with a solution of hydrochloric acid (the usual hydrochloric acid, or "spirits of salt") about half the chlorine present is evolved, and the gas, being nearly two and a half times as heavy as air, can be collected by leading it to the bottom of upright vessels.

$$MnO_2 + 4HCl = MnCl_2 + Cl_2 + 2H_2O.$$

Chlorine is a yellowish-green gas, possessed of an irritating and suffocating smell, very soluble in water, and of great chemical activity. It readily unites with most metals, and shows a particularly strong tendency to combine with hydrogen. By pressure and cold, chlorine can be liquefied. The properties of chlorine which are most valued in the arts are its bleaching, disinfecting and deodorising powers. It readily destroys most organic colouring matters, and is largely employed in bleaching vegetable textile fabrics, *e.g.*, cotton or linen. It cannot be used for woollen or silk fabrics, as it injures the fibres themselves. Chlorine only bleaches in the presence of water, and it really acts by oxidation. Of itself it does not decompose in water, except in the presence of strong light (sunlight), but the combined effect of the organic colouring matter tending to combine with oxygen and the attraction of chlorine for hydrogen bring about the decomposition of water, with the production of some oxidised organic matter, which is generally colourless, and hydrochloric acid. Its action as a disinfectant is probably due to the same process, the oxygen of water combining with the organic matters and micro-organisms and destroying them.

Silicon is extremely abundant in the rocks of the earth's crust, and, though it forms a very important ingredient in soil and occurs in many plant ashes, it does not appear to be essential as a plant food. Recently it has been shown that soluble silica in a soil enables plants to subsist in the presence of a smaller quantity of phosphoric acid than would be necessary without the silica.

The element itself is of little importance. It is prepared from the oxide, silica, SiO_2, by the action of some substance having a very strong affinity for oxygen, the most suitable reducing agents being the alkali metals, potassium or sodium, or magnesium powder. It is usually a brown solid, but, like carbon or sulphur, can be obtained in several allotropic forms.

The oxide, silica, SiO_2, is a very abundant substance, occurring free as quartz, flint and sand, and, in combination, as the very numerous and important class of minerals, the silicates. It has been estimated that nearly half the solid mass of the outer crust of the earth consists of silica.

CHAPTER II.

THE ATMOSPHERE.

Physical Properties.—Most terrestrial plants and animals live surrounded by air, and many of the processes of life are directly dependent upon chemical actions in which the constituents of air take part. Air also plays an important part in the formation of soils and in the changes which occur in their constituents. It is therefore essential that the student should have some knowledge of the properties and composition of the atmosphere if he is to understand the nature of the chemical processes which are concerned in the life and growth of plants and animals.

That air is a material substance only becomes apparent under certain conditions. The space around us is apparently empty, for air is invisible and seems to permit of bodies moving freely within it. It is well known, however, that when a body of considerable area is moved rapidly in air great resistance is offered, thus proving that air is a material substance. Moreover, by depressing a glass vessel, *e.g.*, a beaker or tumbler, mouth downwards beneath the surface of water it will be observed that the water only enters the vessel to a slight extent, and that it is kept back by the air within the vessel. These simple phenomena and many others prove the material nature of air. It is quite easy, too, to show that air has weight. If a spherical flask be provided with an india-rubber stopper fitted with a short piece of glass tubing to which a piece of rubber tubing and a pinch-cock is fitted, it is possible to extract a large portion of the air, either by means of an air-pump or more simply by placing some water in the flask and heating it to boiling. The steam from the water drives the air out of the flask, and if the pinch-cock be closed and the flame removed from under the flask the steam within will gradually condense. When quite cold the flask can be accurately weighed. If the pinch-cock be then opened for a moment air will be heard to enter the flask to take the place of the steam which has condensed, and the flask will then be found to have increased in weight, the increase being the weight of the air which has entered. In this way it can be shown that a litre of air weighs, under ordinary conditions, about $1\frac{1}{4}$ grammes, or 1000 cubic feet weigh about 80 lb.

In consequence of its weight, air is pulled down towards the surface of the earth, and those portions nearest the surface are compressed by the weight of those above; consequently all bodies on the earth are subjected to the pressure of the air above and around them, for air, like other fluids, transmits pressure in all directions. The pressure exerted is very high, amounting on the average at the sea-level to about $14\frac{3}{4}$ lb. per square inch, or 1033 grammes per square centimetre. This pressure is a direct measure of the weight of the air. On every square foot of surface at the sea-level, therefore, there rests $14 \cdot 75 \times 144 = 724$ lb. of air, or upon an acre the total weight of air would be about 41,300 tons.

The Barometer.—The pressure of the air is measured by means of an instrument called a barometer. In its simplest form it consists of a glass tube (preferably rather wide in bore) about 32 or 33 inches long, closed at one end, open at the other, filled completely with mercury and inverted into a trough of mercury. It is then found that the mercury sinks in the tube only a few inches, and comes to rest with the mercury surface in the tube about 30 inches above that in the trough. Equilibrium is reached when the weight of the mercury column is equal to the weight of an air column of the same sectional area whose base is at the mercury surface in the trough or cistern and which extends to the utmost limits of the atmosphere. This simple form of barometer is the best, and, with proper means for accurately measuring the vertical distance between the two mercury surfaces, is the most accurate. The ordinary *weather-glass*, or wheel barometer, though it can be made very sensitive—*i.e.*, capable of showing even a small change in pressure—has no claims to accuracy.

The *aneroid barometer* depends for its action upon the elasticity of a steel box which has been completely emptied of air. The pressure of the air causes the lid of the box to collapse partially, and the amount of the indentation will be greater or less as the pressure varies. The motion of the lid is indicated by the rotation of a pointer moved by a chain attached to the centre of the lid, and controlled by a light spring.

As the height of the barometer measures the pressure, which depends upon the weight of the air above, it is obvious that the pressure, and therefore the barometric reading, will diminish as the altitude above the sea-level increases. Hence it is possible to measure this by means of the barometer. The relation between the difference in the vertical heights of the two stations and the difference in the barometric readings depends upon several conditions. Roughly speaking, it is found that near sea level for an ascent of about 900 feet the barometer falls one inch, while from a height of 5000 feet an ascent of about 1100 feet is accompanied by a fall of an inch in barometric pressure.

Air, like other gases, is altered in volume by changes in temperature or pressure. If the former remain constant the volume of a given quantity of gas is inversely proportional to the pressure. This relation was discovered by Boyle in 1661, and is nearly true for all gases between small limits of pressure.

If the pressure be constant the volume of gas varies directly as the temperature, measured from the *absolute zero* of temperature. The *absolute zero* is apparently at a point 273° C., or 491° F., below the melting-point of ice—*i.e.*, $-273°$ C., or $-459°$ F. By the application of this generalisation, the calculation of the volume which a known quantity of a gas would occupy under new conditions of temperature and pressure becomes simple. To take an example: Suppose a gas measures 1000 c.c. at a temperature of 15° C. and under a pressure of 740 mm. of mercury, and it is desired to calculate the volume it will occupy at 20° C. and 760 mm. Consider the effect of change of temperature. The absolute temperature of 15° is $273 + 15 = 288$. The absolute temperature of 20° is $273 + 20 = 293$. The volume is directly proportional to the absolute temperature; ∴ the volume will be $1000 \times \frac{293}{288}$ if the pressure were constant. Next consider the influence of pressure. The pressure changes from 740 to 760 mm.; therefore the volume will be diminished; it will thus be $1000 \times \frac{293}{288} \times \frac{740}{760} = 1004{\cdot}3$ c.c.

Chemical Composition of the Air.—Air is a mechanical mixture of several gases, some of which are invariably present, though in variable proportion, while others are sometimes practically absent.

The chief gases are:—

Nitrogen.
Oxygen.
Argon.
Carbon dioxide.
Water vapour.
Ammonia.
Nitric acid or oxides of nitrogen.
Ozone.

Nitrogen is the largest and least variable constituent, its amount in dry air being about 78 per cent. by volume, or 75·5 per cent. by weight. Although so abundant, it plays very little part in the processes going on in the air; indeed, its chief function may almost be said to be that of a diluent. Certain crops have been proved to assimilate the free nitrogen by the aid of tubercles on their roots, and some very low forms of plant-life are believed to be able directly to utilise free nitrogen, but the great majority of plants have apparently no power of utilising nitrogen, except when it is in a state of combination, best in the form of nitrates.

Oxygen is the most active and perhaps most variable constituent. Its average proportion in dry air is nearly 21 per cent. by volume, or 23·2 per cent. by weight. In consequence of the large number of processes of oxidation taking place, the proportion of oxygen is liable to local variations, but these are not so great as might be expected, because of the influences of diffusion, convection, and wind, and the compensating action of vegetation. In towns and over marshy places the amount of oxygen is generally found to be slightly less than in the open country or over the sea. The limits of variation in the outside air are not wide, perhaps from 20·5 to 21·03 per cent.

Argon, a recently discovered constituent, is of little importance from an agricultural or, indeed, from any practical standpoint. The gas, which is about 19·9 times as heavy as hydrogen, is remarkable for its inert character; so far as is known, it takes no part in any chemical processes, and appears to be incapable of uniting with any other element, or even with itself. Its molecule, unlike that of most gases, consists of one atom. Its amount in the atmosphere is about 0·94 per cent. by volume, or 1·3 per cent. by weight. *Helium, neon, krypton* and *xenon* are other new elements which have been found in air in excessively small quantities. So far as is known, they play no part in any chemical change.

Carbon Dioxide is a small but important constituent. Its percentage amount is very variable, being increased by the combustion and decay of all organic bodies and by respiration. The average amount in the air as a whole is estimated at about 0·03 per cent. by volume, but the tendency of recent investigations has been to give somewhat lower numbers. On the land its proportion is greater during the night than in the daytime. but over the sea this daily variation cannot be detected. The quantity present in the atmosphere is increased by many processes, among the most important being:

(1) Emission from volcanoes, deep springs, and other subterranean sources.

(2) Oxidation of carbonaceous matter—*e.g.*, the combustion of most fuels, the decay of animal and vegetable matter, and the respiration of animals and plants.

(3) The dissociation of carbonates by heat—*e.g.*, in lime-burning.

$$CaCO_3 = CaO + CO_2.$$

The chief process tending to diminish its quantity is its decomposition by the green portions of plants under the influence of sunlight. In this case the carbon is retained, being converted into various complex organic compounds, and used in forming the tissues of the plant, while the oxygen is returned in the free state to the atmosphere.

The magnitude of this process of removal of carbon dioxide from the air by plants is enormous. Some conception of it can be formed when it is remembered that about half the dry portion of most plants consists of carbon, and that the whole of this is obtained from the atmosphere. Thus an acre of an average crop of mangolds will abstract from the air before reaching maturity about 3500 lb. of carbon, which represents the carbon dioxide in a 200-feet layer of air covering some 180 acres. The amount of carbon dioxide present in the atmosphere is continually being affected by the two kinds of actions described, oxidation of carbon compounds and decomposition of carbon dioxide by plants, and these processes approximately balance each other.

Ammonia and Nitric Acid, or some oxide of nitrogen, are often present in the air, but in exceedingly small quantities. Near Paris the average amount of ammonia is estimated at 1·7 milligrammes per 100 cubic metres in winter, and 2·1 milligrammes per 100 cubic metres in summer. Other observers have found three times as much in June as in February.

The nitric acid is probably present as ammonium nitrate (or a portion of that reported as nitric acid may really be nitrous acid as ammonium nitrite). The source of the ammonia is probably the putrefaction of nitrogenous organic matter, as the amount is generally larger near towns than in the open country.

The quantities of these substances are generally so small that they can only with great difficulty be estimated, and since they are readily soluble in water they are largely removed from the air by rain. In rain-water, therefore, they become more concentrated, and analyses of rain are of much interest as indicating the quantities of these and other substances present in the air. Many analyses have been published—*e.g.*, those made by Angus Smith in 1872, of which the following is an abstract: the figures represent parts per million of the rain water.

Place of Collection.	Hydrochloric Acid.	Sulphuric Acid.	Ratio H_2SO_4 : 100 HCl.	Free Acid, calculated as H_2SO_4.	Ammonia.	Albuminoid Ammonia.	Nitric Acid.	Oxygen required as Permanganate.
Ireland, Valentia .	48·67	2·73	6	None	·18	·03	·37	·06
Scotland, 8 coast places .	12·91	7·66	59	2·44	·99	·11	·47	·65
„ 12 inland places .	3·38	2·06	61	·31	·53	·04	·31	·26
England, 12 inland places . . .	3·99	5·52	138	None	1·07	·11	·75	·47
Scotland, 6 towns .	5·86	16·50	282	3·16	3·82	·21	1·16	1·86
„ Glasgow .	8·97	70·19	782	15·13	9·10	·30	2·44	10·04
England, 6 towns .	8·70	34·27	394	8·40	4·99	·21	·85	2·74
„ London .	1·25	20·49	1645	3·10	3·45	·21	·84	—
„ Manchester.	5·83	44·82	768	10·17	5·96	·25	1·01	3·22

Experiments at Rothamsted in 1880–89 showed a mean of 0·426 part of nitrogen as ammonia and 0·139 part of nitrogen as nitrates per million of rain, which, with a total annual rainfall of 29·27 inches, gave a total of 2·823 lb. of nitrogen as ammonia and 0·917 lb. of nitrogen as nitrates brought down by the rain on each acre. To these must be added about 0·8 lb. of nitrogen as organic matter, giving a total of about 4·5 lb. of nitrogen per acre per annum.

As the mean of investigations carried on at seven Continental stations between 1864 and 1872, 0·47 part of nitrogen as nitric acid and 1·26 parts of ammonia per million of rain were found, equivalent to a total of 10·18 lb. of combined nitrogen per acre per annum. These results are much higher than the English figures, probably because some of them were obtained in or near towns. In tropical countries the amounts are generally much higher. Thus in Pretoria in the year July 1, 1904, to June 30, 1905, the writer found a mean of 1·194 parts per million of nitrogen as ammonia and 0·196 part per million of nitrogen as nitric acid in the rain, equivalent, with a total rainfall of 24·31 inches, to 7·67 lb. of combined nitrogen per acre per annum. It is also noteworthy that in the Transvaal the whole of this is brought down during the active growing season—the summer, September to April—for the winter months are almost absolutely rainless.

The combined nitrogen of the air in the rain is of considerable importance to plants. The amount given above for Rothamsted, 4·5 lb. combined nitrogen per acre per annum, is equivalent to the application of about 27 lb. of nitrate of soda, while that for Pretoria corresponds to 47·6 lb. of nitrate of soda, or 36·2 lb. of sulphate of ammonia.

Ozone is an active form of oxygen obtained from ordinary oxygen by the action of the electric discharge, especially the form known as the *silent* discharge, or by the slow action of certain readily oxidisable substances—*e.g.*, phosphorus—upon oxygen or air. It is a gas with a peculiar odour, capable of oxidising most organic substances and many metals. It is doubtful if its presence in air has any beneficial effect upon people breathing it, but it affords a proof that the air is free from oxidisable organic matter, and probably from microorganisms. Its amount in the air is very variable, but always very small; in towns or over marshes it is rarely found. It is most abundant in Europe during May or June, especially after violent thunderstorms or gales.

In addition to the substances already mentioned as occurring in air, there are others which may be described as accidental. Near towns or wherever much coal is burnt, air is found to contain *sulphur dioxide*, which, on oxidation, passes into sulphuric acid. The rain of towns is usually distinctly acid from this cause, and to this acidity is mainly attributable the difficulty of growing plants, particularly grasses, in towns.

Air also contains suspended matter of various kinds. Particles mainly composed of common salt, NaCl, are very abundant, resulting from the evaporation of the tiny droplets of sea-water sent up as spray from breaking waves. These particles are carried immense distances by the wind, and are the chief source of the chlorides found in rain-water. The amount is greatest at places near the coast, but even far inland rain often contains considerable quantities of chlorides.

In addition to the inanimate solid matter, air usually contains micro-organisms or their spores. These are most abundant in towns or wherever organic substances are undergoing decay; on mountain-tops they are very rare. The existence of these micro-organisms is very important, since to them are attributable many diseases and many forms of putrefaction and fermentation. They are of particular interest and importance with reference to dairy work, fermentation in breweries, the manufacture of wines and spirits, and the preservation of all forms of organic matter.

CHAPTER III.

THE SOIL.

Soil is the layer of disintegrated rock, mixed with the remains of plants (and animals), which covers a large portion of the land. It also contains living organisms of various kinds, and variable quantities of water and air. The depth of soil varies greatly, being usually from six to twelve inches, but sometimes is as great as several feet. Beneath it is the *subsoil*, which differs from it in being less oxidised and less rich in organic matter. In many cases the line of separation between the soil and subsoil is very clearly marked, often by a difference in colour, the subsoil being generally the lighter coloured.

Soils, consisting so largely of disintegrated rock fragments, naturally depend for their chemical nature mainly upon the character of the rocks beneath. Rocks are often classified by geologists, according to their origin, into three classes :

(1) *Igneous rocks—i.e.*, those which have resulted from the cooling of intensely heated fluid matter.

(2) *Sedimentary rocks—i.e.*, those produced by the settling out of particles suspended (or in some few cases dissolved) in water.

(3) *Metamorphic rocks—i.e.*, those which have been essentially altered in character since their deposition.

Rocks are rarely homogeneous—*i.e.*, alike in all parts—but are generally made up of several components mingled together, often lying side by side in separate crystals. These components, which have a more or less definite molecular structure and composition, are called *minerals*. Distinctly separate minerals are most frequently to be found in the igneous rocks.

Minerals and Rocks.—The following minerals are exceedingly abundant, and are of importance in agriculture:

Quartz is chemically the oxide of silicon, SiO_2. It has been estimated that 35 per cent. of the solid crust of the earth is composed of quartz. It is one of the hardest and most durable of substances, being almost insoluble in water and little affected by weather. In many cases, however, the other constituents of rocks are acted upon by atmospheric agencies, and the quartz crystals, being thus loosened, are removed by running water. Fragments of quartz consisting of crystals rounded and worn by mechanically rubbing against each other form the largest constituent of many soils. Such sand is devoid of plant food.

Felspar is probably the most abundant of all minerals, constituting, it is estimated, 48 per cent. of the earth's crust. Chemically felspar is a double silicate of alumina and potash, soda, or lime. The chief varieties of felspar are;

Orthoclase, $K_2O.Al_2O_3.6SiO_2$;
Albite, $Na_2O.Al_2O_3.6SiO_2$; and
Labradorite $(Na_2.Ca)O.Al_2O_3.3SiO_2$.

Orthoclase, or potash felspar, is the most important. It is a hard mineral, often coloured pink or green, though sometimes white. Although hard, it is easily attacked by water and carbon dioxide, the potash being largely removed in solution as carbonate and silicate, while the final residue left is kaolin, or china clay, $Al_2O_3.2SiO_2.2H_2O$. Orthoclase furnishes a considerable quantity of the potash found in soils.

Mica, another abundant mineral, characterised by its tendency to split into thin elastic plates, is essentially a silicate of alumina and potash, $3Al_2O_3.K_2O.4SiO_2$, though ferric oxide is usually present, replacing a portion of the alumina, and the potash is often partially replaced by magnesia, lime, or soda. Mica also suffers decomposition under the influence of the weather, but not so readily as felspar. It furnishes plant food in the potash, iron and lime which it contains. Its amount in the earth's crust has been estimated at 8 per cent.

Silicates of Magnesia are also very abundant, the magnesia generally being partially replaced by lime, ferrous oxide, or manganese oxide. *Talc* and *steatite* may be taken as typical, their composition being represented by the formula $6MgO.4SiO_2.H_2O$ *Hornblende* and *augite*, $(Mg.Ca.Fe.Mn)OSiO_2$, are also very abundant. They usually contain alumina and ferric oxide. These minerals are easily acted upon by air and water, and often yield brightly coloured (due to presence of iron) clays.

Calcium Carbonate occurs in a great many crystalline forms in the varieties of *calcite* (rhombohedral), and *arragonite* (rhombic), also in the massive form as *chalk*, *limestone* and *marble*. These are all essentially $CaCO_3$, but the calcium is more or less replaced by magnesium, and, moreover, most forms of calcium carbonate contain notable quantities of phosphoric acid. Calcium and magnesium carbonates, though only slightly soluble in pure water, are readily soluble in water containing, as is the case with nearly all forms of natural water, carbon dioxide. Rocks containing these substances, therefore, are quickly eroded by exposure to the atmosphere. Calcium carbonate is of great importance in soils, both on account of its providing plant food and because of its relationship to many of the processes which go on in soils.

Clay in its pure form is hydrated silicate of alumina, $Al_2O_3.2SiO_2.2H_2O$, and is therefore devoid of plant food. Ordinary clay, however, contains iron oxide and potash, the latter remaining from the felspar from which most clays have been formed. It therefore supplies potash to plants. Its physical properties are very important, and greatly influence soils in which it is abundant.

ROCKS

The igneous rocks are the oldest, and it was from the *débris* of igneous rocks that *sandstones*, *shales* and (indirectly) *limestones* were formed.

Sandstones, Grits and Conglomerates consist of the larger fragments of the waste resulting from the denudation of igneous rocks—*e.g.*, *granite*—which, in consequence of their size and weight, have been deposited at or near the mouths of rivers. Their main ingredient is silica, the grains of sand consisting largely of quartz crystals, but in many cases fragments of felspar, mica and other minerals are present. The grains are cemented together either by calcium carbonate (in "calcareous sandstone"), clay ("argillaceous sandstone"), ferric oxide ("ferruginous sandstone"), or colloidal silica ("siliceous sandstone"). Soils produced by the decay of sandstones are light and friable and poor in plant food, unless there be present potash-containing minerals, *e.g.*, felspar and mica.

Shales consist essentially of the plastic, hydrated aluminium silicate, *kaolin*, $Al_2O_3.2SiO_2.2H_2O$, but may contain any other extremely finely divided matter obtained by the erosion of the original rock. Particles of undecomposed or partially decomposed felspar are often present, and these are important because of the potash they contain. Soils formed from shale are "heavy" and clayey, generally sufficiently rich in potash, but poor in phosphates and in calcium carbonate.

Limestones, in which term *chalk* and *magnesian limestone* may also be included, have been formed largely by the abstraction from solution by living organisms—*e.g.*, coral polyps and shellfish—of calcium and magnesium carbonates. They often contain small quantities of clay, ferric oxide, silica and nearly always calcium phosphate in comparatively large quantities

The soil left on limestone or chalk consists mainly of these foreign substances, most of the calcium carbonate itself having been dissolved out by the combined action of water and carbon dioxide. It sometimes happens that the soil on limestones would be benefited by the application of manures containing lime.

Limestone only exerts its characteristic and important functions in a soil when in a very finely divided state; in the form of gravel or sand it is little better than ordinary siliceous sand. In the finely divided condition it has two very valuable functions—as a source of plant food, by virtue of the phosphates, sulphates, and calcium which it contains, and, what is more important, as a basic material necessary for the processes of nitrification.

Sedentary and Transported Soils.—These terms are convenient in distinguishing between soils which are made up of the *dêbris* resulting from the weathering of the particular rock on which they rest (sedentary soils), and those which owe their origin, not to the rock below them, but to matters brought from a distance and deposited there (transported soils). The rich alluvial soil in the lower reaches of river valleys consists largely of matter which has been brought down by the river from the higher parts of the valley, and since the materials have in many cases, been brought from various rock formations the resulting soil generally possesses a greater fertility than would be shown by a soil formed exclusively by the weathering of any one kind of rock.

Other excellent examples of transported soils are afforded by the "warp" soils of the Humber and Trent. In these cases the soil itself is transported, and not merely the materials out of which it is (afterwards) formed.

Glaciers are also the means of transporting large quantities of materials out of which soils may be formed. Large tracts of country are covered with a thick deposit of clay and rock fragments which have been brought from a great distance by glaciers. Such deposits are known as glacial drift, and often quite obscure the actual rock strata beneath. In this case the transportation of the soil took place many ages ago.

Wind also sometimes acts as a means of transporting sand, volcanic ashes, &c., from a distance and depositing them in a new position, there to form a soil.

Formation of Soils.—In the formation of a soil the first step is the mechanical breaking down of the rock into small fragments. The chief agencies by which this is accomplished are:

1. **Water,** which acts in several ways.

(*a*) **Mechanically**—

(i) *By Liquid Water.*—The flow of water over the surface of a rock abrades it slightly. The action is greatly increased by the attrition of pebbles, gravel, &c., urged by the current over the rock. In this way streams in the rapid portions of their course carry away large quantities of sand, gravel, &c., and deposit them in the lower and quieter portions of their course as alluvial deposits.

(ii) *By Glaciers.*—Glaciers are slowly moving masses of ice formed by the compression of snow by its own weight. In their descent glaciers, aided by fragments of rocks imbedded in them, grind away the rock over which they pass, and the stream which issues from the snout of a glacier is always heavily charged with the finest mud, while the termination of a glacier is marked by huge piles of rock fragments of all sizes ("moraines") carried down on the surface of the moving ice. This agency has been very active in past ages, even in countries —*e.g.*, Britain—where no glaciers are now to be found.

(*b*) **By Alternate Frost and Thaw.**—Ice occupies a greater volume than the water from which it is formed. The increase in volume in the act of freezing amounts to about 10 per cent., and unless this increase be allowed to occur water cannot freeze, however much it be cooled. In the disintegration of rocks this agency is very powerful. During the warm part of a wet winter's day the crevices of a rock become filled with water. If the temperature falls, the water begins to freeze, at first on the surface, so that every crevice becomes plugged with ice. As the liquid within continues to lose heat it tends to solidify. This it can only do if it be allowed to expand, and in order to do this it must either widen or lengthen the crevice which contains it. When the next thaw comes the enlarged crevice again fills with water; the next frost repeats the action, and so the process goes on, and in this way a rock, even the hardest, is soon broken up into fragments Continuous frost appears rather to hinder denudation by cementing the parts of a rock more firmly together. In addition to the effect of expansion just described, ice formation probably acts as a disintegrating agent upon soils and rocks by virtue of crystallisation; the mere growth of crystals of ice, apart altogether from the expansion which accompanies their formation, exerts a disruptive effect upon the material in which they are formed.

(*c*) **Chemically.**—Many minerals when exposed to the action of water are acted upon in such a way as to lead to their disintegration. A portion is often carried away in solution, while the remainder crumbles away and is removed by rain or running water. In many rocks the cementing material which holds the grains of silica together is thus acted upon, when the silica, though perhaps not appreciably dissolved by water, becomes loosened and easily removed. Calcium, ferrous and magnesium carbonates are particularly liable to be thus removed, for though they are only very slightly soluble in pure water they readily dissolve if carbon dioxide be present, owing to the formation of bicarbonates; thus—

$$CaCO_3 + H_2CO_3 = Ca(HCO_3)_2.$$

2. **Air.**—This also acts in various ways.

(*a*) **Mechanically.**—Wind actually detaches large projecting pieces of rock in mountainous districts, and sends them crashing down on to the rocks or screes below. In addition, by hurling sand and small pebbles against the surface of rocks it brings about the erosion of the latter. In most cases the effects of this form of erosion are masked and hidden by those of other denuding agents, but occasionally—*e.g.*, at Brimham Rocks, in Yorkshire—the curious undercuttings produced by this action are very clearly shown.

(*b*) **Chemically.**—In many rocks are minerals capable of taking up oxygen—*e.g.*, ferrous carbonate. On exposure to air oxidation occurs, and the mineral swells up, and often crumbles to powder, thus loosening the other minerals in the rocks. The oxidation is in many cases accompanied by a change in colour, from green or grey to yellow or red. The carbon dioxide in the air also acts corrosively on carbonates in the presence of water.

3. **Animals.**—Burrowing animals—*e.g.*, rabbits and moles—admit air into soil or sand, and thus favour the changes which air produces. The part played by the humbler creatures, earthworms, is probably much more important. They bring portions of the subsoil to the surface, they draw dead leaves and other vegetable refuse into their burrows, and they pass large quantities of the soil through their bodies and deposit it on the surface at a rate which has been estimated, on the average, to be about ten tons per acre per annum.

Ants in some hot countries—*e.g.*, Africa—perform much the same work as earthworms, though perhaps even on a larger scale. In many parts of South Africa the veld is thickly studded with the hills of the white ant, usually about two feet high and about two or three feet in diameter, though much larger ones are often found. The ant hills are full of cavities and chambers inhabited by the insects, and much vegetable matter is stored in them. The material of the ant-hills consists of the smaller parts of the surrounding soil, the particles being cemented together and the whole made practically water-tight. When the veld is ploughed and sown it is always noticed that where ant-hills had formerly been, the crop is heavier than elsewhere. The following analyses of ant-heap material and the adjacent soil, taken by the writer near Christiana, in the Transvaal, will show the richness of such substances:

	Ant-heap. Per cent.	Veld soil. Per cent.
Stones removed by 3 mm. sieve	None	8·66
The fine portion contained—		
Moisture	3·28	1·98
Loss on ignition *	13·03	4·14
Insoluble matter (sand, &c.)	74·59	82·86
Iron oxide and alumina	8·79	9·89
Lime	0·30	0·12
Magnesia	0·40	0·18
Potash	0·39	0·25
Phosphoric acid (P_2O_5)	0·06	0·06
	100·84	99·48

* Containing nitrogen	0·343	0·080
"Available" potash	0·0182	0·0121
"Available" phosphoric acid	0·0102	0·0017

4. **Plants.**—These act in several ways:—

(*a*) **Mechanically.**—The roots penetrate the rocks or soils, rendering them porous, and thus admitting air and water. Plants growing on rocks also tend to keep the surface moist, and thus favour erosion.

(*b*) **Chemically**:—

(i) *During life.*—By the corrosive action of the liquid secreted by the roots and root-hairs.†

(ii) *After death.*—By producing carbon dioxide and various vegetable acids which have solvent properties upon certain constituents of soils.

The formation of a mass of pulverised rock, however, is not all that is necessary for producing a fertile soil. Ordinary plants require the presence of organic nitrogen compounds of the nature of "humus," and the chief source of such matter is the remains of previous plants. The question at once suggests itself, how did the soil first obtain its organic matter necessary for plant growth? According to recent researches,

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† Recent work seems to point to carbon dioxide evolved by the root-hairs as the corrosive agent, not any vegetable acid.

micro-organisms capable of assimilating free nitrogen from the air and carbonaceous matter from carbon dioxide are to be found on rock surfaces even near the summits of mountains. Certain lichens and algæ are also apparently able to grow without combined nitrogen. Such growths, when they die, furnish organic matter to the soil, and gradually fit it for sustaining the life of higher plants.

The Constituents of Soil.—A popular and convenient classification of soil constituents is the following:

1. *Sand*—mainly silica, but containing small fragments of felspar, mica, limestone, &c.

2. *Clay*—mainly kaolin, but containing also finely divided silica, felspar, &c.

3. *Limestone*—finely divided calcium carbonate.

4. *Humus*—the somewhat indefinite nitrogenous and carbonaceous material resulting from the decay of plants.

These constituents have great influence upon both the physical and chemical properties of soil. The physical properties of the constituents themselves can be gathered from the following table:

—	Real Specific Gravity.	Apparent Specific Gravity.	Specific Heat, Equal Weights.	Specific Heat, Equal Vols.	Conductivity for Heat.	Water held by 100 Parts by Weight of Substance.
Sand . .	2·62	1·45	·189	·499	100	25
Clay . .	2·50	1·01	·233	·568	90·7	70
Limestone .	2·6	—	·206	·561	85·2	85
Humus. .	1·30	0·34	·477	·587	90·7	181

It may be desirable to explain the meaning of the terms in the above table.

Real specific gravity is the weight of any volume of the solid material compared with that of an equal volume of water. Apparent specific gravity is the weight of any volume of the powdered material, with its enclosed air spaces, compared with that of an equal volume of water.

Specific heat, *equal weights*, is the ratio of the amount of heat necessary to raise the temperature of a certain quantity of the substance through, say, 10°, compared with that required to raise an equal weight of water through the same range of temperature. (See also chap. iv.)

Specific heat, *equal volumes*, is easily understood—the relative amounts of heat required to raise equal volumes of the material and of water through a given range of temperature.

Conductivity for heat is the quantity of heat which passes through a cube of the substance when its opposite faces are kept at different but constant temperatures, compared with that which passes through a similar cube of another substance under exactly similar conditions. In the table the numbers referred to silica = 100 are given. The meaning of the figures in the last column is sufficiently explained in its heading.

It is to be noted that some of the above values will vary with difference in degree of fineness of the material and other circumstances.

Sand is seen to have the greatest conductivity for heat and the highest specific gravity, but the lowest specific heat and lowest water-retaining power of all soil constituents. As a plant food sand is practically valueless, except for the small amounts of potassium, iron, and calcium sometimes present in fragments of minerals occurring mixed with the true sand. Its physical properties have great and often valuable effects upon the character of a soil, particularly with regard to friability and its relations towards water and heat.

Clay, if pure, is free from plant food, but is usually well supplied with potash because of the felspar present. Common clay, however, often contains quartz and calcium carbonate (as in marls) in addition to felspar, the true clay, or *kaolin*, $Al_2O_3.2SiO_2.2H_2O$, acting as a kind of cement to the grains of other minerals.

It is thought that even in the purest clay there is a small quantity of aluminium silicate more hydrated than the rest, to which the tenacity and plasticity of the clay is due. If this constituent be fully swollen with water the clay is sticky and impervious, while if it be shrunken or coagulated the clay becomes more friable and less plastic. Coagulation is easily brought about by the addition of acids or of many salts; calcium compounds are particularly effective in this respect, and it is to this cause that the improvement in the texture of heavy clay soils produced by the application of lime is due. It can be illustrated by shaking up some pure clay with distilled water and pouring the muddy liquid into two cylinders; if to one some lime-water be added, the clay will be coagulated or flocculated, and will settle to the bottom in a short time, leaving a clear liquid above it, while the other will fail to clarify even after standing a day or two.

The plasticity of clay is permanently destroyed by heat, which expels the two molecules of water of hydration, the anhydrous aluminium silicate left (*e.g.*, in the making of bricks or tiles) not being capable of again combining with water.

Limestone.—Calcium carbonate is present in a soil in a finely divided state disseminated among the other constituents, but in addition there are often small fragments which are classed with the "sand." The former condition, however, is the one which is of importance. It furnishes plant food by virtue of the calcium, magnesium and phosphoric acid present, but it plays other, perhaps more important, functions. It modifies the plasticity of the clay in the manner characteristic of calcium compounds, and acts as a weak base, for, though it is a true salt, the carbonic acid is so weak an acid that it is readily displaced by stronger acids, which unite with the calcium, and thus lose their acidity. Acids are produced by the decay and fermentation of vegetable matter, and if large quantities of such material are present in a soil there is often a great tendency for the production and accumulation of free acid, and the conditions then become unfavourable for the growth of most useful plants. Such land is often spoken of as "sour," and can best be restored to fertility by the application of free lime or of calcium carbonate. In soils containing an abundance of calcium carbonate such sourness never occurs.

Another important function performed by the calcium carbonate is that of acting as a basic material necessary for the important process known as *nitrification;* this will be explained hereafter. It is also important in the chemical changes which are produced by the application of certain manures to soil—*e.g.*, in the case of ammonium sulphate, when the sulphuric acid radical unites with calcium and runs off in the drainage water, the ammonia being retained by the soil.

Humus, the characteristic organic matter of soil, is of great importance on account of its chemical and physical properties. The chemical nature is little understood, despite many investigations. Many analyses of humus extracted from soils have been made, but no definite constitution has yet been assigned to it. Thus four samples gave the following:

Carbon	44–50 per cent.
Hydrogen	3–6 ,,
Nitrogen	6·5–10 ,,
Oxygen	28–35 ,,
Ash	4–12 ,,

The ash was found to contain 7·5 per cent. of potash, 12·4 per cent. of phosphorus pentoxide, together with silica, ferric oxide, alumina, soda, and other substances. According to other investigations, humus contains several distinct and complicated acids: *humic, ulmic, crenic* and *apocrenic acids;* but the nature of these bodies, which are said to be compounds of carbon, hydrogen and oxygen, is not known, though several formulæ have been suggested for them.

Humus seems to be of an acid nature, and the calcium compound is insoluble in water. The ash constituents associated with humus are thought to be of considerable importance, because they are apparently easily available for plants. The nitrogen is of the utmost value to plants, though in most cases it cannot be directly utilised. but must first be converted into nitrates by oxidation brought about under the influence of the micro-organisms in the soil.

The physical properties of humus are also of importance. It is a dark-coloured, bulky, porous substance, possessing considerable tenacity or cementing power and a great capacity for holding water, also for absorbing and retaining many important items of plant food—*e.g.*, ammonia, potash and lime. The dark colour causes soils rich in humus to become heated by the sun's rays more rapidly than light-coloured ones. The bulkiness and porosity permit of freer admission of air, and so promote oxidation. In clay soils these properties confer lightness and permeability. The cementing power is particularly important in sandy soils, to which it imparts coherence and water-retaining power, while its absorptive power is of great value in retaining for the use of the plant many soluble substances which might otherwise be removed in the drainage.

By the decay of humus, which is always going on, the proportion of carbon dioxide in the soil water is increased, and thus the solvent powers of the latter for plant food existing in the mineral portions of the soil are enhanced.

Chemical Changes occurring in Soils.—The reactions taking place in a soil are very numerous, and of a type not familiar to a student of elementary chemistry, the direction of the change being largely dependent upon the conditions of temperature, concentration, relative quantities of the reacting substances, and other circumstances.

The inorganic matter is subjected to the same influences as lead to its breaking down in the formation of the soil from the rock, but the changes go on at an accelerated rate, because of the greater quantity of carbon dioxide produced by the decay of the organic matter. Fragments of felspar, for example, are probably decomposed in accordance with the equation

$$Al_2O_3.K_2O.6SiO_2 + CO_2 + 10H_2O = Al_2O_3.2SiO_2.2H_2O + K_2CO_3 + 4H_4SiO_4,$$

the silicic acid and potassium carbonate being dissolved and either carried away in the drainage, or the latter may be absorbed by the roots of a plant or by some of the absorptive constituents of the soil. The calcium carbonate is dissolved by the carbon dioxide solution—

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$$

—and is either carried away or absorbed, or perhaps acts upon felspar or other silicate :

$$Al_2O_3.K_2O.6SiO_2 + Ca(HCO_3)_2 + 9H_2O = K_2CO_3 + CaCO_3 + Al_2O_3.2SiO_2.2H_2O + 4H_4SiO_4.$$

The phosphoric acid in minerals probably exists largely as tricalcium phosphate, $Ca_3P_2O_8$. This substance is nearly insoluble in water, but by the action of carbon dioxide may be changed thus :

$$Ca_3P_2O_8 + 2CO_2 + 2H_2O = Ca_2H_2P_2O_8 + Ca(HCO_3)_2.$$

The dihydrogen dicalcium phosphate, or, as it may be called, the monocalcium monohydrogen phosphate, $CaHPO_4$, is slightly soluble in water, and therefore available for plants. In contact with ferric hydrate or aluminium hydrate it is converted into ferric phosphate, $FePO_4$, or aluminium phosphate, $AlPO_4$, and held back in the soil in a very finely divided state, and, though then insoluble in water, is capable of being dissolved by the acid juices of plants' roots. In fact, many of the substances which become soluble owing to the action of carbon dioxide, water, or other reagents do not necessarily remain in a soluble form. If they did they would be to a great extent washed out in the drainage water.

Most soils contain substances which have the power of uniting with potassium, ammonium, and, to a less extent, calcium compounds, and with phosphates, converting them into insoluble compounds. If solutions of potassium or ammonium sulphate or of sodium phosphate be filtered through a thick layer of soil, the filtrate will be found to be almost free from potassium, ammonium, or phosphoric acid, though the sulphuric acid may be present in the filtrate in the form of calcium sulphate. The substances which exert this retentive power in the soil are believed to be:

1. *The humus*, which, in addition to acting as an acid, has the absorptive power characteristic of extremely porous substances—*e.g.*, charcoal.

2. *Hydrated double silicates*, probably transition bodies, produced by the weathering of felspar, &c., possessing a composition similar to the minerals known as *zeolites* (so called from a Greek word meaning, 'to boil," and applied to them because of their frothing up—due to the escape of steam—when they are heated before the blowpipe). In many cases if one metal be absorbed an equivalent quantity of another metal (often calcium or magnesium) is given up to take its place, and is carried away by the drainage water.

3. *Ferric and Aluminium Hydrates.*—These substances can combine with phosphoric acid, forming the very insoluble phosphates of iron or aluminium; they can also retain lime, potash and ammonia, probably owing to the fact that they have weak acidic functions. The bases, however, are not retained very tenaciously, and can be removed by prolonged washing with water.

Phosphoric acid is retained most tenaciously by nearly all soils, and the loss of this substance in the drainage is usually insignificant.

The dissolved matter in soil water is distributed in two ways:

1. *By diffusion*—*i.e.*, the motion of the dissolved substance from one part of the solvent to another. This process, which tends to make the liquid uniform in concentration, takes place more rapidly with some substances than others. Colloidal bodies, or those which resemble glue or gum in character, have the lowest rate of diffusion, whilst small differences are shown by the various acid radicals and the metals of salts; thus chlorides diffuse more rapidly than nitrates or

sulphates, and potassium salts than ammonium or calcium compounds.

2. *The Motion of the Liquid itself.*—The solution in a soil moves from two causes:

(i) GRAVITATION.—This is the attraction of the earth for water, and only acts vertically downwards, tending to make the solution sink into the soil.

(ii) SURFACE PRESSURE.—Every liquid surface exerts a pressure upon the liquid within it. This is readily understood when it is remembered that in a liquid every particle is attracted by its neighbours, with a considerable force by those particles nearest to it, and with less and less force by particles more and more distant. Those at the surface are only affected by the attraction of those within the liquid; the surface, therefore, is under a pressure acting inwards. A liquid free to move always arranges itself so as to have the smallest possible surface. If no other forces were acting it would always assume a spherical form. Under ordinary conditions gravitation far overpowers the effects of surface pressure, but if the quantity of liquid be small the gravitation effect becomes small and surface pressure asserts itself; the liquid thus tends to become spherical. Solid substances often exert an attractive force (adhesion) upon liquids, so that when they touch a liquid they become wetted.

The pressure exerted by a liquid surface depends upon its form; it is less than that of a plane if the surface be concave, greater if convex. This can be understood by reference to the diagram.

Let *A B* (Fig. 1) represent a plane surface of a liquid, and consider any particle, *C*, well below the surface. The particles whose attractive forces for *C* have any appreciable magnitude may be assumed to lie within an imaginary sphere encircling *C*, and represented in section by the circle. It is evident that the resultant of all the attractive forces acting upon *C* will be *nil*, since it will be attracted equally in all directions. It therefore remains in equilibrium. Now consider a particle, *D*, at the surface. The imaginary limit of the particles which have any appreciable effect on *D* would be represented by a similar sphere, or, rather, by a hemisphere, since above the surface there are no liquid particles. The resultant of the forces acting upon *D* will be a considerable force acting towards the body of the liquid and at right angles to the surface. The same would apply to all particles on the surface, and to a less degree upon all particles nearer to the surface than the radius of the imaginary hemisphere. Hence a plane surface exerts a pressure upon the liquid within it.

FIG. 1.

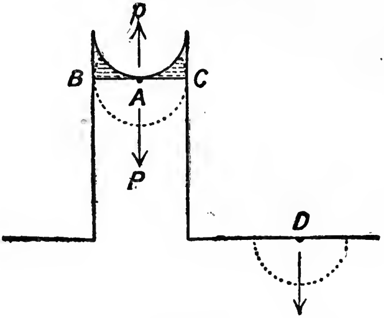

FIG. 2.

Now take a surface which is concave, and consider a particle, *A* (Fig. 2), on the surface. Draw a circle, with *A* as centre, to represent the imaginary limit beyond which the attraction of particles for *A* becomes inappreciable.

Through A draw a horizontal line, BC. It is evident now that the downward pressure exerted by the forces acting upon A are less if the surface be concave than if it were horizontal, because there is, in the former case, the upward resultant of the forces exerted by the particles in the shaded spaces. Let this upward attraction be represented by p, and the downward force, if the surface were plane, be represented by P. The final resultant will be P for the plane surface and $P - p$ for the concave, acting upon each particle on the surface. It is also evident that the more concave the surface is, the greater will be p and the less will be $P - p$.

Hence when a tube which is wetted by a liquid, and which therefore has within it a concave surface of the liquid, is immersed in a liquid the latter rises until the hydrostatic pressure in the tube is capable of balancing the difference between the pressure exerted by the liquid surface outside the tube (which will be approximately P if the area of the vessel be large) and that exerted by the surface in the tube—*i.e.*, $P - p$. This is the cause of *capillarity*, as the rise of liquid in hair-like tubes is called.

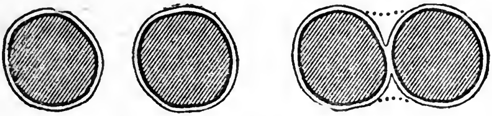

FIG. 3.

Many writers on soils appear to think that in soils there are such tubes, and they ascribe the rise of water to this action. It is extremely improbable that this assumption is correct, for the interstices of a soil are not filled with water, but, as is well known, are largely occupied by air. True capillarity may perhaps operate to a small extent, in some of the composite particles of soil where the interstices among the cohering fragments become entirely filled with water. But, in the great mass of the soil, the motion of the water must be due to the action of surface pressure exerted in the manner described. The rise of water is due to the same cause as that which produces capillarity, but acting in a different way. If two particles of soil, each covered with a thin film of closely adherent water, be caused to touch, the water films at the point of contact must take up a concave surface. At this point the pressure exerted by the liquid surface is less than elsewhere. Consequently water moves from the films around the particles and tends to accumulate at the space between them until the curvature becomes less, indicated by the dotted line (Fig. 3). The water is thus held between the particles by a surface tension effect of the same kind as that which causes capillarity. Now suppose three particles to be in contact, each with its film of moisture, and assume that the amount of water held between *B* and *C* (Fig. 4) is greater than that between *A* and *B*. The water surfaces at the line of contact between *A* and *B* will be more concave than those between *B* and *C*, and consequently the surface pressure exerted there will be less. Water will therefore move round *B* in the direction of *A* until the pressure exerted by the concave surface between *A* and *B* is equal to that exerted between *B* and *C*. This action will occur at every surface between neighbouring particles, and will account for the movements of water from particle to particle, even though there be many interstices filled with air.

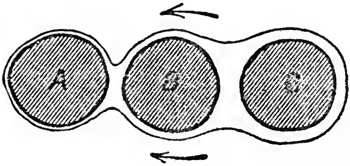

FIG. 4.

It is to be noted that the movements of water due to this cause may be in any direction; it will practically always be from a more wet to a less wet part of the soil. The structure of soil, therefore, in respect to the cause of the rise of water from below is to be regarded in this way, and not by assuming that the soil particles form hair-like tubes filled with water. The quantity of water which is held by a soil and the readiness with which the water is raised from below is thus largely dependent upon the number of points of contact of the soil particles, each contact giving rise to the formation of a concave surface of the water layer, thus determining the movement of water to that part. The number of these re-entering angles or concave surfaces of water will increase with the fineness of subdivision of the soil. At the same time excessive fineness of the particles will tend to make the process slower, by increasing the friction offered to the motion of the water.

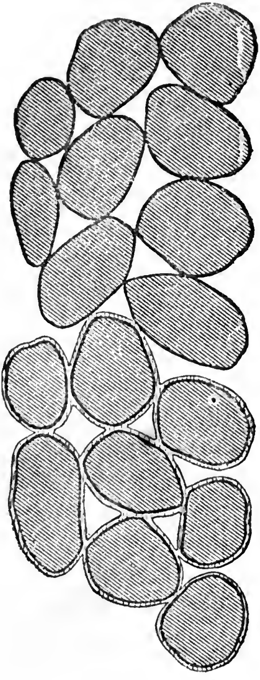

FIG. 5.

If all the particles are already wet the action described will occur rapidly, but if some of the particles are dry, then the action will not occur until the dry particles become wetted by a slow, creeping movement of the water over them. Hence, although stirring a soil increases the rapidity of evaporation from its surface, the total loss of water may be diminished if the upper layers be frequently stirred; they thus become dry, the particles have fewer points of contact, and the flow of water from below is greatly impeded by abolishing, for a time, the production of the concave surfaces of water films (at the contacts of the particles), which, as described above, are so powerful in assisting the movements of the water.

Nitrification.—Perhaps the most important reactions going on in a soil are those connected with the decay of organic matter and the change in the state of combination of the nitrogen. The organic matter is continually being oxidised, the carbon being mainly converted into carbon dioxide, though certain organic acids are also formed, and may be injurious if the soil be deficient in limestone or other substance capable of acting as a base. The nitrogen originally present as complex organic bodies is eventually converted into nitrates, and this change is known as *nitrification*. It is really a process of oxidation, and may be divided into three stages:

1. The conversion of the complex nitrogenous organic compound into ammonium compounds.
2. The oxidation of ammonia into nitrites.
3. The oxidation of nitrites into nitrates.

The first step is very easily brought about in some cases; *e.g.*, urea, the characteristic constituent of urine, only requires to combine with water to give ammonium carbonate:

$$\underset{\text{Urea}}{CO(NH_2)_2} + \underset{\text{Water}}{2H_2O} = \underset{\substack{\text{Ammonium}\\ \text{carbonate}}}{(NH_4)_2CO_3}.$$

This occurs very readily, and is the cause of the strong ammoniacal smell perceptible in stables. With other nitrogenous compounds the change does not occur so readily. In almost all cases, the reaction is brought about by the life processes of some micro-organisms; in some cases, *moulds*, in others, *bacteria* are the agents which do the work.

The ammonium compounds thus formed are absorbed by the constituents of the soil, until another set of organisms act upon them. The chemical reaction involved is very simple:

$$\underset{\substack{\text{Ammonium}\\\text{carbonate}}}{(NH_4)_2CO_3} + \underset{\text{Oxygen}}{3O_2} = \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \underset{\substack{\text{Nitrous}\\\text{acid}}}{2HNO_2} + \underset{\text{Water}}{3H_2O}.$$

This change, however, can only occur if some basic material be present to neutralise the nitrous acid, probably calcium carbonate—

$$\underset{\substack{\text{Calcium}\\\text{carbonate}}}{CaCO_3} + \underset{\substack{\text{Nitrous}\\\text{acid}}}{2HNO_2} = \underset{\substack{\text{Calcium}\\\text{nitrite}}}{Ca(NO_2)_2} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \underset{\text{Water}}{H_2O}$$

—and is accomplished by the action of a micro-organism, which may conveniently be called the *nitrous organism*, or *Nitrosococcus*. Lastly, the nitrite is converted by oxidation into a nitrate—

$$\underset{\substack{\text{Calcium}\\\text{nitrite}}}{Ca(NO_2)_2} + \underset{\text{Oxygen}}{O_2} = \underset{\substack{\text{Calcium}\\\text{nitrate}}}{Ca(NO_3)_2}$$

—by the action of the *nitric organism*, or *Nitrobacter*.

The conditions favourable for nitrification, assuming the necessary organisms to be present, are:

1. *Suitable Food.*—Mineral matters, especially potassium, calcium, sulphates and phosphates must be present. Carbon dioxide, either as gas, in solution, or as bicarbonates, appears also to be essential. Organic matter is not required for either the nitrous or nitric organism.

2. *The Presence of some basic material.*—As already stated, calcium or magnesium carbonate generally acts as the base. The medium must not be more than slightly alkaline, or it may be neutral, but if strongly alkaline or acid the process is stopped.

3. *Suitable temperature.*—Nitrification ceases about the freezing temperature, is most active about 30°C., and stops at about 50° or 55° C.

4. *Presence of moisture.*

5. *Absence of Strong Light.*—Sunlight stops the action of, and, if continued, destroys the organisms.

6. *Abundance of Oxygen.*

Denitrification.—This is a process resulting in the liberation of free nitrogen from nitrates, brought about by micro-organisms which are probably nearly always present in soil, but which can only act when free oxygen is absent—that is, the organisms are *anaerobic.* If a soil be consolidated, water-logged, or highly charged with oxidisable carbonaceous matter the conditions become favourable for denitrification. The application of very large dressings of dung along with nitrate of soda sometimes causes a considerale loss of nitrogen from this cause.

Fixation of Atmospheric Nitrogen in Soils.—Certain micro-organisms, able to absorb free nitrogen from the air and to convert it into compounds capable of being utilised by plants, have been discovered. Indeed, some years ago cultures of such organisms were prepared for sale under the name of *Alinit*, but the success attending their employment was doubtful, and their manufacture has ceased. Recently further attention has been directed to the subject, and other organisms possessed of similar powers have been discovered. Among others, a large bacterium, which has been named *Azotobacter*, is said to possess this power, in soils rich in organic matter, the necessary energy being believed to be derived from the oxidation of the carbonaceous material. It is thought that the fertility and richness in nitrogen of forest or prairie soil is largely due to the activity of this and similar organisms, which would find suitable conditions for growth in the large quantity of organic carbonaceous matter contained in such soils.

Gases in a Soil.—The interstices of a soil are usually occupied by air, but, in consequence of the chemical changes going on in the soil, this air becomes robbed of some of its oxygen and enriched with carbon dioxide. The air is not stagnant, but undergoes constant renewal by diffusion from the air above. The gases sucked out from soil vary considerably in composition; the oxygen may be anything between 10 and 20 per cent., the carbon dioxide from 1 to 10 per cent., while the nitrogen usually differs very little in amount from that in the atmosphere—about 78 per cent. The amount of carbon dioxide is greater and of oxygen less during the summer and autumn than in the winter or spring.

The Water in a Soil.—This is normally present as a liquid film enclosing the particles composing the soil, and contains, in dilute solution, the soluble matter of the soil, and also dissolved gases. Its origin is usually rain, and it therefore retains any dissolved substances—chlorides, sulphates, &c.—which the rain contained. The actual composition of the water in a soil must necessarily vary greatly, according to the amount of rain which has recently fallen and other circumstances.

Of the rain which falls a large proportion sinks into the soil by the action both of gravitation and surface pressure. Some of this runs off in the drains, carrying with it a proportion of dissolved matter; the rest remains in the interstices, and of this a proportion is brought up to the surface by surface pressure. and is there evaporated. It consequently becomes more concentrated, and, in dry weather particularly, the water in the upper portion of a soil may contain very many times the amount of dissolved substances which is found in drainage water. As the liquid becomes more concentrated, doubtless many of its constituents are absorbed by the soil. Evaporation from the top layers thus causes the soil water, by the surface pressure phenomenon already described, to bring up into the upper parts of the soil considerable quantities of plant food and other dissolved matter. In extreme cases in somewhat arid regions, the soil may become so charged with dissolved substances from this cause that it is unfit for plant growth. Such soils are known as "alkali" or "brak" soils.

The proportion of the rainfall which drains away varies with many circumstances—the distribution of the rainfall, the retentiveness of the soil, the rapidity of evaporation from the surface, and others. The amount evaporated depends largely upon whether the soil is bare or covered with vegetation, being very much greater in the latter case.

At Rothamsted, as the average of twenty years (1877–78 to 1896–97) with a rainfall of 29·5 inches, the drainage through 5 feet of bare soil amounted to 14·7 inches. In very wet seasons the amount and proportion of drainage is greater; *e.g.*, in 1878–79 the total rainfall was 41 inches and the drainage 24·4 inches, while in the very dry year 1897–98 the numbers were 19·5 and 6·5 respectively.

From cultivated soil bearing a crop the drainage is much less. In experiments conducted in France, fallow soil gave a total drainage of 11·5 inches, while similar soil with a crop of potatoes gave only 5·83 inches.

Losses caused by Drainage.—The water draining from land always carries with it dissolved matter. The substances whose removal in this way is the most important are the nitrates. The loss is greatest from uncropped soil, for several reasons—

(1) Because of the greater amount of drainage;

(2) Because no absorption of nitrates by the roots of plants occurs;

(3) Because the land, being free from crops, dries more slowly, and so the moisture favourable for nitrification is retained for a longer period, especially in dry weather, when the temperature is often high, and, therefore, most favourable for nitrification.

The average annual loss of nitrogen as nitrates from uncropped land at Rothamsted for the twenty years 1877–78 to 1896–97 amounted to 33·8 lb. per acre (equivalent to 216 lb. of commercial nitrate of soda). The loss, of course, will vary greatly with the nature of the soil. At Grignon, near Paris, in the year 1896–97 the loss of nitrogen from fallow soil was found to be about 190 lb. per acre, while from plots of the same soil bearing crops the loss was in some cases very small—*e.g.*, with rye grass only 2·3 lb.*

The other substances carried off in drainage water, though considerable in quantity, are of less importance from a practical standpoint. The largest is the calcium carbonate, and this naturally varies very much in different soils. From soils on igneous rocks its amount is estimated by Continental observers at 500 lb. per acre per annum, while from the chalk soils as much as 2700 lb. per acre may be removed in a year. The amount is increased when ammonium compounds are used as manure. English estimates are lower.

The loss of phosphoric acid is probably very small, except in the case of peaty soils, which, though often very deficient in this constituent, generally lose much in the drainage, probably because of the solvent action of the vegetable acids and the carbon dioxide produced by the decay of organic matter. In German experiments the annual loss per acre varied from about 8 lb. from clay to 19·6 lb. from peaty soils.

The loss of potash is very variable, but seldom of much importance in this country. Of course, under exceptional circumstances drainage water may be very rich in dissolved matter; *e.g.*, the drainage water from gardens, when excessively large quantities of manure are used, may contain as much as 8·4 parts per million of potash and 33 parts of nitrogen pentoxide.

Analysis of Soils.—The presence of an adequate store of constituents of plant food in a soil is not sufficient to ensure fertility, and this is true even when the physical condition of the soil is suitable, for it is necessary that the constituents of plant food should be in such a state that they can readily be assimilated by the plant. A *complete analysis* of a soil, stating

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* These losses refer to nitrate, &c., carried off in the drainage water. In some cases, a soil may, in spite of such losses, actually become richer in combined nitrogen owing to fixation of atmospheric nitrogen by micro-organisms, *e.g.*, *Azotobacter* (*see* p. 56).

the percentage amount of each constituent present, is often of little use in leading to any judgment as to its fertility or manurial requirements. A case illustrating this point may be quoted. Two pasture soils, A and B, gave the following results on analysis:

	A. Per cent.	B. Per cent.
Moisture	3·13	1·70
Loss on ignition	10·85	7·79
(Nitrogen	0·274	0·247)
Insoluble matter	67·38	80·28
Ferric oxide and alumina	15·61	8·16
Lime	0·29	0·13
Magnesia	0·31	0·21
Potash	0·86	0·48
Phosphorus pentoxide	0·15	0·12
Not determined	1·42	1·13
	100·00	100·00

From these numbers A is evidently better provided with lime and phosphorus pentoxide than B, and since there is also more nitrogen present it would seem that B needed phosphoric acid and lime more than A. Actual trial shows just the opposite; for basic slag (containing chiefly calcium phosphate and free lime) gives a decided increase of crop on soil A, but has no marked effect on soil B.

Evidently the phosphoric acid and lime in B, though less in amount, are more available to the roots of plants than those in soil A. Dr. Dyer suggested the determination of the amounts of phosphoric acid and of potash which a soil could yield to a solution of citric acid containing 1 per cent. of the acid, as a means of estimating the amounts of these ingredients present in an available form. This strength of acid was suggested because it corresponds to the acidity of the sap contained in the roots and root-hairs of many plants. By the application of this process to the two soils mentioned the following results were obtained:

	A. Per cent.	B. Per cent.
"Available" potash	0·0062	0·0060
"Available" phosphorus pentoxide	0·0049	0·0205

The superiority of soil B in "available" phosphates is thus evident; it contains more than four times as much as A. 0·01 per cent. "available" phosphates and 0·005 per cent. "available" potash are suggested as the lower limits for fertility for most crops. If less be found the soil requires manure. It is obvious that the limits will be different for different crops, since both their requirements and power of assimilating food materials differ greatly. The amounts of potash and phosphoric acid extracted by 1 per cent. citric acid solution, though not claimed to be an accurate measure of that which plants are able to obtain from the soil, probably furnish one of the best chemical means of estimating their fertility so far as their requirements are concerned. Another point to consider in this connection is the rate at which the "unavailable" plant food becomes "available." In some cases it has been found that a soil deprived of all "available" plant food by prolonged treatment with a one per cent. solution of citric acid soon acquires, when kept moist, additional quantities of the former. There seems little doubt that in warm climates the renewal of the available plant food in soil occurs more rapidly than in colder ones. In tropical soils, therefore, the occurrence of smaller quantities of "available" plant food may suffice for the requirements of crops, owing to the greater rapidity with which it is renewed. This is one of the reasons why such soils, which appear poor on analysis when compared with English soils, often prove very fertile.

For details of analytical processes which cannot be given here, a manual of agricultural analysis should be consulted.

CHAPTER IV.

NATURAL WATERS.

PURE water—*i.e.*, the substance hydrogen oxide, H_2O—practically never occurs in nature. Owing to its remarkable solvent properties, water dissolves smaller or larger quantities of every substance with which it comes in contact.

The purest form of natural water is rain, although, as shown by the analysis on p. 30, rain-water is never pure, but contains varying quantities of dissolved matter. In addition to those mentioned in the Table, rain-water contains dissolved gases. When it reaches the earth the water at once commences to dissolve the substances upon which it falls. In districts where the surface is composed of hard, igneous rocks the quantity dissolved is small, while on limestone or chalk large amounts of calcium carbonate particularly go into solution. The water which drains away from a soil amounts in England to about half the annual rainfall. Part of it finds its way into the nearest watercourse, thence to a stream or river, and finally to the sea. Another portion sinks into the earth until stopped by some impervious layer of rock—*e.g.*, shale—when it accumulates, and eventually finds an outlet at some lower level in the form of a spring.

The chief forms of natural waters may be classed as follows.

1. Rain water.
2. Spring water.
3. River water.
4. Sea water.

1. **Rain Water.**—The composition and character of this has already been described in chap. ii. The acidity of the

rain in districts where much coal is burnt is of great importance as affecting the growth of plants, particularly of the grasses and certain trees. In addition to its direct injurious effect upon the foliage, it exerts a deleterious action upon the soil, tending to remove the calcium carbonate or other basic material, to interfere with the growth of micro-organisms, *e.g.*, those of nitrification, and to promote "sourness," so unfavourable to the growth of most useful plants. Grass land under such circumstances often becomes almost sterile, the last plants to succumb to the unfavourable conditions being the "sorrel" or "sour dock."

The combined nitrogen brought down by the rain has been already referred to (see Chap. II. p. 30).

Spring Water.—The water issuing from springs varies greatly in the amount and nature of the dissolved matter which it contains. If this be small, and not possessed of strong taste or odour, the water is described as fresh water; but if a large quantity of dissolved matter be present, or if the water possess pronounced taste, odour, or medicinal properties, it is known as a *mineral water.*

Most spring-waters contain the following substances, but in very varying amounts:

(1) Calcium and magnesium carbonates dissolved in excess of carbon dioxide.

(2) Calcium or magnesium sulphate.

(3) Sodium or potassium chloride.

(4) Alkaline silicates.

(5) Dissolved gases—oxygen, nitrogen, and especially carbon dioxide.

Calcium and magnesium carbonates are almost insoluble in water, but if the water contain carbon dioxide the readily soluble bicarbonates are formed:

$$CaCO_3 + H_2O + CO_2 = \underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2}.$$

Such action occurs largely in all limestone or chalk districts, the removal of the rock in solution giving rise to the caves and underground watercourses so common in these districts. When such water is boiled the bicarbonates are decomposed, the normal carbonates being again formed and precipitated:

$$\underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2} = CaCO_3 + H_2O + CO_2.$$

In many cases the precipitated calcium or magnesium carbonate forms a firmly adherent coating ("fur" or "crust") upon the bottom and sides of the kettle or boiler.

Calcium and magnesium sulphates are soluble in water, the former to the extent of about 1·7 grammes per litre. Waters containing calcium or magnesium compounds are known as "hard" waters, and have a peculiar and well-known action on soap. The latter is essentially the sodium salt of a fatty acid—*e.g.*, stearic acid, $HC_{18}H_{35}O_2$, the calcium and magnesium salts of which are insoluble in water. For water to form a lather with soap or properly exercise its cleansing power it is necessary that the water should contain some dissolved sodium stearate. When a small quantity of soap is dissolved in hard water, the calcium or magnesium present in the water, by double decomposition with the soap, gives a curdy, flocculent precipitate of the calcium or magnesium salts of the fatty acids: *e.g.*,

$$\underset{\substack{\text{Sodium}\\ \text{stearate}}}{2NaC_{18}H_{35}O_2} + \underset{\substack{\text{Calcium}\\ \text{sulphate}}}{CaSO_4} = \underset{\substack{\text{Calcium}\\ \text{stearate}}}{Ca(C_{18}H_{35}O_2)_2} + \underset{\substack{\text{Sodium}\\ \text{sulphate}}}{Na_2SO_4}.$$

The dissolved soap is thus removed, and more has to be dissolved before the proper cleansing action can be exerted. Hence hard waters are unsuitable for domestic use, especially for laundry purposes; they involve the consumption of large quantities of soap, and contaminate the articles washed with the precipitated "lime" or "magnesia soaps."

Hard waters are also unsuited for steam-raising, since the deposit of calcium carbonate or of calcium sulphate upon the boiler plates greatly increases the consumption of fuel required for the production of a certain quantity of steam.

A distinction is often made between waters which contain their calcium and magnesium as bicarbonates and those in which the salts present are the sulphates. The former are known as "temporarily," the latter as "permanently" hard waters. By the removal of the excess of carbon dioxide from the former the calcium and magnesium carbonates are precipitated, while with the latter the salts are dissolved *per se*, and cannot conveniently be removed. The usual plan adopted to effect the softening of temporarily hard water is to add lime, CaH_2O_2, in sufficient quantity to combine with the free carbon dioxide and that present as bicarbonates, when the precipitate formed contains the calcium (and magnesium) carbonate originally present, together with that formed from the added lime:

$$Ca(HCO_3)_2 + CaH_2O_2 = 2CaCO_3 + 3H_2O.$$

On standing the precipitate settles out, and the clear liquid is then almost free from calcium and magnesium and is "soft." It is much improved both for washing and for steam-raising purposes.

In a drinking water the presence of calcium compounds, except in excessive amounts, is not very objectionable—indeed, is often advantageous, furnishing a portion of the lime necessary for the building up of the hard parts (bones or shells) of the animal. Moreover, in many cases water is delivered through leaden pipes, and soft waters, especially if they contain vegetable acids—*e.g.*, from peat—attack and dissolve lead, often to such an extent as to cause lead poisoning in those who drink them. The presence of calcium sulphate renders water incapable of this dangerous action upon lead, for the metal becomes coated with a film of the very insoluble lead sulphate, which protects it from further contact with the water.

Of greater importance than the mineral matter in drinking water is the amount and nature of the organic matter.

This in itself is comparatively harmless; its importance lies in the influence it has upon the kinds of micro-organisms which accompany it. Animal excreta is the most dangerous contamination, since the micro-organisms which cause various diseases—*e.g.*, typhoid and cholera—are liable to be thus introduced into the water. Animal organic matter is richer in nitrogen than most vegetable refuse, so that in practice the detection of much combined nitrogen, whether as organic matter, ammonium salts, or nitrates, is regarded as sufficient to indicate that the water has been contaminated with sewage or other animal matter. If much organic matter of animal origin be present there must always be considerable risk of pathogenic (disease-producing) organisms finding their way into the bodies of those who drink it; and though such contaminated water may be, and often is, drunk for years with impunity its consumption is decidedly dangerous.

Another substance characteristic of sewage is common salt; consequently the presence of much chlorine in a water is generally indicative of sewage contamination, unless the water is derived from some rock containing salt or is collected near the sea.

Analyses of typically good and bad drinking waters are given by Roscoe and Schorlemmer as follows:

CONSTITUENTS	Good water.		Bad water.	
	Parts per million.	Grains per gallon.	Parts per million.	Grains per gallon.
Total solids	63·0	4·4	530	37·1
N as nitrites and nitrates	0·25	0·017	7·8	0·546
"Free" ammonia	0·03	0·002	4·32	0·303
"Albuminoid" ammonia	0·07	0·005	0·9	0·063
Chlorine	11·4	0 8	69	4·8
Temporary hardness	—	0·1	—	7·2
Permanent hardness	—	2·4	—	14·4
Total hardness	—	2·5	—	21·6

By *hardness* is meant the number of grains of calcium carbonate equivalent to the total amount of calcium and magnesium salts present in one gallon of the water. The meanings attached to "temporary" and "permanent" have already been given. Numerically they too are expressed in terms of the equivalent amount of calcium carbonate in grains per gallon.

By albuminoid ammonia in the above table is meant the quantity of ammonia which is evolved from the water by the decomposition of organic nitrogenous substances by distillation with an alkaline solution of potassium permanganate.

River Water.—Most rivers originate in springs, so that at first their water resembles that of their source. A considerable influx of surface-water, however, generally enters the river and alters its composition. The surface-water usually contains less dissolved matter than spring water, but often more organic matter and suspended particles. The composition of the river water greatly depends upon the character of the rocks from which it is collected. When the surface consists of igneous rocks or of sandstones the water is usually soft, while in chalk or limestone districts it will be hard. Some rivers—*e.g.*, the Trent—are very rich in calcium sulphate, and to this fact the excellence of the Burton ales has been ascribed.

The table on page 68 is given by Roscoe and Schorlemmer as representing the average composition of the waters of several well-known rivers. The remarkable softness of the water of the Dee, collected from the granite district in Aberdeenshire, will be noted.

River water rarely contains excessively large quantities of calcium carbonate, such as occur in some springs, since, owing to its free contact with air, it never retains very large quantities of dissolved carbon dioxide. Calcium sulphate in river water is usually accompanied by sodium chloride and by magnesium salts.

In thickly populated and manufacturing districts the rivers are contaminated with the sewage and trade effluent of the towns and villages, and thus often become foul and evil-smelling. This is to be deplored both on account of the annoyance and injury to health which they cause, and also because of the serious loss to the community of the valuable combined nitrogen and other manurial constituents contained in the sewage.

CONSTITUENTS.	Grains per gallon.		
	Thames.	Trent.	Dee.
Total solids	20·81	50·06	3·89
Calcium carbonate	10·80	0·32	0·85
Calcium sulphate	3·00	21·55	0·12
Calcium nitrate	0·17	—	—
Magnesium carbonate	1·25	5·66	0·36
Sodium chloride	1·80	17·63	0·72
Silica	0·56	0·72	0·14
Iron oxide and alumina	0·27	0·50	0·06
Calcium phosphate	Trace	Trace	Trace
Organic matter	2·36	3·68	1·54
Hardness	14·0	26·5	1·5

The amount of suspended matter in river water varies enormously, depending upon the rainfall, the character of the surrounding soil, and other circumstances. Soft waters or those containing carbonate of soda are often muddy, while hard waters tend to deposit their suspended clay and become clear. The very muddy nature of many South African streams is believed by the writer to be due to their containing sodium carbonate. In some cases, the quantity of suspended matter is very great, and the dense, muddy river-water, if it overflows the banks, deposits upon the soil a layer of finely-divided particles of materials brought down from higher up the valley. The sediment is often rich in plant food and forms an important fertiliser. In some few places in England —*e.g.*, on the Humber and Trent—land is systematically treated with the flood-water in order to increase the thickness of the soil. The process is known as "warping," and the "warp" soils are extremely rich and fertile. The Nile in Egypt affords a still better example of a river used in this manner.

In countries of limited or unevenly distributed rainfall irrigation is often practised. In this case, since there is very little drainage, the composition of the water used is of importance. If the water be charged with common salt, sodium sulphate, or sodium carbonate, there is a grave danger of the surface soil, by the prolonged concentration of the water, becoming charged with the soluble matter to such an extent as to seriously interfere with plant growth. The soil is then said to become "brak" or "alkali." The usual causes of this sterile condition are sodium sulphate and chloride ("white alkali") or sodium carbonate ("black alkali") derived either from the soil itself, or partly from the water used for irrigation.

Different crops are possessed of different resistant powers to these salts. As a rule, sodium carbonate is the most effective in causing injury to plants, and sodium sulphate the least. Fortunately, however, "black alkali"—*i.e.*, sodium carbonate—can be rendered almost innocuous by the application of gypsum to the soil, when by double decomposition calcium carbonate and sodium sulphate are formed :

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3.$$

If "white alkali" be due to common salt it cannot be cured, except by drainage.

According to American results (and in various parts of the United States large areas of alkali soils exist), the following table gives the highest proportions of sodium chloride, sodium sulphate, and sodium carbonate which may be present in soils without injury to the plants named. The figures represent the amounts in pounds of the various constituents present in the upper four feet of soil per acre :

Plant.	Sodium Chloride.	Sodium Sulphate.	Sodium Carbonate.
Grape	9,640	40,800	7,550
Fig	800	24,480	1,120
Orange	3,360	18,000	3,840
Pear	1,360	17,800	1,760
Apple	1,240	14,240	640
Peach	1,000	9,600	680
Apricot	960	8,640	480
Lemon	800	4,480	480
Mulberry	2,240	3,360	160
Eucalyptus	2,960	34,720	2,720
Oriental sycamore	20,320	19,240	3,200
Date palm	—	5,500	2,800
Salt bush	12,520	125,640	18,560
Lucerne, old	5,760	102,480	2,360
,, young	760	11,120	—
Sugar beet	5,440	52,640	4,000
Sunflower	5,440	52,640	1,760
Radish	2,240	51,880	8,720
Carrot	2,360	24,880	1,240
Rye	1,720	9,800	960
Wheat	1,160	15,120	1,480
Barley	5,100	12,020	12,170
Lupine	3,040	5,440	2,720
Celery	9,600	4,080	—
Sorghum	9,680	61,840	9,840

In the above table it is assumed that the weight of soil to a depth of four feet per acre is 16,000,000 lb.—*i.e.*, that each foot depth of soil per acre weighs 4,000,000 lb. 1 per cent. of any constituent would thus correspond to 40,000 lb. per acre in a depth of one foot, one-tenth per cent. to 4000 lb., and so on.

Sea water varies locally in composition, being affected by the influx of fresh water from large rivers, &c., but far out from land it is very constant in composition. The average amount of total solid matter is about 36 grammes per litre, or 2520 grains per gallon. Thorpe found as the constituents of 1000 grammes of water of the Irish Sea, in 1870, the following:—

	Grammes.
Sodium chloride	26·439
Potassium chloride	0·746
Magnesium chloride	3·150
Magnesium bromide	0·071
Magnesium sulphate	2·066
Magnesium carbonate	Traces
Magnesium nitrate	·002
Calcium sulphate	1·332
Calcium carbonate	0 048
Ammonium chloride	0·0004
Ferrous carbonate	0·005
Silicic acid	Traces
	33·859

In certain lakes having no communication with the ocean the concentration of the water becomes much greater, and the total solid matter may reach seven or eight times that found in the ocean. Examples of such waters are found in the Dead Sea and the Great Salt Lake of Utah.

Relations of Water to Heat.—The physical properties of water, especially in its relations towards heat, are remarkable in many ways, and of the utmost importance. It is therefore desirable that the student should be familiar with these properties, in order that he may realise the parts played by water in nature.

Pure water is usually described as colourless, but careful examination will show that when seen in sufficiently thick layers it has a bluish-green colour. It is a bad conductor of heat—*i.e.*, heat travels slowly from one particle of water to another—but usually a mass of water is warmed readily, especially if the source of heat be below. In this case the distribution of heat is effected by a process distinct from conduction, known as *convection.* The particles of water nearest the source of heat become warmed, expand, and consequently rise, the cooler, and therefore heavier, particles above or around them taking their place. A circulation is thus set up, the warmer water continually rising and the colder sinking.

Specific Heat.—Water has a high *specific heat.* By this is meant that to raise the temperature of a given mass of water through a certain interval a relatively large amount of heat is necessary. The specific heat of water is much higher than that of mercury. The meaning of this statement can be readily understood by considering two experiments. If 1 kilogramme of water at 100° C. be mixed with 1 kilogramme of water at 0° the temperature of the mixture will be approximately 50°. The heat lost by the hot water in cooling from 100° to 50° has just been sufficient to raise the temperature of the same weight of cold water from 0° to 50°. If a kilogramme of water at 100° be stirred with a kilogramme of mercury at 0° the temperature of the mixture will be approximately 96·7° C. In this case the water in cooling through only 3·3° C. gave out enough heat to raise an equal weight of mercury through 96·7° C. From this result it follows that water requires about thirty times as much heat to raise its temperature through any specified interval as an equal weight of mercury. The specific heat of water is taken as unity, so that the specific heat of mercury will be $\frac{1}{30}$, or ·033.

The specific heat of a substance is thus the quantity of heat required to raise the temperature of any weight of the substance through any interval, compared with the amount of heat necessary to raise the temperature of the same weight of water through the same interval.

Since water has the highest known capacity for heat, the specific heats of other substances are represented by numbers less than 1. The following is a list of specific heats of various common substances:

Table of Specific Heats

Water	1·000	Glass	0·198
Alcohol	0·620	Silica	0·189
Turpentine	0·426	Steel	0·118
Glycerine	0·555	Copper	0·094
Sulphuric acid	0·355	Brass	0·094
Humus	0·477	Tin	0·056
Clay	0·233	Mercury	0·033
Aluminium	0·214	Lead	0·031
Calcium carbonate	0·206		

Water is remarkable with respect to the influence of changes of temperature upon its volume. Like most substances, it expands when heated and contracts when cooled; but a careful examination will reveal the fact that this statement, though roughly correct, is too general, and that at a certain temperature water is most dense and expands whether it be heated or cooled. This *temperature of maximum density* is about 4° C. When water changes into ice an expansion occurs (see chap. iii.). In this respect water is unlike most other substances. It is owing to water being most dense at 4° C. that the temperature of the water in deep lakes or ponds even in the coldest weather is usually found to be about 4° at considerable depths below the ice.

Latent Heat.—When a liquid changes into a solid heat is evolved, and, conversely, when a solid becomes liquid heat is absorbed.

If a quantity of ice or snow, say at – 10° C., be placed in a vessel and heat be applied, a thermometer placed in the material will show a slow rise in temperature until 0° C. is reached, when, although the supply of heat be maintained, no further rise will ensue until all the ice or snow is melted.

The amount of heat thus absorbed is very considerable, and is exactly equal to that which was evolved when the ice was formed from liquid water.

If a kilogramme of water at 80° C. be mixed with a kilogramme of ice at 0° it will be found that the ice will be melted but the temperature of the resulting liquid will only be 0°. It is thus evident that to melt a kilogramme of ice without producing any change of temperature as much heat is required as would raise a kilogramme of water through 80° C., or 80 kilogrammes of water through 1° C. Heat so absorbed is called *latent*, since it is hidden, so far as a thermometer is concerned. Conversely, when water freezes, each kilogramme converted into ice gives out as much heat as would raise 80 kilogrammes of water through 1° C. It is for this reason that during cold weather ice only forms slowly on the surface of water, and that snow and ice melt so slowly when a thaw sets in.

The latent heat of ice, or of the fusion of ice, is thus said to be 80.

Another change of state occurs when liquid water becomes gaseous. If a quantity of water at the ordinary temperature be gradually and regularly supplied with heat, a thermometer placed in the liquid will indicate a steady rise of temperature. It is evident that the heat supplied is being used in raising the temperature of the water. This will go on almost regularly until a temperature of about 100° C. is reached. No further rise will occur, and even if the rate of supply of heat be doubled or quadrupled no effect upon the thermometer will be observed; the water, however, will now be slowly changing into steam, which, as it leaves the liquid, has the same temperature (100° C.). Evidently the heat supplied is now being used up in converting the liquid into vapour without producing any rise in temperature. The quantity of heat required to change the unit weight of water at 100° into steam at 100° is called the *latent heat of steam*, or of the vaporisation of water. It is very large, being 536 times as great as the amount required to raise the same weight of water through 1° in temperature.

The quantity of heat necessary to raise 1 gramme of water from 0° to 1° is called the *thermal unit*, *unit of heat*, or *calorie*.

Now water evaporates into dry air (or into any gas or space not already saturated with aqueous vapour) at any temperature, and since that which is converted into vapour requires its latent heat, a considerable absorption of heat ensues. This is the reason why wetted things are cooled when exposed to air; it is not because the water is cooler than other substances, but because it evaporates and absorbs the heat necessary for its conversion into vapour. The more rapid the evaporation, the greater is the reduction of temperature. The rapidity is increased by higher temperature and by quicker renewal of the atmosphere in contact with the wet surface, *e.g.*, by a draught of air or wind.

The conversion of a liquid into a vapour is always attended by an absorption of heat. Though the amount of heat required to convert a gramme of the liquid into vapour varies with the nature of the liquid, in no case is it so great as with water. The following experiment furnishes a striking proof of this heat absorption :

A small, thin glass beaker is placed on a few drops of water on a wooden block ; a little ether is placed in the beaker, and by means of a tube and bellows a current of air is blown into the beaker so as to cause the ether to evaporate rapidly. In being converted into vapour it absorbs heat from the beaker ; this cools the water below, and in a short time the loss of heat becomes so great that the water freezes, and the little beaker is cemented to the block of wood by a thin film of ice.

The high specific and latent heats of water lead to important consequences in nature. The former explains the temperate character of the climate of places near large masses of water. Islands or places near the coasts of large areas of water have much smaller ranges of temperature than places far inland.

A wet soil is cold because of both these causes. The heat of the sun shining on the soil can only warm it slightly, because (1) of the high specific heat of the water present, and (2) a large portion of the heat is absorbed by the evaporation of a portion of the water. The magnitude of this second effect is greatly increased if a wind be blowing, since the rate of evaporation is thereby accelerated.

CHAPTER V.

THE PLANT.

A BRIEF account of the functions of the various parts of a plant will be given in this chapter, followed by a short description of the chief chemical compounds existing as its constituents. For detailed accounts of the structure and life-history of plants a treatise on botany would naturally be consulted.

Germination.—A seed is essentially a germ, with a store of material, out of which the future plant is to be formed. All seeds contain complex nitrogenous compounds (proteids) and either carbohydrates or fats, together with mineral matter.

Seeds may be kept unchanged for some time, provided they be protected from moisture. In order that germination may occur, the access of moisture and oxygen, a suitable temperature, and the removal of evolved carbon dioxide are necessary. If these conditions are complied with, seeds will germinate readily without requiring any mineral or other food. Oxygen is absorbed, heat is produced and carbon dioxide is evolved.

Unorganised ferments, or enzymes—*i.e.*, substances which are soluble in water, and which have the power of bringing about chemical changes apparently without themselves being altered—are produced, and the starch or other insoluble constituents of the seed are converted by the enzymes into sugars or other soluble compounds capable of being transported to the plumule (the rudiment of the stem) and radicle (eventually the root), and so permitting of their growth. When the plumule reaches the surface, and on exposure to light becomes green in colour from the formation of chlorophyll, it is then capable of assimilating carbon dioxide. The radicle soon develops root-hairs, through which mineral substances and nitrates, if present in the solution outside, can enter the plant.

The main parts of a plant are the roots, the stem, the leaves, the flowers, and the seeds.

The Roots.—The radicle, growing from the seed, at first extends vertically downwards, its direction being determined by gravitation or other force acting upon it. It afterwards branches and sends out lateral roots. Near every growing part of the root thin-walled *root-hairs* extend among the particles of soil. As the root thickens the root-hairs die off; they are only found in abundance near the growing ends of roots. The thin walls of the root-hairs probably play a most important part in the growth of the plant. In order to understand their action it is necessary that some knowledge should be possessed of the peculiar phenomena of *diffusion* and *osmotic pressure.*

Some reference to the former has already been made (see chap. iii.). Colloidal, or glue-like substances diffuse very slowly when dissolved in water, and have no power of diffusing through insoluble colloidal bodies—*e.g.*, parchment—while crystallisable bodies diffuse rapidly, and can readily penetrate a colloidal membrane if it be saturated with water. This passage of dissolved *crystalloids*, as they are called, through a colloidal membrane is a process of diffusion, and will always take place from a stronger to a weaker solution, apparently (but only apparently) ceasing when the solutions on either side are equal in concentration.

Certain substances, when arranged as a partition between two solutions of different concentration, permit of the passage of the solvent only, and prevent that of the dissolved substance.

Such substances are termed *semi-permeable*, and though perfect semi-permeable membranes are not known a near approach to them can be obtained. If such a membrane be arranged as a closed cell connected with a manometer, it can be shown that when filled with a solution and immersed in water the water enters the cell, while practically none of the solution leaves it. The consequence is that a pressure, amounting in some cases to several atmospheres, is set up within the cell. This pressure is known as *osmotic pressure*, and is found to increase with the concentration and to become greater with a rise of temperature. The cells of which a plant is composed (or rather the protoplasm within them) are probably approximately semi-permeable. If they be surrounded by a solution of less concentration than their contents they will receive more liquid than they lose and the pressure within will increase, while if surrounded by a solution of greater concentration than their contents more liquid will pass out than passes in and the cells will shrink. The cellulose walls of the cells are not semi-permeable, but permit of free diffusion and are nearly rigid. The shrinking of the protoplasm from the walls of plant cells can be seen under the microscope when they are immersed in salt solution of proper strength. The phenomena is known as *plasmolysis*, and results in the death of the plant.

Most vegetable tissues contain while alive a large proportion of water, but in spite of this they are rigid and firm, because of the swollen and turgid state of their cells. The stems and leaves of plants largely depend for their erectness and rigidity upon the strain set up between the rigid cellulose walls of their cells and the water-distended state of their protoplasmic contents. If the distension relaxes—*e.g.*, by evaporation—the plant wilts or flags, becoming quite flaccid.

Diffusion of dissolved matter through a membrane and the setting up of osmotic pressure within the membrane are processes which are opposed to each other, though they may to some extent occur simultaneously. They probably do so occur in the case of a plant's roots. The protoplasm admits of a slight diffusion, whereby some of the dissolved matters in the soil water enters, while some of the dissolved matter of the plant juice leaves the plant, though at the same time, because of its approximately semi-permeable character, osmotic pressure is set up, owing to the liquid within being more concentrated in dissolved matter (though of different nature) than the liquid without. This latter effect is evident in the *root-pressure* which is shown by plants, and which causes the sap to escape when a stem is cut. In some cases the magnitude of this root-pressure has been measured, and found to amount to two or three atmospheres.

Hence by diffusion through the roots and root-hairs of a plant the mineral matter and nitrates are taken in and forced mainly by osmotic pressure (set up, not by these inorganic substances, but by the sugar and other carbonaceous constituents of the sap) into the stem and leaves. At the same time a portion of the acid juice probably escapes by diffusion from the root-hairs and exerts an important solvent action upon insoluble phosphates and potash compounds present in the soil.* Some of the dissolved phosphates, &c., can then enter the plant again by diffusion.

The Stem may here be regarded as the mere means of communication between the roots and the leaves. It, however, often plays other parts, in some cases acting as a storehouse for reserve materials or for useless matters taken in by the plant.

The Leaves perform a very important part in the chemical processes of plant-life. It is through the leaves that the assimilation of carbonaceous matters takes place, and probably the albuminoids and amides are here formed out of the carbon compounds and the nitrates, phosphates, and sulphates taken in by the roots. Another important function of the leaves is

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* As stated in the footnote on page 41, it is now believed that carbon dioxide is the main agent tending to bring into solution the constituents of the soil which are insoluble in water, and that the acid juices referred to play very little, if any, part in the process.

transpiration, by which the surplus water taken in by the roots is got rid of by evaporation.

The chemical change so characteristic of plant-life (the absorption of carbon dioxide and the elimination of oxygen), is an endothermic reaction—*i.e.*, one which requires energy to bring it about. The necessary energy is derived from light, for it is only in the presence of light that the change takes place. The light is absorbed by the green colouring-matter of the leaves, chlorophyll, and it has been shown that it is just that kind of light which is most absorbed by chlorophyll—red light—which produces the largest amount of assimilation of carbon dioxide. The process takes place in spaces below the outer covering (the *epidermis*) of the leaf, the carbon dioxide entering these spaces by diffusion through the *stomata*, minute apertures which are exceedingly numerous on all leaves, particularly on their under surfaces. The nature of the change by which carbon dioxide is absorbed and oxygen evolved by green leaves in sunlight is not thoroughly known. It has been suggested that the first step is the formation of formaldehyde, CH_2O, by the union of carbon dioxide and water and the evolution of oxygen—

$$CO_2 + H_2O = CH_2O + O_2$$

—and that the formaldehyde then immediately *polymerises*, *i.e.*, several molecules combine together, to form sugar:

$$6CH_2O = C_6H_{12}O_6.$$

However, the matter cannot be said to be definitely settled. It appears probable that in many plants, cane sugar, $C_{12}H_{22}O_{11}$, is first formed, and when its concentration in the sap attains a certain value starch granules begin to form. The change is empirically a very simple one, but how it occurs is not known:

$$\underset{\text{Cane sugar}}{C_{12}H_{22}O_{11}} = 2\underset{\text{Starch}}{C_6H_{10}O_5} + H_2O.$$

The starch granules are attacked by *diastase* and converted into sugar whenever the sugar in the sap falls below a certain concentration. This is important, as only dissolved crystalloids can pass from one portion of the plant to another.

In addition to the formation of carbohydrates, the leaves of plants fulfil other important functions.

Transpiration of water takes place chiefly through the stomata, but probably all exposed parts of a plant allow of the escape of some aqueous vapour. The rapidity with which water is evaporated from a plant depends upon several factors—the temperature, the humidity of the air, the amount of light received, and other circumstances. In consequence of the evaporation of water from the leaves, a diminished pressure is often set up in the upper parts of a plant, so that the rise of water from below becomes easier. Thus a steady stream of dissolved substances taken in by the roots rises into the leaves, where, by transpiration, the water is largely evaporated, and the dissolved substances are elaborated into nutritive materials. If the soil water be very dilute, more water will be evaporated than when the liquid is more concentrated. Thus oats were found to evaporate 688 grammes of water for each gramme of dry substance formed, when grown in a solution containing 0·25 per cent. of nutritive substances, but only 515 grammes when in a 3 per cent. solution.

It is not known how the formation of albuminoids takes place, but it probably occurs in the leaves. The first step appears to be the formation of amino-compounds from the carbohydrates and nitrates, and the subsequent conversion of these into albuminoids. It has been shown that with many plants, leaves cut in the morning contain much less starch and nitrogenous matter than similar leaves cut in the evening, indicating that during the night a transference of the starch and albuminoids formed during the day takes place from the leaves to other parts of the plant. The albuminoids probably have to be converted into amides or amino-acids and the starch into sugar before any movement from cell to cell can occur.

The Flowers and Seeds.—In many plants the formation of flowers and seeds is the last act in their life. During flowering the process of true respiration—*i.e.*, the absorption of oxygen and the production of carbon dioxide—takes place more rapidly than at other times during the growth; indeed, in some cases a distinct rise of temperature has been noted. Respiration occurs during the whole period of a plant's existence, but in daylight it is concealed by the opposite process of assimilation, already described. In *biennial* plants—*e.g.*, turnips and mangolds—the first year of growth is devoted to the formation of a large store of nutritious material, intended to serve during the second year for the formation of flower and seed.

During the production of seed a concentration of nutritive material, including always albuminoids, phosphates, sulphur, potassium, chlorine, and the other elements essential to plant life, takes place, the stem, leaves and roots being robbed of much of their important constituents. The carbonaceous material in a seed may be either mainly carbohydrates (generally starch), or fats. Most seeds contain mainly one of these classes, but some contain both.

Conditions affecting Plant Growth.—Apart from the obvious necessity of a proper supply of food and water, the most important factor in growth is undoubtedly temperature. For every plant three important temperatures may be found—the minimum, optimum, and maximum temperatures at which growth occurs. Temperatures below the minimum or above the maximum, though not necessarily fatal to the plant, cause its growth to cease, and in most cases seriously retard its rate of growth for some time after the temperature has risen or fallen above or below these limits. The cardinal temperatures vary considerably with different plants. The minima are usually about 7° or 8° C., the optima about 32° C., and the maxima about 39° to 43° C.

In all cases the rate of growth increases with a rising temperature from the minimum, slowly at first, then more rapidly, until the optimum temperature is reached, after which it diminishes rapidly to the maximum temperature.

Now, in temperate climates the maximum temperature for most plants is rarely, if ever, reached, and as a rule the growth is greater the higher the temperature. Fortunately, too, in such climates the daily range of variation in temperature is not great. Thus during the growing season the plant is rarely cooled to the minimum or heated to the maximum temperature, and its growth will be greater the longer the time at which it is near the optimum temperature. Moreover, the disturbing effect of excessive heat and cold will be absent.

But in tropical countries, especially at considerable elevation and far inland, the conditions are different. The daily range of temperature is much greater. In the night, and especially in the early morning, the ground temperature may sink below the minimum, while in the hot midday sun it may rise considerably above the maximum temperature of growth. Consequently plants, though they may pass through the optimum temperature perhaps twice in the twenty-four hours, are kept near that temperature for but a short period each day, and even then are not able to take advantage of it, because of their being disturbed by the rapidity of the change. It has been alleged that in such countries—South Africa, for example—the screening off of the early morning sun has a very injurious effect upon many plants, and has led to the belief that there is something peculiarly favourable to plant-life in the rays at sunrise. But the influence can be explained by the temperature effect produced. The following experiment by the writer will show this. In the case of a thermometer on the ground screened from the sunrise rays from 6.30 to 9.30 A.M. the temperature, at first about 6° C., rose very slowly to about 16° at 9.30, and then rapidly (after direct sunshine fell upon it) to 28°, and subsequently gradually to 37° C. at 11 A.M. At the same time a plant receiving the direct rays of the morning sun rose from 6° C. at 6.30 A.M. to 11° at 7.15, attained 16° at

8.0, 21° at 8.45, and 25·5° at 9.15, 28° about 9.30, and thereafter gradually rose to 37° at 11 A.M.

Obviously an unshaded plant would not only pass more gradually through the transition from the too low night to the too high day temperature, but would be maintained at a temperature near its optimum for a much longer period than the screened plant. Consequently the conditions for its growth would be much more favourable. In fact, there can be little doubt that in countries like the Transvaal many plants actually suffer from excessive sunshine, with its attendant heat, while in less sunny lands—*e.g.*, England—they rarely attain even their optimum temperature, and probably never exceed their maximum temperature of growth.

The Constituents of Plants.—The elements present in plants have been enumerated in the first chapter, but of far greater importance are the chemical compounds actually existent in the plant. These compounds may conveniently be grouped as follows :

Non-nitrogenous substances.	I. Carbohydrates.
	II. Fats and waxes.
	III. Essential oils and resins.
	IV. Organic acids and their salts.
	V. Inorganic salts.
Nitrogenous substances.	VI. Albuminoids or proteids.
	VII. Amides and amino-compounds.
	VIII. Alkaloids.
	IX. Chlorophyll and other colouring-matters.

A brief account will now be given of these substances.

I. **The Carbohydrates.**—This is a large group of substances, each of which contains carbon, hydrogen and oxygen, the two latter present in the ratio by weight of 1 : 8, the same ratio as they have in water. Most of them contain some multiple of five or six atoms of carbon in a molecule. They can be subdivided into two classes—

(1) the starches, amyloses, or polysaccharoses;
(2) the sugars.

(1) *The Starches.*—These have the composition expressed by the formula $C_6H_{10}O_5$, but their molecules are much more complex than the formula indicates; $(C_6H_{10}O_5)_n$, where n is a large number, more correctly expresses their constitution. Among the most important members of this group are:

Starch.	Glycogen.
Dextrin.	Cellulose.

Starch is very abundant in vegetable products, acting as a reserve material for the nourishment of the growing portions. It possesses an organised structure, being in the form of granules, which possess different forms and sizes in different plants. It is insoluble in cold water, but when heated to about 60° or 70° C. with water the granules burst, and their contents form with the water a viscid, translucent liquid known as *starch paste.* Starch is coloured intensely blue by free iodine.

Glycogen has the same composition as starch, and occurs in animals, especially in their livers. It is therefore sometimes known as animal starch. It gives a red colour with iodine. It is a white solid, soluble in water.

Dextrin is formed when starch is heated to about 220° C. It is easily soluble in water, and gives no blue with iodine. It is made commercially for adhesive purposes, and is sometimes known as "British gum."

Cellulose is very abundant in the leaves, stems, and roots of plants. It is mingled with other substances, from which it can usually be separated because of its resistance to most reagents. By treating the tissues of a plant successively with chlorine, caustic alkalies, dilute acid, water, alcohol, and ether a residue of almost pure cellulose is left. It is a white substance, insoluble in most solvents, but soluble in zinc chloride or ammoniacal copper oxide solutions. By the action of nitric acid cellulose is converted into nitro-celluloses—*e.g.*, gun-cotton, $C_6H_7(NO_3)_3O_2$, collodion, $C_6H_8(NO_3)_2O_3$.

Parchment paper is another product obtained from cellulose. It is prepared by immersing unsized paper in strong sulphuric acid and then washing it with water. The chief alteration appears to be in the physical properties.

By long boiling with dilute sulphuric acid, cellulose—*e.g.*, filter paper, linen or cotton rags—is converted into dextrin and dextrose.

Similar in many respects to the starches are the bodies known as *pentosans*, of which *araban* and *xylan* may be taken as typical. These substances have the composition $(C_5H_8O_4)_n$, and by boiling with dilute acids yield *arabinose* or *xylose*, $C_5H_{10}O_5$, sugar-like bodies known under the general name of pentoses. The pentosans are very abundant in many plants, especially in wood-gums (of which they constitute from 60 to 92 per cent.), in straw (16–27 per cent.), bran (22–25 per cent.), brewer's grains (27–31 per cent.), and meadow hay (16–18 per cent.). The pentosans and pentoses are probably not digestible. When treated with strong boiling hydrochloric acid they yield furfurol, $C_5H_4O_2$; *e.g.*,

$$\underset{\text{Arabinose}}{C_5H_{10}O_5} = \underset{\text{Furfurol}}{C_4H_3O.CHO} + \underset{\text{Water}}{3H_2O}.$$

Lignose or *lignone* is another ingredient in the stems and woody portions of plants. It exists in association with cellulose, from which it may be regarded as resulting by the removal of water:

$$\underset{\text{Cellulose}}{2C_6H_{10}O_5} = \underset{\text{Ligno-cellulose}}{C_{12}H_{18}O_9} + H_2O.$$

The *Pectin substances* are bodies of unknown constitution which exist as coagulable substances in fruit juices, stems, roots, &c. They resemble the carbohydrates, though whether the oxygen and hydrogen are in the ratio of exactly 8 to 1 seems somewhat uncertain. They readily pass into substances which have the power of gelatinising.

(2) *The Sugars.*—Of these there are many varieties for an account of which a text-book on organic chemistry should be consulted. Only a brief mention of the following can be made here:

Cane sugar, saccharose, $C_{12}H_{22}O_{11}$, occurs in many plants, generally in the sap; it is especially abundant in the juice of the sugar cane (16 or 18 per cent.) in the sugar beet (10 to 18 per cent.), and in the sap of the sugar maple. It melts at 160° C. and becomes brown at about 190° C. It does not reduce copper salts, but rotates the plane of polarised light to the right. By the action of certain enzymes, *e.g., invertase,* present in yeast, or by boiling with dilute acids, it is converted into a mixture of levulose and dextrose ("*inversion*").

Milk sugar, lactose, $C_{12}H_{22}O_{11} + H_2O$, see p. 185.

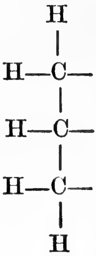
Dextrose, glucose, grape sugar, $C_6H_{12}O_6$, occurs in many fruits and can be obtained by boiling starch or cellulose with dilute sulphuric acid. It reduces copper salts in alkaline solution and rotates polarised light to the right.

Levulose, fructose or *fruit sugar,* has the same empiric composition as dextrose, but rotates the plane of polarised light strongly to the left. It occurs in many fruits, and, like glucose, lactose and *maltose* ($C_{12}H_{22}O_{11} + H_2O$, formed by the action of diastase upon starch), reduces copper salts to red cuprous oxide in alkaline solution.

Milk sugar, dextrose and levulose are much less sweet to the taste than cane sugar.

II. **Fats and Waxes.**—Fats are substances whose constitution has been fairly completely investigated. They, like the carbohydrates, contain only the elements carbon, hydrogen, and oxygen, but the latter element is present in comparatively small quantities, and consequently fats are capable of uniting with considerably more oxygen, thus producing much heat or energy by their oxidation.

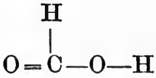
All true fats may be regarded as compounds of organic acids with an organic basic radical, glyceryl (C_3H_5). This radical is trivalent, having the constitution:



$$\begin{array}{c} H \\ | \\ H-C- \\ | \\ H-C- \\ | \\ H-C- \\ | \\ H \end{array}$$

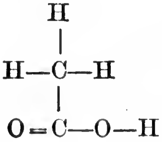
Thus glyceryl stearate would be $C_3H_5(C_{18}H_{35}O_2)_3$.

Glyceryl is present in all true fats. The organic acids, however, vary in different fats, and are usually of high molecular weight. Many of them belong to the *saturated* series of fatty acids, of which formic acid is the simplest example:



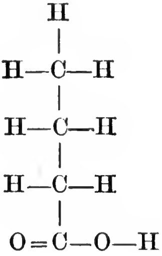
$$\begin{array}{l} H \\ | \\ O=C-O-H \end{array}$$

From this first member a series of fatty acids arises by the successive substitutions of CH_3 groups for hydrogen. Thus:



$$\begin{array}{l} H \\ | \\ H-C-H \\ | \\ O=C-O-H \end{array}$$

is acetic acid.



$$\begin{array}{l} H \\ | \\ H-C-H \\ | \\ H-C-H \\ | \\ H-C-H \\ | \\ O=C-O-H \end{array}$$

is butyric acid

All acids of this series have the general formula

$$C_nH_{2n+1}.COOH,$$

and are saturated, because each carbon atom is united by four combining affinities with other atoms, and the compound is incapable of uniting by addition with other substances.

The oils contain chiefly acids of high molecular weight. Thus capric acid, $C_9H_{19}COOH$, occurs in cocoa-nut oil; myristic acid, $C_{10}H_{21}COOH$, also in cocoa-nut oil; palmitic acid, $C_{15}H_{31}COOH$, in palm oil; stearic acid, $C_{17}H_{35}COOH$, in many oils. These various acids are in combination with glyceryl.

But many oils contain also *unsaturated* fatty acids—*i.e.*, acids in which two or more carbon atoms are linked together by two combining affinities. Such acids can combine *by addition* with other substances—*e.g.*, oxygen, chlorine, or iodine.

The following are examples of unsaturated acids:

Crotonic acid, C_3H_5COOH, in croton oil.
Oleic acid, $C_{17}H_{33}COOH$, in olive and other oils.
Brassic acid, $C_{21}H_{41}COOH$, in colza oil.
Ricinoleic acid, $C_{17}H_{32}(OH)COOH$, in castor oil.

All these have the general formula $C_nH_{2n-1}COOH$ and contain one pair of doubly linked carbon atoms. Another acid, linoleic acid, $C_{17}H_{31}COOH$—*i.e.*, $C_nH_{2n-3}COOH$—and containing two pairs of doubly linked carbon atoms, occurs in linseed and other oils; while a still more unsaturated acid, linolenic acid, $C_{17}H_{29}COOH$ (*i.e.*, $C_nH_{2n-5}COOH$), containing three pairs of doubly linked carbon atoms, also occurs in linseed oil.

Oils containing glyceryl compounds of unsaturated acids tend to absorb oxygen from the air and to become converted into solid or stiff, viscid substances. This property is the more marked the larger the number of doubly linked carbon atoms there are in the molecule.

Oils which contain only saturated acids or acids containing only one pair of doubly linked carbon atoms (*e.g.*, oleic acid) are known as *non-drying oils*, while those containing much of the unsaturated acids are known as *drying oils*. The former—*e.g.*, olive oil—are used for lubricating purposes, while the latter—*e.g.*, linseed oil—are used in the manufacture of paints, linoleum, oil-cloth, varnishes. Oils and fats, both vegetable and animal, are also largely used in the manufacture of soap.

Hard soap consists of sodium salts of various fatty acids, soft soap of corresponding potassium compounds. Soap is made by boiling the oil or fat with a solution of an alkali, whereby the metal of the alkali replaces the glyceryl of the oil, yielding the soap and glycerine (or glycerol, as it is now more systematically called). Thus, to take an example, if soda be boiled with glyceryl oleate (the largest constituent of olive oil) the following reaction occurs:

$$\underset{\text{Glyceryl oleate}}{C_3H_5(C_{17}H_{33}COO)_3} + \underset{\substack{\text{Sodium}\\\text{hydroxide}}}{3NaOH}$$

$$= \underset{\substack{\text{Glycerol or}\\\text{glyceryl hydroxide}}}{3C_3H_5(OH)_3} + \underset{\substack{\text{Sodium oleate}\\\text{or soap}}}{3NaC_{17}H_{33}COO}.$$

Both the soap and the glycerine remain dissolved in the water, from which the soap can be separated in the solid state by adding common salt. Glycerine can be recovered from the remaining brine.

Oils may be present in various parts of a plant, but it is always accumulated in the seed. Many seeds contain large proportions of oil, sometimes up to half their weight. As a rule, if a seed contains a high proportion of oil it is devoid of starch, but many seeds—*e.g.*, maize—which are rich in starch contain a small quantity of oil.

Oil is a concentrated source of energy, one part of oil being equivalent to about two and a half parts of starch or sugar.

Waxes are similar to the fats and oils in constitution, but instead of the trivalent radical glyceryl, they contain monovalent radicals, of more complex character.

III. **Essential Oils and Resins.**—Essential oils are usually volatile and possessed of characteristic odours. They bear no resemblance chemically to the true oils. Many of them are hydrocarbons—*i.e.*, compounds of hydrogen and carbon; others contain, in addition, oxygen or sulphur. The hydrocarbon essential oils or terpenes have the general formula $(C_5H_8)^n$. Many vegetable perfumes consist mainly of these terpenes—*e.g.*, oil of turpentine, of lemon, of orange, or of eucalyptus. Of oxygenated essential oils, many different varieties are known, *e.g.*, oil of bitter almonds contains benzoic aldehyde, C_6H_5CHO; camphor has the empirical formula $C_{10}H_{16}O$; oil of lavender contains linalyl acetate, $C_{10}H_{17}C_2H_3O_2$. Of essential oils containing sulphur, allyl isothiocyanate, C_3H_5NCS, found in oil of mustard, and allyl sulphide, $(C_3H_5)_2S$, present in oil of garlic, may be taken as typical.

The *Resins* may be regarded as oxidation products of terpenes. Their constitution is complex and not well understood. In plants they often occur associated with terpenes.

IV. **Organic Acids and their Salts.**—Many organic acids have been detected in various vegetable products. They generally occur as potassium, sodium, or calcium salts, though sometimes as free acids. All organic acids contain the group COOH, "carboxyl."

Among those commonly occurring in plants the following may be mentioned :

Oxalic acid, $COOH.COOH$.
Tartaric acid, $COOH.CHOH.CHOH.COOH$.
Malic acid, $COOH.CHOH.CH_2.COOH$.
Citric acid, $CH_2(COOH).C(OH)(COOH).CH_2(COOH)$.
Gallo-tannic acid, $C_6H_2(OH)_3.CO.O.C_6H_2(OH)_2.COOH$.
Gallic acid, $C_6H_2(OH)_3.COOH$.

The acidity of fruits is often due to the presence of free acids—*e.g.*, malic acid, which occurs in apples, gooseberries, red currants, blackberries, and sour cherries—but sometimes to the occurrence of acid potassium or calcium salts; thus grapes contain acid potassium tartrate, sweet cherries acid potassium malate. In many fruits two or more acids may occur together; thus gooseberries contain both malic and citric acids.

Calcium oxalate is very frequently found in plants, often in the form of crystals of $CaC_2O_4.3H_2O$. Acid potassium oxalate also often occurs in solution in the sap of plants.

Tannic acid is present in many plants, often associated with glucose.

Organic acids occur in the sap of the roots and root-hairs of plants, and possibly aid in promoting the solubility of the mineral matter of the soil. The nature of these acids has not been much investigated, though it has been shown that in a large number of plants the average acidity of the sap, expressed in terms of hydrogen, is about ·013 per cent., corresponding to about 0·91 per cent. of crystallised citric acid.*

V. **Inorganic Elements.**—Many of the inorganic constituents of plants, the metals in particular, occur in combination with organic acids, as already stated. Others—phosphorus and sulphur—are associated with complex organic compounds, *e.g.*, albuminoids. A few words may be said about the mode of occurrence and functions of each of the inorganic elements found in plants.

Sulphur, though existent in a living plant chiefly as a constituent of albuminoids, is left in the ash as sulphate, or sometimes as sulphide. It is probably obtained by the plant from the sulphates in the soil, and can often be detected in that form in the sap.

Phosphorus is undoubtedly absorbed as phosphates, and exists in that form in the ash. In the living plant, however, it exists partly in union with organic compounds, and appears to move about in association with the albuminoids.

Silicon is probably taken into the plant in the form of alkaline silicates. There is considerable evidence that though silicon is often present, generally as deposits of silica in the outer walls of the stem and leaves (particularly in cereals), it is not indispensable.

Chlorine is found in all plants, but does not appear of much

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* *Vide* footnote on p. 79.

importance, except in the case of a few plants—*e.g.*, buckwheat, mangolds and cabbages.

Potassium is absorbed as various soluble salts. It generally occurs in the plant in union with organic acids, which decompose on burning, leaving potassium carbonate in the ash. In some plants the sap contains nitrate, chloride and sulphate of potash. Potash compounds appear to be necessary for the production of starch, sugar and other carbohydrates, and are always most abundant in the leaves and young shoots.

Calcium exists in union with organic acids, and aids in the conversion of starch into sugar. In many cases it appears to act beneficially in converting vegetable acids into insoluble compounds, which are deposited in the plant—*e.g.*, calcium oxalate. It, too, is found largely in the leaves.

Magnesium is distributed over all parts of the plant, but little is known of its functions. It has recently been shown to be a constituent of chlorophyll.

Iron, though indispensable, usually occurs in very small quantities. It is essential for the production of chlorophyll.

Sodium, though always present in the ash, does not appear to be essential to the plant. It cannot replace potassium.

The metals above mentioned also act as carriers of nitric acid. When nitrate is absorbed by a plant the nitrogen is used in the formation of albuminoid substances, while the bases unite with organic acids. When the plant is burnt the metals are left as carbonates, and it is found that, the richer a plant is in nitrogen, the larger is the amount of bases left as carbonate in the ash.

VI. **Albuminoids or Proteids.**—These are substances which resemble albumin or white of egg. They form a large class of bodies, which differ in physical properties—*e.g.*, solubility and coagulability—are of highly complex composition or constitution, and contain carbon, hydrogen, oxygen, nitrogen and sulphur. They occur in all living matter, being essential constituents of protoplasm. Their composition varies somewhat. the following being the usual limits:

Carbon	51·5 to 54·5	per cent.
Hydrogen	6·9 „ 7·3	„
Oxygen	20·9 „ 23·5	„
Nitrogen	15·2 „ 17·0	„
Sulphur	0·3 „ 2·0	„

The constitution of proteids is not yet fully known, though recently they have been shown to consist of amino-acids.

As illustrating the complexity of albumin, for example, the following empirical formula, among many others, has been proposed as most nearly representing its composition : $C_{240}H_{392}N_{65}O_{75}S_3$. That any definite compound really has such a composition is extremely improbable. When hydrolysed, proteids split up into their constituent amino-acids.

Proteids all give a yellow colouration when heated with strong nitric acid. This coloured substance becomes orange when treated with ammonia. They also give a red colour when heated with an acid solution of nitrate of mercury (Millon's reagent). In analysis it is usual to assume that proteids contain 16 per cent. of nitrogen. The amount of nitrogen in a substance is determined, and, by multiplying the percentage of this element by $\frac{100}{16}$ or 6·25, the product is taken to represent the percentage of albuminoids. The result can only be approximate, since, as already stated, the percentage of nitrogen varies in different albuminoids. The albuminoids are, as a rule, non-crystallisable, colloidal bodies.

VII. **Amides and Amino-acids.**—These, also nitrogenous compounds, have a much simpler constitution than the albuminoids. An amide may be regarded as derived from an organic acid by the replacement of the $-OH$ by $-NH_2$. Thus from acetic acid, $CH_3.COOH$, is derived acetamide, $CH_3.CONH_2$. Amino-acids are derived from organic acids by the replacement of one or more hydrogen atoms *in the organic radical* by $-NH_2$, thus, amino-acetic acid, or glycocoll, is $CH_2(NH_2).COOH$.

Amides occur widely distributed, especially in immature plants, and since they apparently are incapable of forming flesh when fed to animals it is important in food analysis to distinguish between them and the more valuable albuminoids. Many amides have been found in various plants, but *asparagine* (amino-succinamic acid), $CO.(NH_2).C_2H_3(NH_2).CO.OH$, may be taken as typical. This substance, which is both an amide and an amino-acid, is soluble in water, and, like most amides, is crystallisable. It occurs in asparagus, in the young shoots of vetches, beans, peas and many other plants.

VIII. **The Alkaloids.**—These substances may be regarded as derived from ammonia, NH_3, by the replacement of the whole or part of the hydrogen by complex organic groups. They are usually possessed of powerful medicinal properties, and occur only in certain plants, sometimes in the seed, sometimes in the leaves, and sometimes in other parts of the plant. They are of no value as direct foods, but are often valued in medicine.

Caffeine or *theine*, $C_8H_{10}N_4O_2$, occurring in tea and coffee, and *theobromine*, $C_7H_8N_4O_2$, found in cocoa, though by some authorities not regarded as true alkaloids, may be mentioned; while as examples of undoubted alkaloids, *quinine* (in Peruvian bark), $C_{20}H_{24}N_2O_2$, *strychnine* (in nux vomica beans), $C_{21}H_{22}N_2O_2$, *morphine* (in poppy heads), $C_{17}H_{19}NO_3$, and *nicotine* (in tobacco leaves), $C_{14}H_{10}N_2$, may be cited.

IX. **Chlorophyll**, also a nitrogenous body, has been much investigated. It is the green colouring substance present in the leaves and stems of almost all plants, and intimately connected with the assimilation, under the influence of light, of carbon from carbon dioxide. It has the composition represented by the formula, $C_{55}H_{72}O_6N_4Mg$, and contains, as its fundamental constituent, *chlorophyllin* $C_{34}H_{32}O_6N_4Mg$. It is easily extracted by alcohol, ether, or carbon disulphide.

Though iron is essential for its production in the plant, the coloured substance itself is free from iron. Except in this last fact it appears to possess some similarity in composition and constitution to the red colouring substance—hæmoglobin—of the blood of animals. Indeed, recent investigations tend to show that the characteristic constituent of chlorophyll and of hæmatin (the coloured part of hæmoglobin) have the same constitution, except that in chlorophyll, magnesium replaces the iron of hæmatin.

CHAPTER VI.

MANURES.

For a soil to possess fertility—*i.e.*, to be able to properly support the growth of plants—certain conditions are necessary. The following may be mentioned as being perhaps the most important:

1. Its mechanical or physical condition must be suitable.
2. It must contain sufficient plant food in a form which is readily available to the crop.
3. It must not contain any appreciable quantity of poisonous or injurious substances.
4. It must not contain injurious insects, fungi, or other organisms which are destructive to the crop.
5. The temperature, sunshine, rainfall and other climatic conditions must be suitable.

Of these, the second and third, and to a less extent, the first, are matters in which chemistry may be of service.

Every crop removed from a soil robs the latter of materials which have been used in building up the former's tissues. Soil which annually bears a crop must, in time, become exhausted of its store of plant food and unfitted to bear further crops. Generally, one constituent of plant food becomes exhausted first, and in many cases restoration of this constituent would renew the fertility for some time longer. Substances which are added to a soil in order to replace the ingredients which have been removed by previous crops are called *manures.*

All constituents of plants present in a soil, except the carbon, are diminished by the growth of crops upon it, but the substances which usually first become deficient are combined nitrogen, phosphates, calcium carbonate and potash.

Consequently manures are usually valued according to the quantities of these ingredients present in them, although in many cases other constituents may exert an important influence upon the soil.

Farm-yard Manure.—This, formerly the only important manure, is still the most popular.

It consists essentially of:

1. The excreta of the animals of the farm.
2. The litter and waste food.

The *excreta of animals* consists of undigested parts of their food, together with various waste products from the tissues of their bodies. The composition of the excrement varies greatly, some of the factors determining it being:

1. The kind of animal.
2. The character and quantity of the food.
3. Whether the animals are growing, fattening, working, or milking.

Considerable discrepancies are therefore not surprising in analyses of the excreta of animals.

The following table gives the average proportions of the chief manurial ingredients found in the excreta of various animals, according to American analyses:—

	Nitrogen.	Potash.	Phosphorus pentoxide.
	Per cent.	Per cent.	Per cent.
Cattle: dung	0·20	0·10	0·17
urine	0·58	0·49	—
Horses: dung	0·44	0·35	0·17
urine	1·55	1·50	—
Sheep: dung	0·55	0·15	0·31
urine	1·95	2·26	0·01
Pigs: dung	0·60	0·13	0·41
urine	0·43	0·83	0·07
Man: dung	1·00	0·25	1·09
urine	0·60	0·20	0·17

For many reasons, however, the proportions are liable to very considerable variation. The excreta of sheep are less watery than those of the other animals.

It will be noticed that in most cases the urine, though almost free from phosphates, is richer in nitrogen and potash than the dung. The substances found in the urine are those which have been digested by the animal and produced by the waste of tissue while those in the dung are chiefly derived from the undigested food. In addition to the fertilising constituents of the urine and dung, a notable quantity of nitrogen and, particularly, of potash is contained in the perspiration of some animals. Horses and sheep are remarkable in this respect.

The litter renders the manure more bulky and porous, absorbs and retains much of the liquid portion, increases the carbonaceous matter which will eventually pass into humus in the soil, and furnishes a small proportion of plant food. It greatly influences the fermentation of the manure, both by affecting the porosity and admission of air and also by furnishing certain micro-organisms. The average proportions of the chief manurial ingredients present in the various substances used as litter are given in the following table:—

Name of substance.	Nitrogen.	Potash.	Phosphorus pentoxide.
	Per cent.	Per cent.	Per cent.
Wheat straw	0·48	0·9	0·25
Barley straw	0·57	1·2	0·26
Oat straw	0·72	1·2	0·19
Rye straw	0·57	1·4	0·28
Peat-moss	0·85	0·01	0·03
Dried bracken	0·90	0·13	0·20
Dried leaves (autumn) . .	0·75	0·10 to 0·50	0·18
Sawdust	1·00	0·10	0·05
Tanners' refuse	0·16	0·08	0·04

The absorptive and retentive power of these substances for water and ammonia are of much importance. Peat-moss excels in this respect, while leaves and bracken are probably the poorest.

The composition of farm-yard manure is exceedingly variable, and is always very complex. It usually contains from two-thirds to three-quarters of its weight of water, from 0·4 to 0·7 per cent. of total nitrogen, from 0·4 to 1·0 per cent. of potash, and from 0·3 to 0·4 per cent. of phosphorus pentoxide. Very little of the nitrogen is present as ammonium compounds and mere traces as nitrates, the main quantity existing as complex organic compounds.

Various estimates of the amount of manure produced per day by the animals of the farm have been made. According to German authorities, the following are the figures :

Animal.	Total Excrement.	Straw required.	Total Manure.
	lb.	lb.	lb.
Horse	28	5	33
Cow	73	8	81
Sheep	3·8	0·6	4·4
Pig	8·3	4	12·3

American estimates give as the manure per day per 1000 lb. live weight, the animals being fed liberally and littered sufficiently :

Horse	48·8 lb.,	valued at	3·8 pence.
Cow	74·1 „	„	4·0 „
Sheep	34·1 „	„	3·6 „
Pig	83·6 „	„	8·3 „

Preservation of Farm-yard Manure.—The best means of using manure, whether fresh or rotted, and the best methods of avoiding loss of valuable ingredients are matters which have attracted much attention and given rise to much discussion. The drainings from manure are very rich in nitrogenous and potash compounds, and it is evident that allowing them to run to waste is bad economy. They should be preserved either by absorbents—*e.g.*, peat-moss or dry earth—or by being collected in a tank. Access of rain should be prevented by storing the manure in a covered yard. Of greater complexity is the question of losses during fermentation. These losses are chiefly of importance as far as they affect the nitrogen. Nitrogen is lost chiefly in two ways—by volatilisation of ammonia from ammonium carbonate and by the evolution of free nitrogen.

A characteristic constituent of the urine of most animals is the substance known as *urea*, $CO(NH_2)_2$. This body is by the action of micro-organisms converted into ammonium carbonate:

$$\underset{\text{Urea}}{CO(NH_2)_2} + \underset{\text{Water}}{2H_2O} = \underset{\substack{\text{Ammonium}\\ \text{carbonate}}}{(NH_4)_2CO_3}.$$

Ammonium carbonate is a substance which smells of ammonia; indeed, on exposure it is said to decompose into ammonia and carbon dioxide:

$$\underset{\substack{\text{Ammonium}\\ \text{carbonate}}}{(NH_4)_2CO_3} = \underset{\text{Ammonia}}{2NH_3} + \underset{\substack{\text{Carbon}\\ \text{dioxide}}}{CO_2} + \underset{\text{Water}}{H_2O}.$$

This change is hindered by the presence in the atmosphere of large quantities of carbon dioxide or of ammonia. To this decomposition of urea is due the strong smell of ammonia generally perceptible in stables.

In a manure heap numerous chemical changes produced by micro-organisms take place, many of them attended by absorption of oxygen and production of carbon dioxide. Such changes evolve heat, and the temperature of the heap often rises to a very high point. The oxidation of the purely carbonaceous matter in the manure is rather advantageous, since it diminishes the quantity of useless (from a manurial standpoint) matter, and thereby increases the *proportion* of manurial matter in the residue. The high temperature produced, however, tends to increase the amount of ammonia volatilised, especially if the mass becomes dry. On the other hand, the production of carbon dioxide in the interstices of the manure tends to lessen the loss by volatilisation of ammonia. In any case, it is desirable to regulate fermentation so that it goes on regularly, but slowly, and without any excessive rise of temperature. This can be done by a careful admixture of horse and sheep manure which are "hot' (*i.e.*, very prone to rapid fermentation) with cow and pig manure which are "cold" (*i.e.*, ferment slowly), and by keeping the manure moist by occasionally pumping the drainings from the tank on to the heap.

The other way in which nitrogen is lost is by the decomposition of the nitrogen compounds and the evolution of the free element. This is the result of the action of micro-organisms in the *absence* of air. A compact and a thoroughly sodden state of the heap are the conditions favourable to this action. The loss of nitrogen from a manure heap can be greatly lessened by mixing or covering it with soil or peat moss. Another even more effective plan is to add some acid substance—*e.g.*, superphosphate, or even sodium acid sulphate. An objection to these preservatives has been made on the score that they act not merely as absorbents, but as antiseptics, and prevent the decay of the litter.

Other Organic Manures.—The following substances are also used as manure:

1. **Guano.**—This consists mainly of the dried dung of sea-birds. It is found on the coasts of tropical seas. Two varieties are now used, one rich in both nitrogen and phosphates, the other poor in nitrogen but very rich in phosphates. Great variation in composition is shown by guano. An average sample of the first class might contain 7 or 8 per cent. of nitrogen and about 11 per cent. of phosphorus pentoxide, while for the second variety 0·5 to 2 per cent. of nitrogen and 20 to 33 per cent. of phosphorus pentoxide would be fairly representative. Potash is present in many samples of guano, to the extent of about 2 or 3 per cent.

In the nitrogenous varieties the nitrogen is largely present as ammonium salts, and some of the phosphoric acid as soluble alkaline phosphates.

Bats' guano, consisting of the dried excrement of bats, occurring in caves in some countries, is of variable composition, being often mixed with fine silt. It always contains a considerable amount of nitrates.

2. **Poultry** and **pigeon dung** are rich manures, but seldom abundant enough to have much importance in ordinary farming.

3. **Seaweed** is a valuable manure, undergoing rapid decomposition in the soil. In the fresh state it contains about 80 per cent. of water, from 0·3 to 0·7 per cent. of nitrogen, from 0·3 to 2 per cent. potash, and from 0·1 to 0·4 per cent. of phosphorus pentoxide.

4. **Fish Manure or Fish Guano.**—This usually consists of the dried refuse—heads, bones, and other offal—of fish, and is a rich manure, containing about 9 per cent. of nitrogen and 10 per cent. of phosphorus pentoxide. The presence of much oil in this manure is objectionable, because it repels water and hinders decay in the soil, and in some cases it is extracted by means of volatile solvents.

5. **Dried blood** from slaughter-houses is a valuable manure, easily decomposing in the soil. It contains 10 or 11 per cent. of nitrogen, and nearly 2 per cent. of phosphorus pentoxide *Meat meal* is similar in composition, but contains more phosphates.

6. **Shoddy manure** or **woollen waste** is essentially the wool fibres which have become so short by repeated spinning, weaving, &c., that they will no longer hold together. Mixed with the wool residue, however, is a variable quantity of cotton, grease and dirt. The usual product contains about 7 or 8 per cent. of nitrogen, and is remarkable for the slowness with which it decomposes in the soil. It is essentially a nitrogenous manure, but contains small quantities of potash (perhaps 0·5 per cent.) and phosphorus pentoxide (about 0·3 per cent.).

It is largely used for hops, and as a constituent in many mixed manures. Hair, horn, and feathers resemble wool in composition, and are occasionally employed as manure.

7. **Bones** consist of about 70 per cent. of mineral matter, chiefly calcium phosphate, and 30 per cent. of organic matter, containing 3 or 4 per cent. of nitrogen and a variable quantity of fat. Coarse bones decay very slowly; in some soils they can be found almost unchanged several years after their application. They are therefore now reduced to small fragments, and are graded, according to their size, as "half-inch bones," "bone dust," "bone meal," and "bone flour." They are often heated with steam under pressure before grinding, so as to remove the fat and some of the nitrogenous matter. They are then more easily ground and decay more quickly when applied. *Bone ash* is sometimes used; it is free from nitrogen and organic matter, and valuable only for its phosphates.

8. **Soot** consists largely of carbon, but that from house chimneys contains about 3 per cent. of nitrogen, in the form of ammonium salts and organic compounds.

9. **Oil cakes** consist of the husks and residue left after expressing oil from certain seeds, and are rich in all the constituents of plant food. Usually these residues are employed as food, but in some cases they are unpalatable or poisonous. They then form valuable manures, though somewhat slow in action. If the oil has been extracted by solvents the product is improved. Rape seed and castor oil seed cakes are the chief examples. They contain from 5 to 6 per cent. nitrogen, about 1 per cent. of potash and 1·5 per cent. of phosphorus pentoxide.

10. **Human Excreta.**—Where earth-closets are used the night soil has considerable value as a manure, provided it can be used locally. So, too, cess-pools yield a liquid manure rich in fertilising materials. In large towns, however, the excreta of the inhabitants usually passes into the sewers and becomes mixed and diluted with much water and trade effluent. Its

utilisation then becomes very difficult, although highly desirable. Not only is valuable manure lost by the sewers discharging into rivers, but the latter become so polluted as to be a source of annoyance, and even danger.

Many attempts to extract a portable manure from sewage have been made, but without success. A very popular method, known as the A B C process, consists in adding alum, blood, and clay, when the coagulum formed carries down most of the suspended matter, which, when drained and dried, is sold as "native guano." The method, however, fails to remove the large proportion of the nitrogenous matter of the sewage which exists in solution.

Another plan is to utilise the sewage for irrigation purposes. This is a better method, for a suitable soil extracts much valuable fertilising matter from sewage, and will then yield enormous crops. Great difficulty, however, is experienced in obtaining a sufficient area of suitable land (light, sandy soils are best) to deal efficiently with the enormous volume of sewage produced by a large town. Moreover, during frosty weather difficulties arise in dealing with the outfall as rapidly as it is delivered. The land, too, in time becomes so clogged with matters derived from the sewage that it is rendered unfit for further treatment — "sewage-sick." The composition of sewage is naturally very variable, but it is always excessively dilute, its manurial value, assuming that all its fertilising ingredients are available, being about 1½*d.* to 2*d.* per ton.

Green Manuring.—Soil deficient in humus may be greatly enriched in that substance by growing any quick-growing crop and ploughing it in. By this practice not only is the soil enriched with carbonaceous material derived from the air, but a considerable amount of nitrates which have been formed by nitrification during the growth of the crop is assimilated, converted again into complex organic compounds, and restored to the soil. Without the crop these nitrates would have been to a large extent lost by drainage. The planting of "catch crops" for this purpose is best done in the autumn, since nitrification is then very rapid, and loss by the washing out of the nitrates by the winter rains is to a great extent prevented. Rye and mustard are favourite crops for the purpose; and obviously the ploughing in of the crop must take place before the seed is formed, or otherwise the land would be fouled for the next year. If leguminous crops are grown and the crop be ploughed in, a still greater accession to the nitrogenous store of the soil may be secured, for in the presence of the appropriate nodule-forming bacteria such crops draw supplies of nitrogen from the air.

In the case of most plants, the roots absorb from the soil water, the phosphates, potash, nitrates, &c., present and the plant is quite unable to obtain any sustenance from the *free* nitrogen of the air. In the case of peas, beans, clover, lupines and other leguminosæ the roots often possess small nodular swellings or tubercles, inhabited by micro-organisms (*Bacillus radicicola*) which have the power of taking free nitrogen from the air within the soil, building it up into complex organic compounds, probably of an albuminoid nature, and handing it on to the host plant.

When a leguminous plant possesses the nodules and their micro-organisms, it becomes independent of combined nitrogen in the soil, and can thus flourish under circumstances which would induce nitrogen starvation in other plants. Moreover, after such a crop, the soil is often left richer in nitrogen than before, owing to the root-débris remaining after the removal of the crop. These facts were discovered by Hellriegel and Wilfarth in 1886–88, and artificial cultures of appropriate micro-organisms for several crops were put on the market under the name of "Nitragin."

In this connection attention may be called to the recent improvements in the preparation of cultures of nodule-forming bacteria for the various leguminous crops. Both in Germany and in America modified preparations of "Nitragin" have been prepared, which were said to be much more successful than the previous cultures. The German products contained their bacteria in dried agar-agar jelly, and were prepared for use in a medium containing milk, peptone and grape sugar. The American product consisted of cotton-wool impregnated with a culture of the particular organism and dried. The cotton-wool was introduced into a solution containing sugar, potassium phosphate, magnesium sulphate and ammonium phosphate. In this medium the organism developed. In both cases it was claimed that if the seed be moistened with the medium containing the appropriate organisms and dried, the presence of the nitrogen-fixing bacteria when the seed is sown would be ensured.

A considerable sensation was created by popular articles, in which it has been stated that the use of these cultures of nitrogen-fixing organisms, under the name of "Nitro-bacterine," is destined to revolutionise agriculture, but it should be remembered that the most that can be expected of these methods is that the soils rich in the mineral elements of plant food, but deficient in nitrogen, may be gradually enriched in that constituent so as to become capable of supporting the growth of ordinary crops. There seems to be little doubt that the new cultures possess the power of inducing nodule-formations on the roots of leguminous plants, and that even in soils in which nodules are spontaneously formed, inoculation of the seed with the cultures ensures the formation of more numerous and larger nodules. But, on the large scale, these preparations have not been successful enough to secure their general adoption.

Artificial or Chemical Manures.—The organic manures, as a rule, contain all the ingredients necessary for plant life, and, as general manures, are highly satisfactory. Cases often arise, however, in which a soil only requires the addition of one or two fertilising substances in order to fit it to yield a full crop. In such cases, by means of suitable artificial manures, it is possible to add exactly what is required, without introducing other plant food, with which the soil may be abundantly supplied.

(A) Nitrogenous Manures.—The principal members of this class are sodium nitrate and ammonium sulphate.

Sodium Nitrate.—"Chili saltpetre" or "cubic nitre" is found in certain rainless districts in Peru, Chili, and Bolivia. It occurs near the surface in layers varying in thickness from a few inches to 12 feet. The crude deposit is known as *caliche*, and varies greatly in composition. The different varieties are mixed so as to yield a product containing:

	Per cent.
Earth, stones, &c.	50
Sodium nitrate	35
Magnesium, calcium, and sodium chlorides	10
Water, sulphates, and other substances	5

This mixture is treated with water and allowed to settle; iodine, which is present as sodium iodate, $NaIO_3$, is extracted, and the liquor evaporated and crystallised. The crystals so formed, are dried by exposure to the sun, and exported. The average composition of the commercial product is said to be:

Sodium nitrate	96·75
Water	2·10
Sodium chloride	·75
Sulphates	·30
Insoluble matter	·10
	100·00

During recent years much attention has been directed to the presence of sodium perchlorate, $NaClO_4$, in many samples of nitrate, and to the injurious effects produced by the application of such nitrate to many crops. Specimens of nitrate of soda have been found to contain as much as 5 per cent. of this poisonous perchlorate, and in samples used in Germany, an average of about 1 per cent. appears to be present. English samples seem to be comparatively free from this impurity. Pure sodium nitrate, $NaNO_3$, is a white crystalline salt, very soluble in water (100 parts of water dissolving about 80 parts of the salt at ordinary temperatures), and deliquescent in moist air. It is not retained by any constituent of the soil, and is therefore very liable to be lost in the drainage. Hence it should never be applied in heavy dressings, nor much before the crop is sufficiently grown to be able to absorb it.

It has recently been proposed to manufacture nitrates for agricultural purposes by passing strong electric discharges through air. By this means oxides of nitrogen are produced by the union of nitrogen and oxygen, and if an alkali—*e.g.*, soda—be present nitrite and nitrate of the alkali are formed. Where large natural sources of power (*e.g.*, Niagara) are available for producing electricity this process might be profitable.*

Ammonium Sulphate.—This substance is made from the "ammoniacal liquor" of gasworks, coke ovens, or blast-furnaces. When coal, which contains about 1·3 per cent. of nitrogen, is distilled the nitrogen is partly evolved as ammonia, NH_3, which dissolves in the water condensed from the steam formed at the same time. The "gas liquor" so obtained contains many compounds of ammonia, the chief being carbonate, chloride, sulphide, and thiosulphate. The total ammonia in the "gas liquor" amounts usually to about 2 per cent. In order to obtain sulphate of ammonia, the "gas liquor" is distilled with lime, and the ammonia gas evolved is led into sulphuric acid:

$$H_2SO_4 + 2NH_3 = (NH_4)_2SO_4.$$

The liquid is boiled down, and sulphate of ammonia crystallises out. Important impurities sometimes found in commercial ammonium sulphate are ammonium sulphocyanide, NH_4CNS, and arsenious sulphide, As_2S_3. The former is derived from the "gas liquor," the latter from the sulphuric acid, which sometimes contains arsenious oxide, As_2O_3. Both these substances are plant poisons.

Ammonium sulphate crystallises in anhydrous crystals, which

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* Recently at Notodden (Norway) by using lime as the alkali, a basic nitrate of lime, capable of successfully competing as a nitrogenous manure with nitrate of soda, has been produced on a large scale.

are easily soluble in water (100 parts of water at the ordinary temperature will dissolve about 73 parts of the salt). When it is applied to soil it undergoes decomposition, the acid radicle uniting with calcium from the calcium carbonate in the soil and finding its way into the drainage, whilst the ammonium is held back by the humus and other constituents of the soil:

$$(NH_4)_2SO_4 + CaCO_3 = (NH_4)_2CO_3 + CaSO_4.$$

Before it is available for plants ammonia has to be converted into nitrates by the nitrification process, and this involves a further loss of calcium carbonate:

$$\underset{\substack{\text{Oxygen}\\ \text{(from}\\ \text{the air)}}}{4O_2} + \underset{\substack{\text{Ammonium}\\ \text{carbonate}}}{(NH_4)_2CO_3} + CaCO_3 = Ca(NO_3)_2 + 2CO_2 + 4H_2O.$$

It is evident from these reactions that sulphate of ammonia is only suited to soils containing at least a moderate amount of calcium carbonate, and that its use is then attended with considerable loss of calcium to the soil. It is also clear that sulphate of ammonia ought to be applied some time before the crop requires its nitrogen, so that the necessary nitrification can take place. In these respects it differs essentially from nitrate of soda, which is already available for plants, has little or no influence upon the calcium carbonate of the soil, and, as already stated, should not be applied before it is wanted.

Ammonium sulphate has the advantage in a wet season, on account of its retention in the soil. In a very dry season, when nitrification may be checked and little loss of water by drainage occurs, nitrate of soda often gives the better result.

Potassium nitrate, KNO_3, is of double value as a manure, but its price is so high that it is not very largely employed in agriculture.

Calcium cyanamide, $CaCN_2$, has lately been proposed as a nitrogenous manure. The substance is obtained by heating calcium carbide, CaC_2 (now so largely produced by means of the electric furnace from carbon and lime, chiefly for the manufacture of acetylene), in a current of air which has been deprived of oxygen. The crude product, which contains about 20 per cent. of nitrogen instead of the theoretical 35 per cent., is a black powder, resembling basic slag in appearance. When used as a manure it has in many cases yielded as good results as the same amount of nitrogen applied as nitrate of soda or sulphate of ammonia; but on peaty soil it has been found to be harmful to plants, owing, it is said, to the formation of dicyandiamide by the action of the acids present in the soil. This substance is a powerful plant poison.

Under ordinary conditions—*i.e.*, in the absence of acids—the substance probably decomposes thus:

$$CaCN_2 + 3H_2O = CaCO_3 + 2NH_3,$$

the whole of the nitrogen being obtained as ammonia, and thus capable of nitrification.

(B) **Phosphatic Manures.**—Bones, especially steamed and burnt bones, and guano are chiefly valued for the phosphates they contain. These manures have already been described. Other more important (because more abundant) sources of phosphoric acid are known. Before dealing with them it may be advisable to describe briefly the various forms in which phosphoric acid occurs in fertilisers.

1. As *Free phosphoric acid*, H_3PO_4.—This, when pure, is a thick, semi-solid mass, obtained by acting upon a phosphate with sulphuric acid:

$$Ca_3P_2O_8 + 3H_2SO_4 = 3CaSO_4 + 2H_3PO_4.$$

It is soluble to any extent in water. It is found in small quantities in some superphosphates.

2. As *Monocalcium tetrahydrogen phosphate*, $CaH_4P_2O_8$.—This substance is obtained by the action of a smaller proportion of sulphuric acid upon calcium phosphate:

$$Ca_3P_2O_8 + 2H_2SO_4 = CaH_4P_2O_8 + 2CaSO_4.$$

It is very soluble in water, and is the chief valuable constituent of superphosphates.

3. As *Dicalcium hydrogen phosphate*, $Ca_2H_2P_2O_8$, or $CaHPO_4$, a white solid, obtained by precipitating ordinary sodium phosphate, Na_2HPO_4, with calcium chloride, $CaCl_2$:

$$CaCl_2 + Na_2HPO_4 = CaHPO_4 + 2NaCl.$$

It is almost insoluble in water, but dissolves in the presence of certain salts—*e.g.*, ammonium citrate. It is probably more easily available for the roots of a plant than tricalcium phosphate. It is found in superphosphates, especially if they have been kept for some time.

4. As *Tricalcium phosphate*, $Ca_3P_2O_8$.—This is a white substance, almost insoluble in water, but easily soluble in acid. This is the form in which phosphoric acid occurs in bones, mineral phosphates, and most guanos. Its solubility is greatly increased by the presence of carbon dioxide. The solubility, too, depends upon its degree of subdivision and physical state, being much greater if finely divided, amorphous and porous than if coarse, crystalline and compact.

Most mineral phosphates contain also calcium chloride, $CaCl_2$, or calcium fluoride, CaF_2.

5. As *Tetracalcium phosphate*, $Ca_4P_2O_9$. This is practically insoluble in water, but dissolves in many saline solutions. It occurs in the slag formed in the dephosphorisation of cast iron by the basic Bessemer or basic Siemens process.

6. As *Ferric phosphate*, $FePO_4$, and *Aluminium phosphate*, $AlPO_4$. These are practically insoluble in water, and nearly so in dilute vegetable acids. Consequently they are difficultly available for plants, and unless extremely finely divided are almost worthless as manures. When they are formed in the soil by the action of ferric or aluminium hydrate upon soluble phosphates, however, they appear to be capable of affording phosphoric acid to the roots of plants, though not readily.

Generally it may be stated that if a substance is formed by precipitation from solution in the soil itself it will be, as a rule, much more available for plants than if it were applied ready-formed to the soil, even in a finely divided condition.

The chief commercial forms in which phosphates are used as manures are:

1. *Mineral phosphates*, consisting largely of tricalcium phosphate, $Ca_3P_2O_8$. Immense quantities of this material are found in the United States of America, in Belgium, Algeria, and Canada. Generally they are not used directly, but are converted into superphosphate. If very finely ground, however, they are occasionally successful.

2. *Mineral Superphosphates.*—These are made by treating the raw phosphates with sulphuric acid (chamber acid of sp. gr. 1·55), which produces the reaction already described. A superphosphate contains a considerable portion of its phosphoric acid in the form of monocalcium tetrahydrogen phosphate, $CaH_4P_2O_8$, some as unchanged $Ca_3P_2O_8$, and generally some as $CaHPO_4$.

3. *Dissolved Bones.*—These are made by a process similar to the last described, but the product contains nitrogenous matter, and usually a larger proportion of unchanged tricalcium phosphate.

4. *Basic Slag, Thomas Slag, or Thomas Phosphate.*—This product is formed in the basic Bessemer process of making steel from cast iron. It contains its phosphorus pentoxide (usually from 16 to 18 per cent.) in the form of tetracalcium phosphate, $Ca_3P_2O_8$, together with free lime, and is particularly suitable for soils rich in organic matter. It is only effective if applied in a finely divided state, so that its value largely depends upon the thoroughness of the grinding; 80 to 90 per cent. should pass a sieve with 100 meshes to the linear or 10,000 meshes to the square inch. Its phosphoric acid, though insoluble in water, is readily soluble in saline solutions—*e.g.*, solution of ammonium citrate. The composition of the commercial product varies considerably, but a good sample contains about 18 per cent. of phosphorus pentoxide, 45 per cent. of lime, 15 per cent. of ferric oxide, and small quantities of silica, magnesia, alumina, &c.

(C) Potash Manures.—Potash in England is less frequently deficient in soils than nitrogen and phosphorus. Certain crops, however, require more potash than they can readily obtain from some soils, and are much helped by the application of potash manures.

Plant ashes, which contain potassium carbonate, were formerly largely and still are, to some extent, used as a potash manure, but the chief source of potash compounds has been the immense deposit at Stassfurt, overlying huge beds of rock-salt.* This is worked on an enormous scale, some of the products—*e.g.*, kainite—being sent into the market with no preparation other than crushing, while others—*e.g.*, potassium sulphate—are first purified by recrystallisation. The commercial products contain their potassium either as chloride, KCl, or sulphate, K_2SO_4. The former is the more soluble and diffusible, but appears in the case of certain plants—*e.g.*, tobacco, potatoes—to produce ill-effects on the quality of the crops. The following are the chief forms in which potash is purchased for manurial purposes:

Kainite, the most widely used form, is a mixture of several salts, including potassium chloride and sulphate, magnesium chloride and sulphate, sodium chloride and calcium sulphate. It usually contains about 12 to 13 per cent. potash, K_2O, and from 25 to 45 per cent. common salt.

Muriate of Potash.—Under this, the old name for potassium chloride, are sent out various qualities containing 70 to 95 per cent. KCl (corresponding to from 44 to 58 per cent. K_2O), the chief impurity being common salt.

Sulphate of potash is supplied generally either as of 90 or 96 per cent. purity—that is, containing about 49·6 or 52·5 per cent. of K_2O.

Double sulphate of potash and magnesia is obtained by calcining the crystallised salt, $MgSO_4.K_2SO_4.6H_2O$. It usually

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* During the war several sources of potash have been proposed, the most promising being the flue dust from the smelting of certain iron ores.

contains about 50 per cent. K_2SO_4, 34 per cent. $MgSO_4$, and 11·5 per cent. water, corresponding to about 27 per cent. of potash, K_2O.

Potash is most needed on light sandy or calcareous soils, particularly for potatoes, grasses, clovers, peas, and beans. Potash manures are best applied in the autumn or winter, and little loss need be feared from drainage.

(D) **Miscellaneous Manures.**—*Common salt* is generally regarded as possessing no true manurial value, but as being of service because of its action upon the potash, lime, and magnesia compounds in the soil. It has a good effect on mangolds and cabbages. It increases the solubility of phosphates and silicates.

Gypsum, $CaSO_4.2H_2O$, is found to improve clover and turnips. It perhaps acts as a source of sulphur, but probably its good effects are indirect, partly by liberating potash from insoluble silicates and partly by aiding nitrification.

Lime, CaO, *slaked lime*, CaH_2O_2, and *chalk*, *marl*, or *limestone*, $CaCO_3$, are very often useful as manures. They all contain small quantities of phosphates, and thus provide plant food, but their most important effect is that of acting as basic material, and thus (1) neutralising the vegetable acids produced by the decay of organic matter and (2) promoting nitrification. Caustic lime—*i.e.*, either quicklime, CaO, or slaked lime, CaH_2O_2—always has a more decided effect than chalk or limestone, although within a very short time of its application to the soil it is converted into the same compound, $CaCO_3$. This is due to the solubility of calcium hydrate, leading to its more uniform distribution throughout the soil than is possible with even the finest ground chalk or limestone.

Another valuable action of lime is its flocculating effect upon clay. It must be remembered that the too frequent application of lime to a soil may exhaust the nitrogenous matter contained in the humus. Lime from magnesian limestone, which contains magnesia, MgO, is not so good for agricultural purposes as a purer lime, probably because magnesia does not absorb carbon dioxide from the soil water and gases so quickly as lime does; consequently the magnesia retains its causticity for a longer time, and this hinders the growth of plants.

Gas Lime.—This is a waste-product from gasworks, being the residue left after passing coal-gas over slaked lime in order to remove carbon dioxide, CO_2, and sulphuretted hydrogen, H_2S. It consists of a complex mixture containing calcium carbonate and hydrate, together with varying quantities of incompletely oxidised sulphur compounds (*e.g.*, calcium sulphite, $CaSO_3$, sulphide, CaS, thiosulphate, CaS_2O_3). These latter substances are powerful plant poisons, and fresh gas lime is very injurious to plants. It should be kept for some time freely exposed to air, in order to convert the unoxidised sulphur compounds into sulphate, $CaSO_4$.

Ferrous Sulphate, $FeSO_4.7H_2O$, *Green Vitriol;* and *Copper Sulphate*, $CuSO_4.5H_2O$, *Blue Vitriol.*—These substances are rarely used as manures, but are often employed in spraying for the destruction of charlock or of fungoid diseases. The iron compound has been claimed to act as a useful manure for grass, beans, potatoes, mangolds and cereals. It is applied at the rate of about ½ cwt. per acre, and is said to kill moss and to act as a plant food, increasing the amount of chlorophyll in the crop and to a certain extent acting as a substitute for potash manures.

Analysis and Valuation of Manures.

The value of a manure is usually estimated from the quantities of nitrogen, phosphorus pentoxide, and potassium which it contains.

In the trade the results of an analysis are often expressed in percentages of "ammonia" (*i.e.*, NH_3), "phosphates" (by which is meant tricalcium phosphate), and "potash." Now in many manures—*e.g.*, nitrate of soda—the nitrogen is not present as ammonia; so, too, "phosphates," meaning tricalcium phosphate, does not correctly describe the state of existence of the phosphorus pentoxide in many manures; while even "potash," which really means the substance K_2O, is not correctly applied as the name of a constituent of such a manure as "muriate of potash"—*i.e.*, KCl. The trade method of expressing the composition of a sample of superphosphate may be given.

	Per cent.
Monocalcium phosphate, or monobasic phosphate of lime (=tricalcium phosphate rendered soluble, or "soluble phosphates," 23·5 per cent.)	15
Insoluble phosphates	3
Hydrated calcium sulphate	54
Alkaline salts	2
Water	22
Silica	4
	100

By "monobasic phosphate of lime" in such an analysis is meant, not true monocalcium tetrahydrogen phosphate, $CaH_4P_2O_8$, but that substance less two molecules of water, CaP_2O_6 (though this is really calcium metaphosphate, which does not occur in manures). The relation between this substance and the tricalcium phosphate is easily seen from their formulæ:

$$\begin{array}{cc} CaP_2O_6 & Ca_3P_2O_8 \\ 40+62+96=198 & 120+62+128=310 \end{array}$$

i.e., the amount of "monocalcium phosphate" × 310 ÷ 198 = the amount of tricalcium phosphate, or "tribasic phosphate of lime," as it is sometimes called.

In many superphosphates a portion of the phosphorus pentoxide is in the form of calcium hydrogen phosphate, $CaHPO_4$. This substance, though insoluble in water, is soluble in many salt solutions—*e.g.*, ammonium citrate. It is sometimes referred to as "reverted," "retrograde," or "reduced" phosphate; it would be better to call it "citrate soluble." In fact, since phosphorus pentoxide is the really valuable ingredient, it would, in every sense, be better to report the analysis of a phosphatic manure thus:

	Per cent.
Total phosphorus pentoxide :	
Soluble phosphorus pentoxide	
Citrate soluble phosphorus pentoxide . . .	
Insoluble phosphorus pentoxide	

The meaning of these terms would be precise and definite.

In assessing the value of a manure from its analysis it is usual to employ what are known as values "per unit" for the three chief fertilising ingredients. These are the commercial values (and therefore liable to fluctuation) of each per cent. per ton, so that really they are the values of 22·4 lb. of the particular ingredient. Thus, suppose nitrate of soda containing 15·75 per cent. of nitrogen be worth £8 per ton, then the value of the nitrogen will be

$$\frac{8 \times 20}{15\cdot75} = 10\cdot2s., \text{ or } 10s.\ 2\tfrac{1}{2}d. \text{ per "unit."}$$

In sulphate of ammonia at £12 per ton, containing 24·5 per cent. ammonia, equal to $24\cdot5 \times \frac{14}{17} = 20\cdot2$ per cent. nitrogen, the value "per unit" of nitrogen will be

$$\frac{12 \times 20}{20\cdot2} = 11\cdot83s. = 11s.\ 10d.$$

In a similar way the values "per unit" of phosphorus pentoxide and of potash can be calculated from the market prices of the various manures. In these cases, as with nitrogen, the values will vary with different manures. In most tables of values "per unit," "ammonia" and "phosphates" are the substances valued, but for reasons already given it is preferable to give the figures for nitrogen and phosphorus pentoxide.

The values "per unit," as already stated, are liable to fluctuations, and differ somewhat with different manures, so that the following figures are only to be taken as examples:

VALUE "PER UNIT."

	s.	d.		s.	d.
Nitrogen (= ammonia, 8s. 3d. to 9s. 10½d.)	10	0	to	12	0
Soluble phosphorus pentoxide (= soluble phosphates, 2s. 3d. to 3s.)	4	1	to	5	5
Insoluble phosphorus pentoxide (= insoluble phosphates, 1s. 4d. to 1s. 7d.)	2	6	to	2	9
Potassium (= potash, 3s. 4d. to 3s. 9d.)	4	0	to	4	7

An example of the valuation of a manure from analysis may be useful. Suppose it is desired to calculate the value per ton of a mixed manure having the following proportions of fertilising ingredients:

	Per cent.
Ammonia	5
Soluble phosphates	15
Insoluble phosphates	7
Potash	3

Assuming that the unit value for ammonia is 9s., for soluble phosphates 2s. 6d., for insoluble phosphates 1s. 6d., for potash 3s. 6d., the value per ton would be calculated thus:

			s.	d.		£	s.	d.
Ammonia	5	×	9	0	=	2	5	0
Soluble phosphates	15	×	2	6	=	1	17	6
Insoluble phosphates	7	×	1	6	=		10	6
Potash	3	×	3	6	=		10	6
						£5	3	6

CHAPTER VII.

CROPS.

In this chapter a brief account will be given of the composition and manurial requirements of the various crops grown on a farm managed according to the usual English methods, together with a few notes concerning the chief semi-tropical and tropical crops grown in some of the British colonies.

Many methods of classifying crops might be used; the following is convenient, and will be adopted here:

I. Crops in which the seed or fruit is the portion most valued.
II. Crops which are grown mainly for the sake of the root or tuber.
III. Crops in which the foliage and stem are the most important.

Class I. includes chiefly grain crops and fruits.

Class II. comprises turnips, potatoes, beets, &c.

Class III. consists chiefly of gramineous (grasses), leguminous, and other plants.

CLASS I.—GRAIN AND FRUIT CROPS.

These may be subdivided into:

1. *Cereals*—wheat, barley, oats, rye, rice, maize, millet, Kaffir corn, &c.
2 *Leguminous seeds*—beans, peas, cow-pea, soy bean, lentils, lupines, earth-nut.

3. *Miscellaneous seeds*—buckwheat, cotton-seed, linseed, hemp-seed, rape-seed, castor beans, sunflower-seed, &c.
4. *Fruits*—apples, pears, plums, apricots, peaches, oranges, melons, pumpkins, bananas, grapes.

1. **The Cereals.**—The seeds of these plants are characterised by their richness in starch. Their straw generally contains a large amount of silica, which, however, does not appear to be essential to the plant. The silica is probably absorbed in the form of soluble silicates—*e.g.*, of potassium, the metal being used by the plant and the silica deposited, chiefly in the stem, as an excretion.

Another characteristic of cereals is their richness in phosphoric acid and comparative poverty in lime. This is most marked in the grain itself, but is also shared by the straw.

Wheat (*Triticum vulgare*) in temperate climates is usually autumn-sown, and therefore has a longer period of growth than barley or oats. It is consequently better able to supply itself with the necessary food from the soil. The land, however, loses the spring tillage, which, by aerating the soil, is conducive to nitrification, and nitrogenous manures are therefore more often required by wheat than by other common cereals.

Wheat straw, when ripe, is remarkable for the large amount of silica and the small proportion of nutritive matter which it contains.

The wheat grain is particularly suited for the manufacture of bread because of its large content (8 to 10 per cent.) of gluten, and the richness of this gluten in the peculiarly sticky *gliadin*. This enables wheat flour to furnish a light, porous, spongy, and palatable bread when the dough is inflated by carbonic acid, as in baking. In warm climates, especially when much rainy weather occurs in the summer, wheat (also barley and oats) becomes very liable to the attacks of fungous diseases—*e.g.*, rust—and is in consequence only grown for its seed during the dry season, and usually by the aid of irrigation. If intended for fodder, wheat, like other cereals, should be cut while still unripe, as the straw is then more palatable and digestible, and contains nutriment which, if the plant were allowed to ripen, would be transferred to the seed.

Wheat does best generally with a firm seed-bed, and this fact is to be borne in mind in preparing the land before sowing. For the same reason soil containing a fair amount of clay or humus is more suited to wheat than are open, sandy soils.

AVERAGE COMPOSITION OF WHEAT AND WHEAT STRAW.

	Wheat.	Wheat Straw.
Moisture	10·5	9·6
Ash	1·8	4·2
Crude fibre	1·8	38·1
Carbohydrates	71·9	43·4
Protein	11·9	3·4
Fat	2·1	1·3
	100·0	100·0

Barley (*Hordeum distichum*, two-rowed; *Hordeum vulgare*, six-rowed), of which there are many varieties, usually has a shorter period of growth than wheat. The soil must therefore be provided with a sufficiency of plant food, although heavy nitrogenous manuring is not desirable, since the crop is thereby rendered rank and coarse, and the grain unsuited for malting purposes. Barley straw is more palatable and digestible than wheat straw, and is often used as food for cattle. The grain contains less gluten than wheat, and this gluten is not so tenacious as that of wheat. Consequently barley meal does not furnish a satisfactory bread.

Barley is largely used for the preparation of *malt*. The grain is soaked for some hours in water, and then laid in thick layers on floors. The seed germinates and heat is evolved. When the germination has proceeded far enough the sprouted barley is dried in a kiln at a temperature high enough to destroy the vitality of the embryo. The plumule and radicle are then removed—they constitute *malt culms*—and the malt is then ready for use in the preparation of *wort.* The most important change produced by malting is the production of a considerable quantity of a peculiar *unorganised ferment*, or *enzyme*, known as *diastase*, which has the power in the presence of warm water of converting starch into sugar. When malt is *mashed*—*i.e.*, treated for some time with hot water—this change begins, and the liquid gradually becomes charged with sugar, the starch of the barley grain at the same time disappearing. The quantity of diastase in malt is so large that it is capable of converting much larger quantities of starch into sugar than are contained in the malt itself. Consequently unmalted barley or other cereal is sometimes added with the malt. The resulting liquor, known as wort, is then submitted to alcoholic fermentation by means of yeast, hops are added to impart a bitter flavour, and *beer* or *ale* results. Barley is also used as food for animals, in England particularly for pigs.

"Pearl barley" is the grain divested of its outer fibrous coat.

AVERAGE COMPOSITION OF BARLEY AND BARLEY STRAW

	Barley.	Barley Straw.
Moisture	10·9	14·2
Ash	2·4	5·7
Crude fibre	2·7	36·0
Carbohydrates	69·8	39·0
Protein	12·4	3·6
Fat	1·8	1·5
	100·0	100·0

Oats (*Avena sativa*) will ripen in a cooler climate than wheat or barley. The grain retains a large proportion of husk, and varies in size and shape considerably in the different varieties.

Oats are remarkable for the high proportion of fat and ash which they contain. They also contain some constituent capable of exerting a stimulating action upon horses. This substance has been termed "avenin."

Oats in England are usually grown for seed, though occasionally for fodder, especially if mixed with tares. But in America and in South Africa enormous quantities are grown as forage, partly to be eaten green, but mainly to be made into *oat hay*. This product, which in some districts is the staple food of horses, mules, &c., should be made by cutting the oats while still green and drying them in the sun. If allowed to ripen before cutting, the grain robs the straw of most of its nutritive properties, and the resulting hay is neither so palatable nor so digestible.

Oat straw, even when the grain has fully ripened, is more suitable for feeding purposes than wheat or even barley straw.

AVERAGE COMPOSITION OF OATS, OAT FODDER, OAT STRAW AND OAT HAY.

	Oats.	Oat Fodder.	Oat Straw.	Oat Hay.*
Moisture	11·0	62·2	9·2	8·1
Ash	3·0	2·5	5·1	4·3
Crude fibre . . .	9·5	11·2	37·0	31·6
Carbohydrates . .	59·7	19·3	42·4	47·2
Protein . . .	11·8	3·4	4·0	4·9
Fat.	5·0	1·4	2·3	3·9
	100·0	100·0	100·0	100·0

Rye (*Secale cereale*) resembles wheat in many respects. In England rye is usually grown as a green crop for spring feed-

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* Mean of several analyses of South African products. As the sole food of horses or mules, oat hay is too rich in phosphoric acid and too poor in lime for the healthy nutrition of the bones. Where it is used as the exclusive food a disease known as osteoporosis is often prevalent.

ing. On the continent of Europe, however, rye is largely grown for grain, being used for making rye-bread, the staple food of the peasantry in many districts. The straw is long, and valued for thatching. In composition the grain of rye resembles that of wheat, but it does not yield so good a quality of bread.

AVERAGE COMPOSITION OF RYE, RYE STRAW AND RYE FODDER.

	Rye.	Rye Straw.	Rye Fodder.
Moisture	11·6	7·1	76·6
Ash	1·9	3·2	1·8
Crude fibre	1·7	38·9	11·6
Carbohydrates	72·5	46·6	6·8
Protein	10·6	3·0	2·6
Fat	1·7	1·2	0·6
	100·0	100·0	100·0

Rice (*Oryza sativa*) forms the staple food of a large portion of the human race. It is generally grown under irrigation. It requires a warm climate, and generally has to be cultivated under swampy and unhealthy conditions. Two crops per year are usually grown. The rough rice, known as "paddy," obtained from the plant is subjected to a process of milling, by which the brown outer husk is removed and the familiar white rice of commerce is obtained. The by-products of the mills are chiefly *rice polish*, a fine, flour-like substance, and *rice bran*, a coarser and less nutritious material. Sometimes these are mixed and sold as "rice meal," "rice feed," or under some other name. Organic nitrogenous matter—*e.g.*, cotton-seed cake—and superphosphates are recommended as manures.

Another variety, upland or mountain rice, will grow up to elevations of 6000 feet, and without irrigation. It yields excellent fodder. When ripened the grain is similar to ordinary rice, and it is even more prolific, but only one crop can be obtained per annum instead of two.

Whole rice, or "paddy"—*i.e.*, the seed with its husk—contains a fair amount of ash constituents and protein, but the ordinary white rice, deprived of its husk, consists very largely of starch and contains very little ash. The "hulls" or husks, bran and rice polish are much richer in ash, fat and protein.

COMPOSITION OF RICE GRAIN, HUSK, BRAN AND "POLISH."

	Rice.	Husk.	Bran.	"Rice Polish."
Moisture	12·4	8·2	9·7	10·0
Ash	0·4	13 2	10·0	6·7
Crude fibre	0·2	35·7	9·5	6·3
Carbohydrates	79·2	38·6	49·9	59·0
Protein	7·4	3·6	12·1	11·7
Fat	0·4	0·7	8·8	7·3
	100·0	100·0	100·0	100·0

Maize, Indian corn, or "mealies" (*Zea mays*) is perhaps, next to rice, the most extensively cultivated of all the cereals. It was grown by the aborigines of America; hence the name "Indian corn," by which it is widely known in England. In the United States of America it is usually called *corn*, the other cereals being known as *grain*. In South Africa it is always known as "mealies." In England maize (imported) is chiefly used for fattening animals, but in America and other countries it is also largely used for human food. The grain, when crushed or ground, can be fed to horses, mules, or cattle, can be ground to meal and flour and used as porridge for human food, while the unripe grain on the cob is boiled and considered a dainty by some people. The green leaves and stalks can be used as fodder for animals or made into excellent silage, while the spathes or sheaths of the ear can be made into paper. By fine grinding and removal of the bran-like portions of the grain a product known as *maizena* or *cornflour* is obtained, largely used as a substitute for arrowroot and for culinary purposes.

Maize is a fine plant, attaining a height of from five to twelve or fifteen feet. The male flower is borne at the top of the stem in a feathery panicle, while the female flowers, of which there are usually three or four spikes on each plant, grow out from the axils of the leaves, enveloped in membranous sheaths or spathes, the long pink styles hanging out from the tops of the sheaths as silky tassels. The pollen from the male flowers either drops or, more usually, perhaps, is carried by the wind into contact with the styles ("tassels"), and fertilisation is thus effected. Each spike of female flowers then becomes an ear, consisting of a central fibrous woody core of conical form, with the seeds arranged regularly around it, and the whole enveloped in several spathes or husks. An enormous number of varieties of maize have been produced. Great differences in size, shape, colour and chemical composition, are presented by the various varieties, also in the number of rows on the cob. Thus the ear may be from an inch to sixteen inches in length, and have six to forty rows of grains. In practice the varieties may be classed into five types.

(*a*) *Dent Corn.*—If a grain of this variety be split longitudinally there will be seen the germ, horny or glossy starch at the sides, and white, floury starch in the centre, extending to the top of the grain. Owing to the shrinking of the white starch on drying being much greater than that of the horny starch, the grains have an indentation at the top, giving them a supposed resemblance to a tooth; hence the name dent.

(*b*) *Flint Corn.*—In this type the horny starch entirely surrounds the white, floury starch. The top of the grain, therefore, remains smooth, hard, and convex. It has a translucent appearance.

(*c*) *Pop-corn*, in which almost all the starch is glossy or horny.

(*d*) *Soft corn*, or "bread mealie," in which all the starch is white and floury. The top of the grain is smooth, since the contraction on drying is uniform. The grain is opaque.

(*e*) *Sweet corn*, or "sugar mealie," in which the starch is partially converted into glucose. Such grains are translucent, and, owing to the shrinkage in drying, very wrinkled.

Maize will grow well in any warm climate, but will not ripen without abundant sunshine. Its manurial needs in many soils appear to be phosphates, lime, potash, and nitrogen, in the order given. Varieties attain maturity in from 90 to 150 days from sowing, but much depends upon temperature and climate.

AVERAGE COMPOSITION OF MAIZE (AMERICAN RESULTS).

	Dent.	Flint.	Sweet.
Moisture	10·6	11·3	8·8
Ash	1·5	1·4	1·9
Crude fibre	2·2	1·7	2·8
Carbohydrates	70·4	70·1	66·8
Protein	10·3	10·5	11·6
Fat	5·0	5·0	8·1
	100·0	100·0	100·0

The following represents the results of analyses of Transvaal-grown mealies:

	Soft or Bread Mealies.	Dent Mealies.	Flint Mealies.
Moisture	7·72	6·97	7·40
Ash	1·14	1·27	1·85
Crude fibre	1·51	1·94	1·87
Carbohydrates	76·26	75·87	72·74
Protein	9·00	9·42	10·89
Fat	4·37	4·53	5·25
	100·00	100·00	100·00

From the above figures it is seen that the average sweet or sugar maize is richest in protein and ash, while the soft or bread mealies is lowest in these constituents, but richest in starch; also that the flint varieties are richer in protein, ash, and water than the dent.

Queensland- (Australia) grown maize is apparently richer in protein than American-grown maize. But it must be remembered that considerable differences are shown by the various varieties of the same type. As a rule, too, the smaller-grained varieties are more nitrogenous than the larger.

In good soil crops of from 50 to 80 or even 100 bushels of maize per acre can be obtained. Maize is sometimes grown for forage, being either eaten green or made into ensilage. In both cases it should be cut while still unripe, and before the seed has fully formed.

ANALYSES OF MAIZE SILAGE.

	American.	Transvaal.
Moisture	79·1	75·66
Ash	1·4	1·91
Crude fibre	6·0	8·38
Carbohydrates	11·0	10·89
Protein	1·7	2·31
Fat	0·8	0·85
	100·0	100·00

Millet.—Under this term are included many plants. The following may be mentioned as the most important: *Common millet* (*Panicum miliaceum*), grown in America for fodder; this is an annual. *Pearl millet*, or *Kaffir manna-koorn* (*Pennisetum spicatum*), also an annual, growing to a height of from three to six feet, bears its seed in a "head" or spike six to ten inches long, and is chiefly used for green forage in America. *Italian*, or golden millet, *German millet*, or *Hungarian grass*, *and Japanese millet* are varieties of *Setaria italica*. They have long and broad leaves, and a spike-like "head," four to six inches long. They grow to a height of three or four feet.

Boer manna, or *foxtail millet* (*Choetochloa italica*), is also useful as a forage crop. A sample of hay grown near Johannesburg gave the following figures on analysis:

Moisture	8·3
Ash	7·8
Crude fibre	30·9
Carbohydrates	46·2
Protein	5·0
Fat	1·8
	100·0

Sorghum.—Belonging to this genus are several varieties which bear a general resemblance to the millets. In America both saccharine and non-saccharine sorghums are largely grown for forage. The non-saccharine sorghums are most important from our present standpoint, since they are largely grown for seed. The most important are:

Kaffir corn (*Andropogon sorghum* or *Sorghum vulgare*), of which there are several varieties. It is largely grown in South Africa, the grain being used as food for horses, cattle, poultry, and to some extent by the natives. It is also used in the manufacture of Kaffir beer.

Durra or *Dhoura, Egyptian corn, Egyptian rice-corn, Jerusalem corn, Guinea corn, broom corn* (so-called because the panicles after the removal of the seed are used in the manufacture of brooms and clothes-brushes), and *Jowarine* are names given in various hot countries to varieties of this crop. It has the advantage of growing and thriving in hot, arid districts.

In reference to all plants of the millet and sorghum type, an important point to notice is the occurrence of a glucoside, capable of yielding by the action of water hydrocyanic acid (prussic acid), especially in the immature plants. This has given rise to poisoning in animals fed upon second cuttings of sorghum fodder.

The amount of hydrocyanic acid is apparently greater in immature crops. Up to two or more grains per pound of the green material have been found, and it is suggested that anything above half a grain of hydrocyanic acid per pound (*i.e.*, about 0·007 per cent.) of green material indicates the probability of poisoning resulting from the use of the fodder. Small quantities of hydrocyanic acid have also been found in young maize plants and Kaffir corn, as well as in other millets and sorghums. The danger of poison is, however, probably *nil* with maize, slight with matured millets or sorghums, but great with immature sorghums and millets.

COMPOSITION OF SEEDS OF MILLETS AND SORGHUMS.

	Sorghum.	Broom Corn.	Kaffir Corn.	Millet.	Hungarian Grass.
Moisture	12·8	11·7	9·3	14·0	9·5
Ash	2·1	3·4	1·5	3·3	5·0
Crude fibre	2·6	7·1	1·4	9·5	7·7
Carbohydrates	69·8	64·6	74·9	57·4	63·2
Protein	9·1	10·2	9·9	11·8	9·9
Fat	3·6	3·0	3·0	4·0	4·7
	100·0	100·0	100·0	100·0	100·0

2. **Leguminous Seeds.**—Many plants of the "Leguminosæ," or pod-bearing family, are grown as farm crops. They differ in composition from the cereals mainly in containing more nitrogenous matter. The stems and leaves, too, are much poorer in silica and phosphoric acid, but richer in lime than those of the cereals.

Beans.—Several plants go under this general name. The common field-bean (*Vicia faba* or *Faba vulgaris*) is largely grown in some districts. The Scotch horse-bean and the tick-bean, or English horse-bean, are varieties. As a rule beans do best in a clayey soil, and yield about 30 bushels of seed and 1 to 1½ tons of "straw" per acre. French or kidney beans and haricot beans (*Phaseolus vulgaris*), Lima beans (*Phaseolus lunatus*), and a Japanese plant, Adzuki beans (*Phaseolus radiatus*), are also grown, chiefly as vegetables. Soy or Soja beans (*Soja hispida* or *Glycine hispida*) are largely cultivated in Japan, and have been introduced into America and South Africa. The velvet bean (*Mucuna utilis*) also does well in hot climates, and is a useful food for cattle, pigs and poultry. Beans are always rich in protein, and furnish valuable food for man or animals. *Phaseolus lunatus*, however, contains a cyanogenetic glucoside, known as phaseolunatin, which sometimes leads to fatal poisoning when these beans are eaten.

Peas.—The field-pea (*Pisum arvense*), the garden-pea (*Pisum sativum*) and the edible-podded pea (*Pisum macrocarpon*) are the principal species, each including many varieties. As a field crop, peas are very uncertain in yield. They require the soil to contain a considerable proportion of lime. On rich soils they grow luxuriously, but yield little seed.

The *chick-pea* (*Cicer arietinum*) yields a seed of similar composition to the field-pea, and can be used for similar purposes. It is known as "gram" in India. The haulms, however, are of little use as forage. It is well adapted for dry climates.

The *cow-pea* (*Vigna catjang* or *Dolichos sinensis*) rather resembles the bean than the pea. The seed may be used as food for pigs, or the whole plant may be made into hay.

The *pea-nut* (*Arachis hypogæa*) does well in hot countries. After flowering, the stalk bends over and enters the ground, where the seed grows and ripens. A light, porous soil is therefore best. In harvesting, the crop is ploughed up and the vines and pods forked out of the ground. The seed is used for human consumption, as "ground-nuts" or "monkey-nuts," as a source of oil (for salads, &c.), of which the kernels contain from 40 to 45 per cent., and is a valuable food for pigs, who enjoy harvesting it for themselves. The foliage makes good hay.

Lentils (*Lens esculenta*) are highly valued as a rich nitrogenous item of diet for culinary purposes. The vines, too, when cut early, form an excellent fodder or hay for cattle.

Lupines are somewhat too shrubby and woody to yield good fodder, though sometimes used for sheep. Three species are chiefly used—the white (*Lupinus albus*), the blue (*Lupinus hirsutus* or *angustifolius*), and the yellow (*Lupinus luteus*). Lupines contain a bitter alkaloidal constituent, and are not readily eaten by cattle or sheep; moreover, they are sometimes poisonous. The poisonous property can be destroyed by steaming under pressure. They grow well on light, sandy soils, and are often used as green manures.

AVERAGE COMPOSITION OF LEGUMINOUS SEEDS.

	Horse-bean.	Soy Bean.	Pea.	Cow-pea.	Pea-nut.	Lupines.
Moisture . .	11·3	10·8	10·5	14·8	7·3	14·0
Ash . . .	3·8	4·7	2·6	3·2	2·0	3·0
Crude fibre .	7·2	4·8	14·4	4·1	16·1	12·2
Carbohydrates	50·1	28·8	51·1	55·7		34·2
Protein . .	26·6	34·0	20·2	20·8	29·9	30·4
Fat . . .	1·0	16·9	1·2	1·4	44·7	6·2
	100·0	100·0	100·0	100·0	100·0	100·0

Though leguminous seeds (and also the leaves, stems, and roots) are so rich in nitrogen, they usually can grow well in soils comparatively poor in nitrogenous matter, provided mineral plant food be abundant. This is due to the power which they have of obtaining nitrogen from the air by the aid of micro-organisms in tubercles on their roots (see chap. vi. p. 105).

3. **Miscellaneous Seeds.**—*Buckwheat* (*Polygonum fagopyrum*) is grown in certain parts of Europe, being largely used as poultry food, and also for pig- and cow-feeding. Its flowers furnish excellent pasturage for bees. When sown with a cereal—*e.g.*, oats or barley—it furnishes an excellent green fodder.

Cotton (*Gossypium herbaceum*, &c.).—This crop, which is largely grown for its lint, yields also seeds which are valuable both on account of the oil they contain and also because of their richness in nitrogenous matter and ash constituents. Cotton requires a warm climate, and succumbs rapidly to frost. Frequent rain and a damp atmosphere are wanted during the early stages of its growth until the formation of seed commences, then dry weather is favourable to the formation of seed. The lint envelops the seed, and is contained in a boll, which attains the size of a hen's egg, and then bursts into three or five cells. In America about 300 lb. of lint and 600 to 650 lb. of seed per acre are usually obtained. The seed is highly nitrogenous, and also rich in phosphoric acid. The manurial needs of cotton in most soils are phosphoric acid, nitrogen, and potash, in the order given.

The seed is mainly used for the manufacture of oil, which is extracted by pressure. Sometimes the whole seeds are crushed and pressed, but more generally their outer coating is first removed. In the former case, the residue from the press is sold as "undecorticated cotton cake," in the latter as "decorticated cotton cake" or "cotton-seed meal," but cotton-seed itself—best after steaming—is an excellent food for milch cows or fattening oxen and is largely used in the cotton-growing districts.

Linseed, Flax (*Linum*).—The usual species, *Linum usitatissimum*, can be grown either for fibre or for seed, sometimes, though not very successfully, for both. For fibre the plant apparently does best in moist, temperate climates—*e.g.*, Ireland, Belgium, certain parts of Russia and Canada. For seed, however, warmer climates are more favourable, much linseed coming from Russia, India, the United States, Canada, and the Argentine. Any soil which will grow wheat will apparently do well for linseed ; a friable, loamy, alluvial soil with a clay subsoil is probably best. A fair supply of phosphates, potash, and lime is important. If grown for fibre the object is to obtain as tall and little-branched plants as possible, while for seed the more branches and flowers the plants produce the better. In the former case thick seeding, say 100 lb. per acre, is employed, while for the latter from a quarter to half that amount suffices. A fair yield of linseed in America is about 15 bushels of seed (of 56 lb. per bushel) and about 2000 lb. of straw. The usual species (*L. usitatissimum*) attains a height of about two feet, and has blue flowers; another species (*L. americanum album*) is somewhat taller, and has white flowers; while a third (*L. crepitans*), which produces much seed but little fibre, scatters its seeds by the explosive bursting of its capsules.

Linseed is chiefly valuable for the oil which it contains (from 30 to 40 per cent.) and for the large amounts of nitrogenous and mineral matter, particularly phosphates, which are also present in the seed, and which are left in the "cake" after the oil is expressed. Linseed cake is thus highly prized for cattle-feeding.

Oil expressed from the seed obtained from the Baltic ports is usually preferred for the manufacture of linoleum, paints, &c., since it has the power of absorbing the largest quantity of oxygen. Oil is obtained from the seed by crushing it, and then either expressing the oil by heat and pressure (old process) or by extraction with volatile solvents—carbon disulphide or naphtha (new process), in which the oil readily dissolves. In the latter case the solvent is separated from the oil by distillation and from the "meal" by steaming. The "old process" meal usually retains from 8 to 12 per cent. of oil, while the "new process" sometimes contains not more than 1 or 2 per cent. The former is generally preferred for feeding purposes, as it is the more digestible.

Hempseed (*Cannabis sativa*), related to the hop (*Humulus lupulus*) and to ramie, is cultivated both for the fibre yielded by its stem and for its oily seeds. It is an annual, growing to a height of eight or ten feet. It thrives best in a temperate climate, and in any soil suited to maize. The yield of fibre is from 500 to 1500 lb. per acre, of seed from 10 to 30 bushels. The seed is used for feeding poultry, and as a source of oil which is sometimes used to adulterate linseed oil.

AVERAGE COMPOSITION OF HEMP-SEED AND OF HEMP-SEED CAKE.

	Hemp-seed.	Hemp-seed Cake.
Moisture	12·2	11·9
Ash	4·5	7·8
Crude fibre	22·1	24·7
Carbohydrates	11·3	17·3
Protein	16·3	29·8
Fat	33·6	8·5
	100·0	100·0

In hot countries the hairs on the stems and leaves secrete a resinous substance, which has powerful narcotic qualities. In colder climates this secretion does not occur.

Rape, or Cole (*Brassica napus and Brassica campestris*).—A plant belonging to the turnip family, grown either as a fodder crop or for seed. The seed is valued for the oil (about 42 per cent.) which it contains. The oil, either expressed or, more generally, extracted by volatile solvents, is sold as rape oil or colza oil. The plant resembles the turnip plant, except that it has not a fleshy "root" and bears yellow flowers. Several varieties are known, some being sown in the autumn and harvested in the middle of the next summer, others sown in the spring and reaped in the autumn. The residue after extraction of the oil from the seeds is chiefly used for manurial purposes, as it is not readily eaten by cattle. The plant resembles in composition and manurial requirements the turnip or swede.

Castor-seed (*Ricinus communis*).—The castor-oil plant, sometimes called "Palma christi," is well known as an ornamental plant in England. In many warm countries it is almost a weed. In temperate climates it is only an annual, but in tropical countries it becomes a perennial tree, growing to a height of twenty or thirty feet. The plant will grow in almost any soil, but does best on rich sandy soils. If cultivated the land should be cleared, ploughed deeply, and the seeds planted in groups of three or four about six or eight feet apart. The ground should be kept clear of weeds, and when the plants are well up all but one of each group should be destroyed. They usually commence to bear about four or five months after sowing. The main stem may be nipped off so as to favour the growth of lateral branches, and thus increase the yield of seed. The spikes of seed should be gathered before they are quite ripe, and dried in the sun, as the seeds shoot out from the capsules when ripe. The cleaned seeds, whose resemblance to a tick has given rise to the botanical name of the plant, are then sent to be pressed.

Castor oil is a valuable lubricant, and is also largely used as an illuminant and for medicinal purposes. The residue after separation of the oil is suitable for use as a manure. It cannot well be used for feeding purposes, as it contains a poisonous ingredient which is difficult to remove. In America from 15 to 25 bushels of seed per acre are usually obtained. The seeds contain about 50 per cent. of oil. A bushel of seed usually weighs about 46 lb.

Sunflower-seed (*Helianthus annuus*).—The plant is an annual, growing to a height of ten or twelve feet. It can be sown in groups of four at distances of about three or four feet apart. The yield of seed is about 50 bushels per acre; and the dried seeds contain about 20 per cent. of oil. Sunflower-seed is employed as a poultry and cattle food, and also as a source of oil, used as a substitute for olive oil. The "cake" left after the expression of the oil furnishes a valuable cattle food.

4. **Fruits.**—Most fruits are obtained from plants which are perennial in habit, and are therefore hardly to be classed with ordinary farm crops. Orchard management is a distinct branch of agriculture, and reference to it would not be

appropriate here. Broadly speaking, it may be said that fruit-trees, owing to their far-reaching roots, will succeed in finding sufficient nutriment in soils which may be too poor in plant food to yield payable crops of ordinary farm produce.

AVERAGE COMPOSITION OF MISCELLANEOUS SEEDS.

	Buck-wheat.	Cotton-seed.	Linseed.	Rape-seed.	Castor-seed.	Sun-flower-seed.
Moisture . .	13·2	11·4	12·3	11·8	5·1	8·6
Ash . . .	1·8	4·3	3·4	3·9	2·7	2·6
Crude fibre .	15·0	18·9	7·2	10·3	15·0	29·9
Carbohydrates	58·4	20·2	19·6	12·1	12·6	21·4
Protein . .	10·1	19·9	20·5	19·4	17·9	16·3
Fat . . .	1·5	25·3	37·0	42·5	46·7	21·2
	100·0	100·0	100·0	100·0	100·0	100·0

AVERAGE COMPOSITION OF PRODUCTS FROM ABOVE.

	Buck-wheat Bran.	Undecor-ticated Cotton-seed Cake.	Decorti-cated Cotton-seed Cake.	Old Process Linseed Cake.	New Process Linseed Cake.	Sun-flower-seed Cake.
Moisture . .	10·5	10·6	8·9	11·8	9·7	10·8
Ash . . .	3·0	7·2	7·2	7·3	7·3	6·7
Crude fibre .	31·9	24·9	5·7	9·4	8·8	13·5
Carbohydrates	38·9	26·0	19·7	32·1	38·7	27·1
Protein . .	12·4	24·7	43·6	28·7	33·2	32·8
Fat . . .	3·3	6·6	14·9	10·7	2·3	9·1
	100·0	100·0	100·0	100·0	100·0	100·0

Nevertheless it must be remembered that the large growth of a tree locks up in the wood a considerable amount of plant food, and if the tree is to continue to bear fruit additional supplies from the soil must be maintained. In fruit-trees, as in other plants, abundant supplies of nitrogen from the soil tend to favour the growth of leaves and twigs rather than fruit. Fruits are, as a rule, very rich in water, contain sugar and generally some vegetable acid, to which their characteristic taste is partly due. We can only very briefly consider the chemical character of some of the principal typical fruits.

Apples (*Pyrus malus*).—An immense number of varieties of this fruit are known, differing very much in size, shape, colour, and flavour. Doubtless their composition will also vary greatly. They usually contain about 85 per cent. of water, about 12 per cent. of carbohydrates (chiefly sugar), about 0·4 per cent. of ash, 1 per cent. of crude fibre, and 0·2 per cent. of albuminoids. The acidity is due to malic acid ($H_2C_4H_4O_5$), which may amount to from 0·2 to 1 per cent. of the juice. The difference in "sweetness" of different apples is mainly due to the proportion of malic acid present. The sugar present is partly cane sugar (sucrose), partly invert sugar, which is a mixture of dextrose and levulose. In green, immature apples starch is found, sometimes to the extent of 5 per cent., but as the fruit ripens the starch disappears and the sugars increase. Cellulose is present to the extent of about 1 per cent., pentosans up to about 0·5 per cent., and pectin, or perhaps more accurately pectose, from 0·2 to 0·6 per cent. The gelatinising property of pectin is of importance in the preparation of apple jelly.

The following analyses of American Baldwin apples will show the changes which occur during ripening:

	Very Green.	Green.	Ripe.	Over-ripe.
	per cent.	per cent.	per cent.	per cent.
Water	81·33	79·81	80·36	80·30
Solids	18·67	20·19	19·64	19·70
Invert sugar	6·40	6·46	7·70	8·81
Sucrose	1·63	4·05	6·81	5·26
Starch	4·14	3·67	0·17	—
Free malic acid	1·14	—	0·65	0·48
Ash	0·27	—	0·27	0·28

Different varieties show considerable differences in composition; thus the solids in the ripe fruit have been noticed to vary from 13·4 to 23·4 per cent., the invert sugar from 5·3 to 11·7 per cent., the free malic acid from 0·26 to 1·11 per cent., the ash from 0·17 to 0·37 per cent.

As an average of recent American analyses of several varieties the following is given as the typical composition of ripened apples:

	Per cent.
Water	84·0
Ash	0·3
Invert sugar	8·0
Cane sugar	4·0
Starch	0·0
Cellulose	0 9
Lignin	0·4
Pentosans	0·5
Pectin matter	0·4
Malic acid (free)	0·6
" " (in combination)	0·2
Oil	0·3
Protein	0·1
Undetermined (tannin, &c.)	0·3
	100·0

The ash consists chiefly of potassium carbonate, magnesium and potassium phosphates, calcium sulphate, free lime, with traces of common salt, silica, iron oxide, and alumina.

Pears (*Pyrus communis*) resemble apples in their chemical composition, but contain less acid and more "crude fibre." As a rule the trees have deeper roots, and thus range over a larger volume of soil for their sustenance.

Plums (*Prunus spp.*).—Belonging to this genus are many species, including sloes or blackthorn (*P. spinosa*), bullace and damsons (*P. insititia*), various true plums (*P. domestica*), apricots (*P. Armeniaca*), wild dwarf cherry (*P. cerasus*), wild cherry (*P. avium*), almond (*P. amygdalus* or *Amygdalus communis*), nectarine and peach (*P. persica*). The fruit consists of a central kernel (the true seed), a hard, bony layer surrounding the kernel (known as the "stone" or "pit") and a fleshy pulp (the edible portion), the whole being covered with a thin skin. The kernel, and in some cases the bark and leaves, contains a glucoside known as *amygdalin*, $C_{20}H_{27}NO_{11}$, which under the influence of an enzyme—*emulsin*—generally present in the kernel, decomposes in the presence of water, thus:

$$C_{20}H_{27}NO_{11} + 2H_2O = C_6H_5CHO + HCN + 2C_6H_{12}O_6,$$

the products being benzaldehyde, hydrocyanic or prussic acid, and glucose. The flesh of all fruits of the plum family is rich in sugar and faintly acid with various organic acids, of which malic ($H_2C_4H_4O_5$) and citric acid ($H_3C_6H_5O_7$) are the principal.

The following are partial analyses of the fruits:

	Apricots.	Peaches.	Cherries.	Nectarines.	Plums.
Moisture	81·12	80·03	80·26	79·00	81·18
Ash	0·82	0·69	0·73	0·50	0·71
Crude fibre	5·27	6·06	6·07	—	5·41
Carbohydrates	12·30	12·57	12·32	—	11·92
Protein	0·49	0·65	0·62	0·73	0·78
	100·00	100·00	100·00	—	100·00
Sugar in juice	11·10	17·00	12·89	14·10	—
Acid (as SO_3) in fruit	0·68	0·24	0·48	0·24	—

Citrus Fruits.—The chief varieties are the orange, the lemon, the lime, the citron, and the shaddock or pompelmous. All members of this family thrive only in warm climates. Frost is very liable to cause death to the trees. They do best in rich, deep, mellow soil, with porous subsoil. The fruits contain sugar, citric acid, and comparatively small quantities of cellulose and ash constituents, while the rind contains considerable quantities of essential oils.

AVERAGE COMPOSITION OF ORANGES AND LEMONS.

	Oranges.	Lemons.
Moisture	85·2	83·8
Ash	0·4	0·6
Crude fibre	—	1·1
Carbohydrates	—	12·7
Protein	1·2	0·9
Fat	—	0·9
	—	100·0
Sugar	9·7	2·1
Citric acid	1·3	7·2

Grapes (*Vitis spp.*).—Vines are best suited by a damp winter and spring, and a dry, fine summer for the ripening of the fruit. Climate is of more importance than the soil in most cases. Their manurial requirements are not great, but an open, deep, friable soil is advantageous. Great differences in composition of grapes are shown, according to the variety, soil, season, and climate. The grape is characterised by containing grape sugar (dextrose) and tartaric acid ($H_2C_4H_4O_6$).

AVERAGE COMPOSITION OF GRAPES.

	Per cent.
Water	78·17
Ash	0·53
Crude fibre	3·60
Carbohydrates	17·11
Protein	0·59
Fat	—
	100·00

The Banana (*Musa sapientum*) is one of the most characteristic and imposing products of the tropics. If the climate be sufficiently warm and moist almost any soil will support the plant, but the best crops are obtained on deep loams with a plentiful supply of humus. The plants are propagated by suckers out of the parent stem. These are planted about 15 feet apart, and under favourable conditions fruit will be produced in about a year. In successive years suckers from the original plants replace the first stem, which is cut down after the fruit is gathered.

AVERAGE COMPOSITION OF BANANAS.

	Per cent.
Moisture	66·25
Ash	1·15
Crude fibre	0·96
Carbohydrates	28·88
Protein	1·41
Fat	1·35
	100·00

According to American estimates, the following table represents the amounts of the chief fertilising materials contained in various fruits and removed by an average crop from an acre of land:

	Potash.	Phosphoric Acid.	Nitrogen.
	lb.	lb.	lb.
Grapes, per cent.	0·50	0·15	0·17
10,000 lb. per acre	50	15·2	17
Oranges, per cent.	0·28	0·07	0·27
20,000 lb. per acre	55·6	13·4	53·8
Pears, per cent.	0·18	0·05	0 06
20,000 lb. per acre	36·0	10	12
Plums, per cent.	0·17	0·04	0·42
30,000 lb. per acre	51·6	13·2	127·7
Apples, per cent.	0·08	0·03	0·06
20,000 lb. per acre	16	6	12

The heavy demands upon nitrogen made by plums and the small amounts required by apples and pears are noticeable features.

CLASS II.—ROOT CROPS.

The principal members of this class are the turnip, the beet and the potato.

The *Turnip* (*Brassica rapa*) is a biennial, producing in its first year a large store of material in its "root," intended to serve as food for production of stem, flowers, and seed during the second season. There are many varieties, differing in the shape and colour of their "bulbs" or roots.

The *Swede Turnip* (*Brassica rutabaga*) closely resembles the ordinary turnip in composition and habit, but is distinguished by the possession of a distinct "neck," from which the leaves spring. The foliage of swedes is generally bluer and less grass-green than that of the turnip. The flesh is firmer and less watery than that of the turnip, and the roots generally keep better after being dug.

Turnips do best on open, loamy soils and in somewhat dull, damp climates. They are usually drilled in rows from 20 to 27 inches apart, and "singled" so as to be from 11 to 13 inches apart in the rows.

Turnips respond readily to applications of phosphatic manures. They also require to be well supplied with nitrogenous material. From 15 to 25 tons per acre is a fair yield of turnips.

The Beet (*Beta vulgaris*).—There are many varieties, obtained by careful selection. *Mangel-wurzel*, or *field-beets*, include many varieties, which may be classified into long, tankard, and globe forms. Differences in colour of the flesh are also shown. *Mangolds*, or *mangels*, as they are often called, require a warm, fairly dry climate and a deep, somewhat clayey soil. The usual yield is from 18 to 25 tons per acre. Mangolds require much nitrogen, and readily respond to applications of nitrate of soda. Being descended from a maritime plant, they also appreciate chlorides, and are benefited by applications of common salt. They form excellent food for cattle, but should not be used until they have been stored for a few months.

The *Sugar-beet* is a variety of the mangold, which has been developed especially for its richness in sugar. Many varieties are grown, but they are usually conical in shape, grow with the root entirely underground, and should be, compared with ordinary mangolds, small in size. The best probably weigh about 2 lb. each. They thrive in a warm and moderately damp summer and dry, hot autumn. A deep, medium loam with a fair proportion of lime is the soil best suited for their growth. Late nitrogenous manuring should be only sparingly done. The seed is usually sown in rows 14 or 15 inches apart, and the plants are afterwards singled so as to stand 6 or 8 inches apart in the rows. The usual yield is from 12 to 16 tons per acre.

Turnips and mangolds are very watery, and in nearly all cases the large roots are much more watery, and therefore less valuable, weight for weight, than the small ones of the same variety.

The sugar-beet is now a most important crop, especially in Germany, Russia, France, Austria, and the United States. Beet sugar is gradually replacing cane sugar. In 1903–4, for example, it was estimated that the European production of beet sugar amounted to 5,910,000 tons, while the world's production of cane sugar was estimated at 3,535,000 tons.

AVERAGE COMPOSITION OF TURNIPS, SWEDES, MANGOLDS, AND BEETS.

	Turnip.	Swede.	Mangold.	Sugar-beet.
Water	92·0	87·0	88·0	81·5
Ash	0·7	1·0	0·8	0·7
Crude fibre	0·8	1·1	0·9	1·3
Carbohydrates	5·3	9·5	9·1	15·4
Protein	1·1	1·3	1·1	1 0
Fat	0·1	0·1	0·1	0·1
	100·0	100·0	100·0	100 0

The Potato (*Solanum tuberosum*).—The valued product of this plant is the underground stem, known as a tuber. Usually the crop is grown from the tubers or "sets."

The best soil is a deep, warm one, with good drainage and free from acidity, well supplied with potash and nitrogen. Heavy manuring is generally done for this crop, and farmyard manure is especially useful for its water-retaining power in dry seasons, though open to the objection that it favours "scab." On soils rich in lime, superphosphate, potassium sulphate and sulphate of ammonia are suitable artificial manures, applied before planting, while on soils poor in lime, basic slag should be substituted for the superphosphate and nitrate of soda (as top-dressing to the growing crop) for the sulphate of ammonia. From 12 to 15 cwt. of "sets" per acre are usually required. In wet districts these are sown in the ridge, in dry ones on the flat. The rows are usually 20 to 30 inches apart, and the "sets" are placed from 12 to 18 inches apart. Potatoes about the size of a hen's egg should be used as "sets"; if larger, they should be cut, care being taken to leave at least two "eyes" on each piece. The cut surfaces are often dusted with quicklime before planting.

The fruit of the potato—"apple" or "berry"—is poisonous, as are also, though to a less extent, the leaves or "haulms." Potatoes consist largely of starch, with very small amounts of protein and ash constituents. The amount of water present is subject to considerable variation—from about 75 to as high as 83 per cent. Potatoes are largely used as food for men and animals; also, especially on the continent of Europe, for the manufacture of alcohol and of fusel oil.

AVERAGE COMPOSITION OF POTATOES.

	Per cent.
Water	78·9
Ash	1·0
Crude fibre	0·6
Carbohydrates	17·3
Protein	2·1
Fat	0·1
	100·0

The Sweet Potato (*Ipomœa batatas or Batata edulis*).—This is a convolvulus-like plant, usually with purple flowers, producing tubers on its roots, sometimes of great size, up to 12 lb. or more in weight. It is essentially a tropical or sub-tropical crop, and does best in light, friable soils rich in organic matter. It is propagated by cuttings, and once established on land will yield several crops in succession. A fair crop is four or five tons to the acre.

The tubers are used in the same way as the ordinary potatoes, but are sweeter and more nutritious. The leaves and stems are eaten greedily by horses, cattle, and sheep, but it has recently been shown that they sometimes contain a glucoside which decomposes and yields hydrocyanic acid (prussic acid). Amounts varying from 0·014 to 0·019 per cent. of the green material were found. Numerous cases of death in pigs fed on sweet potato vines were observed in Queensland in 1905.

AVERAGE COMPOSITION OF SWEET POTATOES AND THEIR VINES.

	Tubers.	Vines.
Water	71·1	41·6
Ash	1·0	5·8
Crude fibre	1·3	13·6
Carbohydrates	24·7	29·3
Protein	1·5	7·6
Fat	0·4	2·1
	100·0	100·0

The *Carrot* (*Daucus carota*) and the *Parsnip* (*Pastinaca sativa*) are also sometimes grown as farm crops. The roots are used as vegetables, and as an excellent food for horses and cattle. Also belonging to this family of Umbelliferæ are Celery (*Apium graveolens*), Parsley (*Petroselinum sativum*), and Caraway (*Carum carui*).

AVERAGE COMPOSITION OF CARROTS AND PARSNIPS.

—	Carrots.	Parsnips.
Water	88·6	80·3
Ash	1·0	1·0
Crude fibre	1·3	0·5
Carbohydrates	7·6	16·1
Protein	1·1	1·4
Fat	0·4	0·7
	100·0	100·0

CLASS III.—FODDER CROPS.

These, which include some of the crops already mentioned, are grown to provide bulky food for cattle. They are used in three principal forms:

1. In the fresh, green state, being either pastured or cut, and fed green to animals—"*soiling.*"
2. In the dried (and generally fermented) state, as *hay.*
3. In the fermented state, as *ensilage.*

In the case of all forage crops it is desirable to cut or use the plant some time before it ripens its seed, otherwise the stems and leaves become woody and indigestible, and to a great extent robbed of their nutriment.

The principal forage crops may be classed in three main groups:

1. Gramineous crops.
2. Leguminous crops.
3. Miscellaneous forage crops.

1. **Gramineous Crops.**—These are used for pasturing, and for hay-making or for soiling. Some of the cereals already described are used in this way.

Pasture and meadow grasses usually consist of a complex mixture of plants. The grasses, which usually predominate, resemble the cereals in general chemical composition, being rich in silica and potash and comparatively poor in nitrogenous organic matter. Grasses are usually surface-feeders, and the root *débris* gradually imparts a peaty character to the upper portion of the soil, thus leading to nitrification and loss of calcium compounds. Hence phosphatic and calcareous manures — basic slag, bones, lime — are beneficial. Heavy dressings of nitrogenous manures favour the growth of coarse grasses at the expense of clovers and some of the finer grasses.

Grasses are used on the farm either as permanent pastures and meadows, or in the rotation in the form of "small seeds" —rye-grass usually mixed with clover. There are numerous species of grass, differing in chemical composition and palatability.

AVERAGE COMPOSITION OF VARIOUS GREEN FODDERS.

—	Pasture Grasses.	Timothy.	Meadow Fescue.	Italian Rye-grass.	Green Oats.
Water	80·0	61·6	69·9	73·0	62·2
Ash	2·0	2·1	1·8	2·5	2·5
Crude fibre	4·0	11·8	10·8	6·8	11·2
Carbohydrates	9·7	20·2	14·3	13·3	19·3
Protein	3·5	3·1	2·4	3·1	3·4
Fat	0·8	1·2	0·8	1·3	1·4
	100·0	100·0	100·0	100·0	100·C

2. **Leguminous Fodder Crops.**—Some leguminous plants are usually present in pastures and meadows. Their growth is favoured by additions of potash, lime and phosphates, and by stinting the nitrogenous manuring; the clovers, &c., having their own peculiar supply of nitrogen (see chap. vi.), are thus able to hold their own in competition with the grasses, which in the presence of abundant supplies of nitrogen would probably outgrow and smother the Leguminosæ.

As already stated, the leguminous plants are remarkable for the large amounts of nitrogenous matter, potash and lime which they contain. Their power of collecting nitrogen from the air by the aid of the micro-organisms in the nodules on their roots renders their after-effect on land of great value (see p. 105).

Lucerne (*Medicago sativa*), known as alfalfa in America, is particularly valuable in hot, somewhat dry climates, since when once established its deep-reaching roots enable it to bring up water from the subsoil and to stand long drought. It will then yield repeated cuttings of valuable forage for many years. Other valuable leguminous fodder crops are red clover (*Trifolium pratense*), crimson clover (*T. incarnatum*), white clover (*T. repens*), alsike clover (*T. hybridum*), sainfoin (*Onobrychis sativa*), trefoil (*Medicago lupulina*), vetches or tares (*Vicia sativa*) and serradella (*Ornithopus sativus*). The characteristic of the leguminous crops is their ability to grow on soils poor in nitrogen, provided mineral constituents are sufficiently abundant.

Composition of Green Leguminous Fodder.

	Lucerne.	Red Clover.	White Clover.	Alsike.	Serra-della.	Vetches.
Water . .	74·0	80·4	80·5	82·0	81·0	82·0
Ash . . .	2·0	1·3	2·0	1·8	1·8	1·8
Crude fibre .	9·5	5·8	6·0	6·0	5·8	5·5
Carbohydrates	9·2	8·9	7·2	6·3	6·9	6·6
Protein . .	4·5	3·0	3·5	3·3	3·7	3·5
Fat . . .	0·8	0·6	0·8	0·6	0·8	0·6
	100·0	100·0	100·0	100·0	100·0	100·0

3. **Miscellaneous Fodder Crops.**—*Prickly Comfrey* (*Symphytum asperrimum*).—This plant has been from time to time highly praised as a forage crop, but has not received much public favour. It is a shrubby, perennial plant,

generally propagated by root cuttings, planted two or three feet apart. It may be cut several times in a season, and the total weight per acre amounts to about 30 tons per annum. It is not readily eaten by cattle until they acquire the taste for it.

Rape (*Brassica napus*) has already been described (p. 135). It is often grown as green fodder, especially for sheep. If used in large quantities as food for milch cows it is liable to taint the milk.

Buckwheat is also grown for green forage.

Sugar-cane (*Saccharum officinarum*) is also grown for the sake of the young shoots, which are greatly relished by stock. They are either eaten green or made into ensilage.

Pumpkins (*Cucurbita spp.*) are sometimes grown in warm countries as cattle food, being excellent for dairy cows and for pigs. They are necessarily very watery.

Cabbages (*Brassica oleracea*) with abundant manuring or on rich land yield large crops of excellent green food for cattle and sheep. Cabbages are gross feeders, and are greatly benefited by nitrate of soda. Common salt also seems to be beneficial to this crop.

Sugar-beet leaves are sometimes used as food for cattle; but they contain a considerable proportion of oxalic acid, which prohibits their use except in small quantities. By sprinkling lime over them and keeping them in heaps for some time the oxalic acid may be neutralised and its injurious effect diminished.

COMPOSITION OF MISCELLANEOUS FORAGE CROPS.

—	Water.	Ash.	Crude Fibre.	Carbohydrates.	Protein.	Fat.
Prickly comfrey	87·7	2·2	1·7	5·0	3·0	0·4
Buckwheat	85·0	1·4	4·2	6·4	2·4	0·6
Rape	85·9	1·3	3·5	5·7	2·8	0·8
Cabbage	89·0	1·2	2·0	5·9	1·5	0·4
Pumpkin	90·9	0·5	1·7	5·2	1·3	0·4
Beet leaves	82·6	3·4	10·1		3·6	0·3

Hay making.—When green forage has to be preserved for the winter or future use it is either made into hay or into ensilage. Hay-making consists essentially in drying the plants by exposure to sun and air to a sufficient extent to prevent excessive fermentation when the material is bulked together. The most important change is the removal of water. Ordinary meadow grass contains nearly 75 per cent. of water, while the hay from it will contain about 15 or 16 per cent. The yield of hay from a given weight of grass must obviously vary greatly; it will usually be between 30 and 40 per cent. The plants should always be cut while flowering, for if left longer the resulting hay will be poorer in albuminoids and ash, though richer in carbohydrates and crude fibre.

Grass and other green plants are always well supplied with micro-organisms, which at once attack the sap as soon as the grass is cut, producing carbon dioxide and promoting oxidation, with its resulting evolution of heat. If the green material be spread out the heat is quickly dissipated and no rise of temperature occurs, and as the water evaporates the activity of the micro-organisms is soon checked; but if the green vegetable matter be piled together in large masses, so as to prevent the escape of heat by convection currents, the temperature rises and the processes of fermentation proceed more and more rapidly. The rise of temperature may be so great as to start direct chemical oxidation and finally to set fire to the material. Such an occurrence is often observed when imperfectly dried hay is collected in stacks or barns. The presence of too much moisture is one of the most powerful causes tending to set up dangerous heating of haystacks. Thorough drying of the hay is obviously the best method of minimising the risk, but this is open to the objection that the proper aroma, flavour and colour of hay is not produced unless a certain amount of fermentation occur in the stack. If somewhat green hay has to be stacked, danger of overheating may be lessened either by mixing salt with it or by allowing free ventilation in the stack. The first method checks fermentation, and so prevents the evolution of heat; the second is efficacious chiefly by carrying the heat away as it is evolved, and thus keeping down the temperature.

The pleasant odour of hay, upon which its palatability chiefly depends, is partly due to compound ethers and other fragrant products of fermentation, and partly to *coumarin*, $C_9H_6O_2$, which is present in wood-ruff (*Asperula odorata*), in Bokhara clover (*Melilotus alba*), and in sweet-scented vernal grass (*Anthoxanthum odoratum*). Though the odour of coumarin is generally considered pleasant, there is some reason to think that horses and cattle are not very fond of it.

AVERAGE COMPOSITION OF HAY.

—	Water.	Ash.	Crude Fibre.	Carbo-hydrates.	Protein.	Fat.
Meadow hay	14·1	6·2	26·3	41·4	9·5	2·5
Rye-grass	14·3	6·5	36·2	36·1	8·2	2·7
Timothy	14·3	4·5	22·7	45·8	9·7	3·0
Sainfoin	15·8	6·7	24·9	34·0	15·4	3·2
Lucerne	16·0	6·2	23·0	37·9	14·4	2·5
Red clover	16·0	5·3	26·0	38·2	12·3	2·2
Serradella	16·7	8·1	25·6	30·3	16·2	3·1
Alsike	16·0	6·0	27·0	32·7	15·0	3·3
Lupines	16·7	4·6	28·5	30·9	17·1	2·2
Rye	14·1	5·1	23·1	44·5	10·4	2·8
Oats	11·5	6·1	30·1	42·4	7·5	2·4
Natal blue grass	8·0	6·0	38·5	41·8	4·4	1·3
Boer manna hay	8·3	7·8	30·9	46·2	5·0	1·8

Ensilage, or Silage.—When green fodder is closely compacted so as to prevent access of air as much as possible, fermentation is hindered and restricted, and the fodder may be kept for some time. Originally all silos were pits or buildings of stone or wood, intended to be air-tight, in which the fodder could be subjected to great pressure. The simpler plan of merely stacking the green fodder in the open, treading it well, and finally weighting it with stones or earth is now often adopted.

In a silo fermentation is limited by exclusion of air, while in a haystack it is chiefly lack of moisture which determines the cessation of change. If the silo be filled slowly the temperature rises so high (to about 60° C.) that the micro-organisms which produce acetic, lactic, and butyric acids are killed, and only the other organisms remain. The resulting silage is known as "sweet silage." On the other hand, when the silo is rapidly built and pressed as soon as possible the temperature attained is not so high, and the acid-forming organisms have opportunity for full development, and "sour silage" results.

The chief changes produced by conversion of fodder into ensilage are a diminution of the albuminoids and of the carbohydrates, while the "crude fibre" seems to be increased. A more serious loss, however, is a considerable diminution in the digestibility of the albuminoids. In the case of red clover it was found that 100 lb. of dry matter containing

Ash.	Fibre.	Carbohydrates.	Albuminoids.	Amides.
9·5	23·8	46·3	16·5	3·9

gave 90·5 lb. of dry matter in the ensilage, containing

Ash.	Fibre.	Carbohydrates.	Albuminoids.	Amides.
9·5	27·4	33·9	15·7	4·0

It would appear, therefore, to be most economical to make ensilage of fodders low in albuminoids, and to convert leguminous plants into hay.

AVERAGE COMPOSITION OF SILAGE

	Water.	Ash.	Crude Fibre.	Carbohydrates.	Protein.	Fat.
Maize . . .	79·1	1·4	6·0	11·0	1·7	0·8
Sorghum . .	76·1	1·1	6·4	15·3	0·8	0·3
Rye . . .	80·7	1·6	5·8	9·2	2·4	0·3
Grass . .	68·0	2·7	9·9	12·9	3·8	2·7
Buckwheat . .	72·3	2·2	7·7	14·1	2·8	0·9
Lucerne . .	72·5	3·5	10·7	6·1	4·0	2·2
Red clover . .	70·0	2·3	8·5	11·6	5·6	2·0
Lupines . .	80·3	1·4	9·5	4·9	2·9	1·0

ROTATION OF CROPS.

In all countries where farming has been long established, the plan of alternating different crops on any particular portion of land has become general. It is only in the first few years after virgin soil has come into cultivation, that the same crop is grown, year after year, on the same land.

The practice of rotation of crops has many advantages; some with respect to the practical operations of cultivation, seeding and reaping, some in diminishing the ravages of plant diseases, insect pests, weeds and other troubles, and some in connection with the power of the soil to supply the needs of plants. The obvious advantages of distributing the labour involved in the ploughing, drilling, harrowing and reaping of the crops, more evenly over the year, which a variety of crops affords, need not be discussed here. So, too, the benefits derived from changing the crop from time to time, in preventing the continuance of any particular disease or blight which may attack a certain kind of crop, or in destroying the weeds which may accompany it, hardly require more than passing mention.

With the effect of rotation upon the soil's ability to supply plant food, however, chemistry has more to deal, and a short account of the advantages of rotation, from this aspect, may appropriately be given.

These advantages mainly depend upon the following:

1. Differences in the root range. Some crops, *e.g.*, barley, have only shallow roots which draw their sustenance from the uppermost layers of soil, while others, *e.g.*, mangolds, depend chiefly for their food, upon the matters present in the lower parts of the soil. By alternating shallow-rooted and deep-rooted plants, all parts of the soil, in turn, are called upon tc contribute plant food.

2. Utilisation of crop residues. The root *débris*, stubble and waste left in the field after the removal of any crop, afford, on decay, good food for another kind of crop, while such residues are often of little benefit, indeed, in some instances,

are actually injurious, to a second crop of the same species. The *débris* of leguminous crops, *e.g.*, clover, is particularly rich in combined nitrogen, owing to the power which such crops possess, of absorbing nitrogen from the air, and afford important supplies of this material, slowly (as nitrification occurs) to a crop of, say, wheat, which follows.

3. Variations in the relative requirements as to plant food. Some crops require relatively large supplies of one particular item of plant food. Thus an average crop of wheat or potatoes consumes only about 50 lb. of nitrogen per acre, while an average crop of mangolds removes about 150 lb. per acre.

Again, too liberal a supply of nitrogen may do actual harm to one crop, *e.g.*, barley for malting purposes, but after the addition of farmyard manure, barley may safely follow, if the too abundant nitrogen be depleted by first taking off a crop of some nitrogen-loving plant, *e.g.*, mangolds.

4. The obtaining of suitable mechanical conditions in the soil. Some crops do best when the soil is loose and open at seed time, *e.g.*, barley, which often follows roots; the land is then loose and friable and free from weeds, owing to the possibility of hoeing during the growth of the turnips or mangolds. Other seeds, *e.g.*, wheat, grow best in a firm, compact soil, and in this condition the land is left after a crop of clover, which can be harvested early in the summer, giving ample time for preparation of the land for the autumn sowing of wheat.

Many systems of rotation are in vogue in different parts of the country, various modifications being introduced to suit the local conditions and requirements. For details of such systems, reference to some manual of agriculture should be made. The most generally adopted system is known as the Norfolk four-course rotation, which in its simplest form, consists of—

1. Roots, eaten on the land by sheep.
2. Barley.
3. Clover, generally made into hay, or sometimes grazed.
4. Wheat.

the farmyard manure being applied before the root crop.

CHAPTER VIII.

THE CHEMISTRY OF THE ANIMAL BODY.

The compounds present in the body of an animal are numerous, and in many cases, very complex. Only a very brief and superficial survey of the principal ones can be made here. The elements present in animal tissues are the same as those found in vegetable matter, but their relative proportions differ materially. Calcium, phosphoric acid, fluorine, chlorine and sodium appear to be of much more importance to animals than to plants.

The constituents of the animal body may be divided into:

1. Inorganic compounds, including water, various acids, and numerous salts: some in the solid state—*e.g.*, calcium phosphate; others in solution—*e.g.*, sodium chloride.

2. Organic compounds—
   - (A) Nitrogenous
     - Proteids—*e.g.*, albumin.
     - Amides—*e.g.*, urea.
   - (B) Non-nitrogenous
     - Fats.
     - Carbohydrates.

According to Lawes and Gilbert, the composition of the whole bodies of various animals is, on the average:

Animal.	Water.	Fat.	Proteids.	Ash.	Contents of Stomach, &c.
Fat calf	63·0	14·8	15·2	3·8	3·2
Half-fat ox	51·5	19·1	16·6	4·6	8·2
Fat ox	45·5	30·1	14·5	3·9	6·0
Fat lamb	47·8	28·5	12·3	2·9	8·5
Store sheep	57·3	18·7	14·8	3·2	6·0
Half-fat sheep	50·2	23·5	14·0	3·2	9·1
Fat sheep	43·4	35·6	12·2	2·8	6·0
Store pig	55·1	23·3	13·7	2·7	5·2
Fat pig	41·3	42·2	10·9	1·6	4·0

The nitrogenous matter shows the least variation, while the water and fat are more or less complementary to each other—*i.e.*, as the one increases the other decreases. The ash is dependent chiefly upon the proportion of bone present.

The chief parts of an animal's body are:

1. Blood.
2. Bones.
3. Muscular tissue.
4. Fatty tissue.
5. Connective tissue.

Blood consists of a colourless liquid—"plasma"—holding, in suspension, enormous numbers of small solid particles—the red and white corpuscles. When taken from an animal, the plasma quickly deposits one of its nitrogenous constituents—*fibrin*—which, entangling the corpuscles, causes them to separate as a clot from the yellowish liquid—the serum. *Blood plasma* is thus the liquid portion of fresh blood, *blood serum* the liquid portion after clotting. The latter differs from the former by having lost its fibrin, or *fibrinogen*, as it is now called, and a portion of its lime, magnesia, and phosphoric acid. Blood serum contains about 9 per cent. of total solids, of which 7·5 are albuminoid. Its ash amounts to about 0·85 per cent., and consists chiefly of common salt, with small quantities of potash, lime, and magnesia.

The clot of blood consists of red and colourless corpuscles entangled in a network of fibrin. The red corpuscles consist of circular, biconcave discs, though their shape and size vary in different animals. They are largest in reptiles. In birds, fishes, and in the camel they are elliptical and biconvex. In man, the average diameter of a blood corpuscle is ·007 mm. (about $\frac{1}{3200}$ of an inch), and its thickness about ·0019 mm. ($\frac{1}{12800}$ of an inch). When blood corpuscles are treated with water, ether, or other solvents they lose their colouring-matter and leave a nitrogenous residue, which retains the shape of the original corpuscles.

The colour of blood is due to *hæmoglobin* and *oxyhæmoglobin*. These are extremely complex in chemical constitution, and contain carbon, hydrogen, oxygen, nitrogen, sulphur, and iron. Hæmoglobin contains about 16 to 17 per cent. of nitrogen and about 0·4 to 0·45 per cent. of iron. It is a dark purplish-red coloured substance, which readily combines with oxygen to form the oxy compound, which is bright red in colour. The hæmoglobin of the red corpuscles plays an important part in respiration. In the lungs the blood is brought into contact with air, oxygen is absorbed by the hæmoglobin, thus causing the purplish red colour of the venous blood to become bright red, almost scarlet. At the same time a considerable quantity of carbon dioxide, most of which is in solution in the blood plasma, probably as bicarbonates, is given up to the air within the lungs. When blood is put under a vacuum, gases are given off. On the average 100 volumes of blood yield:

—	Arterial Blood.	Venous Blood.
Oxygen	20	8 to 12
Nitrogen and argon	1 to 2	1 to 2
Carbon dioxide	40	46

A change in the composition of the air is produced by respiration. The average composition of air before and after respiration is as follows:

—	Inspired Air.	Expired Air.
Nitrogen	78·00	78·09
Argon and neon	0·97	0·98
Oxygen	21·00	16·50
Carbon dioxide	0·03	4·43
Water vapour	Variable	Saturated
Temperature	Variable	36° C.

The chief changes produced on air by respiration are the removal of oxygen, the addition of carbon dioxide, and its saturation with aqueous vapour. When oxygen combines with carbon it yields its own volume of carbon dioxide, but in respiration the increase in volume of the carbon dioxide is less than the decrease in that of oxygen, being generally about 90 per cent. of that decrease. This is probably due to some of the oxygen being used to oxidise some hydrogen of the food or tissues to water. Though the absorption of oxygen takes place almost wholly in the lungs, it is not there that the act of combination of the carbon and hydrogen of the body with the oxygen takes place. The blood, by the hæmoglobin of the red corpuscles, acts as a carrier of oxygen, and the actual combustion of the products derived from the food occurs in the tissues themselves.

Bones consist essentially of an earthy framework composed mainly of calcium phosphate, permeated by an albuminoid known as *ossein*, and by nerves, blood-vessels, &c. In the hollow centre of many bones is the *marrow*, which consists largely of fat and albuminoids. The relative proportions of mineral and organic matter in bones vary considerably. The latter usually varies from 30 to 50 per cent. of the weight of the whole bone. The proportions of nitrogen and phosphate of lime in average bones have already been discussed in the chapter on manures.

The ash of bones, however, is not entirely phosphate of lime, but contains also carbonates, fluorides, chlorides and magnesia. An analysis of the ash of ox-bones gave:

Calcium phosphate	86·0
Magnesium phosphate	1·0
Calcium as carbonate, chloride and fluoride	7·3
Carbon dioxide	6·2
Chlorine	0·2
Fluorine	0·3
	101·0

Muscular tissue consists largely of albuminoids and water, but contains also small quantities of fat, glycogen (or animal starch), "nitrogenous extractives" of which *creatine*, $C_4H_9N_3O_2$, *sarcine*, $C_5H_4N_4O$, *xanthine*, $C_5H_4N_4O_2$, *guanine*, $C_5H_5N_5O$ and *carnine*, $C_7H_8N_4O_3$, are the chief, and sugar. The ash of muscle consists largely of potash and phosphoric acid compounds, but sodium, magnesium, calcium, chlorine and iron are also present. Muscle usually contains from 75 to 78 per cent. of water, and 22 to 25 per cent. of solids. Living muscle has an alkaline reaction, but after death it becomes acid, probably owing to the formation of sarcolactic acid, $CH_3.CHOH.COOH$.

When a muscle does work the glycogen and sugar, and possibly the fat, are oxidised at an increased rate, and the blood which bathes the muscle receives increased quantities of carbon dioxide. The nitrogenous waste of muscle, which is not now believed to be increased by exertion, is excreted in the form of urea and uric acid.

Fatty tissue consists of cells, the walls of which are composed of a membrane of albuminoids, filled with fat, which during life is fluid. The fat, which resembles in constitution the vegetable oils already described, contains stearic, oleic and palmitic acids combined with glyceryl.

Fatty tissue contains water, membranes and fat in about the following proportions:

	From the ox.	From the sheep.	From the pig.
Water . . .	9·96	10·48	6·44
Membrane . .	1·16	1·64	1·35
Fat	88·88	87·88	92·21

Fat is stored in the body as a reserve from which the animal can draw in times of scarcity of food. It is the most concentrated form in which energy can be stored.

Connective tissue, of which tendons, ligaments, cartilage and skin are mainly composed, consists of substances which yield gelatin when heated with water. Three different substances have been recognised, *viz.*, *elastin*, *collagen* and *keratin*. The first is almost free from sulphur, the second contains about

0·6 per cent., while the last usually has about 4 or 5 per cent. of sulphur. Keratin is the main constituent of horns, hoofs, skin, feathers, hair, wool, nails, &c. It is insoluble in water, alcohol, or ether, but by heating with water under pressure to 150° or 200° C. it can be rendered soluble, and then constitutes glue.

Digestion.—An important process by which the food of an animal is rendered capable of being absorbed into the system and utilised in building up or renewing the tissues of the body. It is accomplished partly by mechanical means, but mainly by chemical changes, which are produced chiefly by the action of enzymes.

The first step is mastication, by which the food is subdivided and crushed by the action of the teeth and thoroughly mixed with *saliva*, a special secretion poured by glands into the mouth. Saliva is a highly dilute liquid of faint alkaline reaction, and contains an enzyme, *ptyalin*, or *salivary diastase*, which has the power of bringing about the same changes as are produced by plant diastase, *viz.*, the conversion of starch into sugar (maltose). Ruminants, whose food usually contains much starchy material, secrete enormous quantities of saliva—estimated in the case of the ox at about 1 cwt. per day.

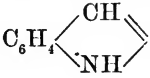
The food, after mastication, passes into the stomach, though in the case of ruminants it is brought back from the paunch or rumen into the mouth to undergo a second mastication ("chewing the cud"). It then passes into the stomach, where it meets with the characteristic secretion—the *gastric juice.* The gastric juice contains various salts (chlorides and phosphates of calcium, magnesium, sodium, and potassium), free hydrochloric acid, and two enzymes, *pepsin* and *rennet* (or *chymosin*). The former has the power of converting insoluble proteids into soluble and diffusible albumoses and peptones, the latter of coagulating casein. These properties are possessed in acid, but not in alkaline solutions. Pepsin acts best in a liquid containing from 0·1 to 0·3 per cent. of free hydrochloric acid. The gastric juice of sheep contains about the lower, that of the dog the higher of these amounts.

The walls of the stomach move about when food is present, and knead and incorporate it with gastric juice, producing a pulpy mass known as *chyme.* In this process the proteids are largely dissolved, being converted ultimately into amino-acids, the fat is melted, and the cell walls of the fatty tissue are removed. A certain amount of hydrolysis of starch (*i.e.*, conversion of this substance into sugar) also occurs in the stomach. The chyme then passes into the intestines, the secretion of which has an alkaline reaction. The acidity due to the gastric juice is therefore neutralised, and the chyme then receives the secretions of the pancreas and liver.

Pancreatic juice is a viscid, alkaline liquid containing various organic substances and inorganic salts. Its specific constituents, however, are three enzymes: (1) a diastatic one, *amylopsin*, acting rapidly upon starch and converting it into dextrin and maltose; (2) a fat-splitting one, *steapsin* or *pialyn*, possessing the power of decomposing fats into glycerol and free fatty acids, at the same time emulsifying the unchanged fat; and (3) a proteolytic enzyme, *trypsin*, which resembles pepsin in its properties, except that it works best in an alkaline liquid. Pancreatic juice is thus capable of completing the work commenced by the saliva and the gastric juice, and, in addition, has the power of bringing about the emulsification of the fat. This latter process, however, is greatly aided by the *bile*, the alkaline secretion of the liver.

Bile is a reddish-yellow (in carnivorous animals) or green (in herbivora) liquid, with an alkaline reaction and intensely bitter taste. It contains alkaline salts of bile acids, bile pigments, fats, soaps and mineral matter. The bile acids are mainly *glycocholic acid*, $C_{26}H_{43}NO_6$, and *taurocholic acid*, $C_{26}H_{45}NO_7S$, and to these substances the bitter taste of bile is mainly due. The bile pigments consist chiefly of *bilirubin*, $C_{16}H_{18}N_2O_3$, a reddish-yellow substance, insoluble in water but soluble in alcohol, chloroform, or alkalies. It is found especially in the bile of the carnivora, and by exposure to air in alkaline solution absorbs oxygen and passes into *biliverdin*, $C_{16}H_{18}N_2O_4$, an amorphous green substance, insoluble in water, but soluble in alcohol and alkalies. This substance is found in bile and in the shells of many birds' eggs.

Bile has a slight power of dissolving fats (a familiar application of this is afforded by the use of ox-gall for removing grease, &c., from carpets and other textile fabrics), and has a distinct antiseptic effect upon the contents of the intestines. Bile is to a large extent reabsorbed in the intestines.

In the intestines many chemical changes occur, many being induced by bacteria, which grow freely in the alkaline contents, producing various putrefactive decompositions. Carbohydrates produce lactic acid, cellulose splits into carbon dioxide and marsh gas, while butyric acid, $C_3H_7.COOH$, and valeric acid, $C_4H_9.COOH$, result from the bacterial hydrolysis of fats. Two characteristic substances—*indol*,  $C_6H_4\left\langle\begin{array}{c}CH\\NH\end{array}\right\rangle CH$, and *skatol*, or methyl indol,  $C_6H_4\left\langle\begin{array}{c}C(CH_3)\\NH\end{array}\right\rangle CH$, crystalline substances with very unpleasant odours, have been extracted from the contents of the intestines, and it is to the presence of these substances that the unpleasant smell of fæces is largely due.

Destination of Digested Food.—Some few constituents of the food can be absorbed without undergoing chemical changes; this is the case with water and common salt, perhaps also with some soluble proteids. Absorption commences in the stomach, but is mainly accomplished in the intestines by the lacteals and lymphatics.

The carbohydrates are probably entirely absorbed in the form of maltose or glucose, being converted into these compounds by the enzymes of the saliva, pancreatic juice, and intestines. Some of these enter the blood stream and are conveyed to the tissues, while another portion is stored in the liver in the form of *glycogen*, $C_6H_{10}O_5$, an amorphous white powder occurring in the liver to the extent of from very little or none in starvation to 10 or 12 per cent. under a rich carbohydrate diet.

Only a small portion of the fat is saponified (*i.e.*, decomposed into glycerol and fatty acids), the greater portion being merely emulsified by the action of the pancreatic fluid and the bile. The minute globules of fat apparently pass through the walls of the intestines into the lacteals, and thus into the blood. The proteids are chiefly absorbed as peptones and albumoses, though apparently they are transformed back into proteids in the act of absorption, for no peptones can be found in the blood.

According to recent researches proteids are hydrolysed by the digestive juices into amino-acids, and in this form enter the blood stream. The amino-acids are then used by the animal in building up the proteids required in its tissues. Unless all the amino-acids necessary for forming animal proteids are present in sufficient quantities in the proteids of the food proper nutrition cannot occur. In the case of the proteids of certain food-stuffs—*e.g.*, of maize—all the necessary amino-acids are not present, and such food-stuffs cannot, of themselves, support life for long. The subject is at present receiving much attention from biological chemists, and, in the near future, much new light will doubtless be thrown upon it.

The digestion of the food thus commences in the mouth and is completed in the stomach and intestines, while the digested materials are absorbed by the lacteals and poured into the blood stream from which they are extracted in the building up of tissue.

The carbohydrates and fats which are oxidised in keeping up the animal heat or in furnishing energy, are exhaled as carbon dioxide and water from the blood in the lungs, while the nitrogenous waste products of the breaking down of muscle,

&c., and the mineral matter are chiefly excreted from the blood, by the kidneys and appear in the urine.

Urine.—Urine varies greatly in composition, being affected by the food, amount of exercise, water consumed and other circumstances. In carnivorous animals it is usually acid, in herbivora alkaline or neutral. The characteristic constituent is *urea*, or *carbamide*, $CO(NH_2)_2$, of which there is usually more in the urine of carnivora than in that of herbivora.

Uric acid, $H_2C_5H_2N_4O_3$, occurs very largely in the excrements of birds and reptiles, also in the urine of carnivora, and to a small extent in that of herbivora. In certain diseases—*e.g.*, gout and rheumatism—deposits of uric acid and urates are formed in the body.

In the urine of herbivorous animals, uric acid is replaced by *hippuric acid* (benzoyl-amino-acetic acid), $C_9H_9NO_3$, which occurs to the extent of about 2 per cent. in the urine of horses and cattle. By hydrolysis (taking up of water) hippuric acid readily passes into benzoic acid, $C_6H_5.COOH$, and amino-acetic acid, or glycocoll, $CH_2(NH_2).COOH$:

$$C_6H_5CO.NH.CH_2.COOH + H_2O$$
$$= C_6H_5.COOH + CH_2(NH_2).COOH.$$

CHAPTER IX.

THE FEEDING OF ANIMALS.

THE food of the animals of the farm consists mainly of various vegetable products, being either a part or the whole of the plant, or some bye-product resulting from the utilisation of the vegetable matter for some other purpose (*e.g.*, oil-cakes).

The actual essentials of the food of animals can be deduced from the composition of their first natural food—their mother's milk.

All animals are alike in requiring, as ingredients of their food, the following classes of constituents:

1. Nitrogenous organic compounds—*proteids.*
2. Richly carbonaceous, non-nitrogenous compounds—*fats* or *carbohydrates.*
3. *Mineral compounds,* including especially lime, iron, potash, sodium, phosphates, sulphates, &c.

In addition, almost all food-stuffs contain more or less woody, fibrous matter, which is usually known as "crude fibre."

The composition of most substances used as food has been given in chap. vii. A little explanation of the meaning of the terms used in stating the composition of a food may, however, be useful.

The common method of expressing the results of the analysis of a food-stuff is to give the amounts of the following constituents:

Moisture.
Ash.
Crude fibre.
N-free extract.
Protein.
Fat.

By *moisture* is meant the loss which the food-stuff undergoes when heated in a steam-bath until constant. This may be taken without much error to be water, though other volatile constituents of the material may be lost. An error in the opposite direction may be introduced by the oxidation of some constituent, unless the heating is done, as it sometimes is, in a current of hydrogen or of nitrogen. Certain oils—*e.g.*, linseed—absorb a considerable quantity of oxygen when heated in air.

Ash is the amount left by heating the material to redness in air until all black portions of carbon have disappeared. The residue obtained does not necessarily contain the true mineral constituents of the food-stuff in the same form as they were actually present. Indeed, it almost invariably happens that the various constituents are left in an entirely different state; *e.g.*, potassium and calcium are left in the ash largely as carbonates, though in the plant they are doubtless present as organic salts (malates or oxalates). The sulphates in the ash, too, are often derived from sulphur existing as albuminoids.

Crude fibre is determined by the somewhat arbitrary method of boiling a weighed portion of the material successively with dilute sulphuric acid and a solution of caustic soda. The organic matter which resists this treatment is reported as crude fibre. It consists generally of woody matter, but it is quite empiric to assume, as is sometimes done, that it is a measure of the material which would resist digestion if fed to an animal.

N-free Extract, or Soluble Carbohydrates.—This is always determined by difference—by subtracting the sum of all the other constituents from 100. The result, which includes the accumulated errors of all the other items, is assumed to consist of starch, sugar, and other carbohydrates. This is not very satisfactory, but is still the usual way of expressing analytical results.

Protein.—This is obtained by multiplying the percentage of total nitrogen present by 6·25, on the assumption that all the nitrogen is present as albuminoids and that the latter contain 16 per cent. of nitrogen. Both these assumptions are generally wrong. Many food-stuffs contain a considerable portion of their nitrogen in the form of *amides*, which are less valuable for feeding purposes than albuminoids (see chap. v.). However, in recent analyses distinction is made between albuminoids and amides.

Fat, or *ether extract*, as it is sometimes more accurately called, is, as the latter name indicates, the proportion of the material which is soluble in ether. It generally includes true fat or oil, chlorophyll, and other colouring substances and resinous bodies.

The value of a food depends partly upon its composition, but also upon its palatability and digestibility. The last can be determined experimentally by experiments with animals. Weighed quantities of the food are fed to animals kept in such a way that their excrement can be collected and analysed for a considerable period of time. In this way the proportion of each food constituent digested out of 100 parts by weight supplied can be determined. This proportion is known as the "digestion coefficient," but differs with the kind of animal, and even with different individuals of the same kind.

The "digestibility" of a food constituent, however, in this sense, has no reference to the ease or rapidity of its assimilation, nor to its effect upon the health or comfort of the animals consuming it.

Animals differ in their power of digesting any given food or food-constituent. Thus ruminants, by their more thorough and repeated mastication, are better able to digest bulky fodder than are pigs and horses.

In the following table are given the average digestion coefficients of the constituents of various foods according to

American and German experiments. It must be remembered that the figures have no pretensions to accuracy, since in any given case differences may be produced by variations (1) in the food or (2) in the animals consuming it.

AVERAGE DIGESTION COEFFICIENTS IN VARIOUS FOODS.

	Protein.	Carbohydrates.	Fat.	Crude fibre.	Total dry matter.
I.—FOR RUMINANTS.					
Maize	76	93	86	58	91
Gluten meal	89	93	93	—	88
Gluten feed	85	87	83	72	84
Wheat bran	79	69	68	22	61
Wheat sharps	82	85	85	36	79
Rye meal	84	92	64	—	87
Barley	70	92	89	50	86
Malt sprouts or culms	80	69	100	34	67
Brewers' grains, wet	73	62	86	40	63
„ „ dry	79	59	91	53	62
Oats	78	76	83	20	70
Rice meal	63	86	85	26	75
Linseed	91	55	86	61	77
Linseed oil, rich in oil	89	78	89	57	79
„ „ poor in oil	85	84	93	74	80
Cotton seed	68	50	87	76	66
Cotton cake, decorticated	88	64	93	32	76
„ „ undecorticated	62	54	85	46	55
Pea meal	83	73	85	—	79
Meadow hay	57	64	53	60	61
Timothy hay	48	63	57	52	57
Red clover hay	62	69	62	49	61
Alsike hay	66	71	50	53	62
White clover hay	73	70	51	61	66
Lucerne hay	74	66	39	43	60
Sainfoin hay	70	74	66	36	62
Wheat straw	11	38	31	52	43
Rye straw	21	37	32	60	46
Oat straw	30	44	33	54	48
Barley straw	20	54	42	56	53
Pasture grass, green	70	73	63	76	71
Timothy grass, green	50	64	47	52	58
Green oats, in bloom	75	63	70	60	64
Red clover, green	67	78	65	53	66
Crimson clover, green	77	74	66	56	69
Lucerne, green	81	76	52	45	67

Average Digestion Coefficients in Various Foods—*continued.*

	Protein.	Carbohydrates.	Fat.	Crude fibre.	Total dry matter.
I.—For Ruminants—*continued.*					
Potatoes	61	90	—	—	85
Mangolds	77	96	—	—	88
Turnips	90	97	98	100	93
Swedes	80	95	84	74	87
Cows' milk	94	98	100	—	98
II.—For Pigs.					
Maize meal	86	95	76	40	92
Pea meal	89	95	50	78	90
Barley meal	76	90	65	15	82
Wheat	70	74	60	30	72
Wheat bran	75	66	72	34	61
Wheat sharps	73	87	—	37	77
Potatoes	73	98	—	55	93
Dried blood	72	92	—	—	72
Flesh meal	97	—	87	—	92
Sour milk	96	99	95	—	95

By combining such results with a table of the composition of food-stuffs it is possible to construct a table giving the digestible constituents of various foods, which, though not necessarily accurate in any particular case, is very useful as a guide in framing rations for animals. The following is such a table, compiled from American and German experiments; appended to it are the fertilising constituents present in the various foods, which enable the manurial value of the foods to be gauged.

Of the "digestible protein" given in the above table a portion only consists of true albuminoids. In cakes, grain, &c., the proportion of true albuminoids to total "protein" is high, while with grasses, and especially with roots, it is very small. Thus in cakes, peas, beans, wheat, barley, oats, maize, &c., the proportion is 80 per cent. or over, in barley straw and meadow

DIGESTIBLE AND FERTILISING CONSTITUENTS OF VARIOUS FOOD-STUFFS.

Food.	Dry matter per cent.	Digestible constituents. Percentages.			Fertilising constituents. Percentages.		
		Protein.	Carbo-hydrates.	Fat.	Potash.	Phosphoric acid.	Nitrogen.
Maize	89·1	7·9	66·7	4·3	0·40	0·70	1·82
Maize bran	90·9	7·4	59·8	4·6	0·68	1·21	1·63
Gluten meal	91·8	25·8	43·3	11·0	0·05	0·33	5·03
Germ meal	89·6	9·0	61·2	6·2	0·50	0·80	2·65
Wheat	89·5	10·2	69·2	1·7	0·50	0·79	2·36
Flour	87·6	8·9	62·4	0·9	0·15	0·22	1·89
Wheat bran	88·1	12·2	39·2	2·7	1·61	2·89	2·67
Sharps or shorts	88·2	12·2	50·0	3·8	0·59	1·35	2·82
Rye	88·4	9·9	67·6	1·1	0·54	0·82	1·76
Rye bran	88·4	11·5	50·3	2·0	1·40	2·28	2·32
Barley	89·1	8·7	65·6	1·6	0·48	0·79	1·51
Malt culms	89·8	18·6	37·1	1·7	1·63	1·43	3·55
Brewers' grains, wet	24·3	3·9	9·3	1·4	0·05	0·31	0·89
Brewers' grains, dry	91·8	15·7	36·3	5·1	0·09	1·03	3·62
Oats	89·0	9·2	47·3	4·2	0·62	0·82	2·06
Oat meal	92·1	11·5	52·1	5·9	—	—	—
Rice	87·6	4·8	72·2	0·3	0·09	0·18	1·08
Rice bran	90·3	5·3	45·1	7·3	0·24	0·29	0·71
Buckwheat	87·4	7·7	49·2	1·8	0·21	0·44	1·44
Linseed	90·8	20·6	17·1	29·0	1·03	1·39	3·61
Linseed meal, pressure	90·8	29·3	32·7	7·0	1·37	1·66	5·43
Linseed meal, solvent	89·9	28·2	40·1	2·8	1·39	1·83	5·78
Cotton seed	89·7	12·5	30·0	17·3	1·17	1·27	3.13
Cotton-seed meal	91·8	37·2	16·9	12·2	0·87	2·88	6·79
Palm-nut meal	89·6	16·0	52·6	9·0	0·50	1·10	2·69
Sunflower seed	92·5	12·1	20·8	29·0	0·56	1·22	2·28
Sunflower cake	91·8	31·2	19·6	12·8	1·17	2·15	5·55
Pea-nut meal	89·3	42·9	22·8	6·9	1·50	1·31	7·56
Rape-seed meal	90·0	25·2	23·7	7·5	1·30	2·00	4·96
Peas	89·5	16·8	51·8	0·7	0·99	0·82	3·08
Horse-beans	85·7	22·4	49·3	1·2	1·29	1·20	4·07
Pasture grass	20·0	2·5	10·2	0·5	0·75	0·23	0·91
Timothy grass	38·4	1·2	19·1	0·6	0·76	0·26	0·48
Green oats	37·8	2·6	18·9	1·0	0·38	0·13	0·49
Meadow fescue	30·1	1·5	16·8	0·4	—	—	—
Green barley	21·0	1·9	10·2	0·4	—	—	—

DIGESTIBLE CONSTITUENTS, &c.—*continued.*

Food.	Dry matter per cent.	Digestible constituents. Percentages.			Fertilising constituents. Percentages.		
		Protein.	Carbo-hydrates.	Fat.	Potash.	Phosphoric acid.	Nitrogen.
Timothy hay	86·8	2·8	43·4	1·4	0·90	0·53	1·26
Mixed grass hay	87·1	5·9	40·9	1·2	1·55	0·27	1·41
Meadow fescue hay	80·0	4·2	43·3	1·7	2·10	0·40	0·99
Wheat straw	90·4	0·4	36·3	0·4	0·51	0·12	0·59
Rye straw	92·9	0·6	40·6	0·4	0·79	0·28	0·46
Oat straw	90·8	1·2	38·6	0·8	1·24	0·20	0·62
Barley straw	85·8	0·7	41·2	0·6	2·99	0·30	1·31
Red clover, green	29·2	2·9	14·8	0·7	0·46	0·13	0·53
Alsike clover	25·2	2·7	13·1	0·6	0·20	0·11	0·44
Crimson clover	19·1	2·4	9·1	0·5	0·49	0·13	0·43
Lucerne	28·2	3·9	12·7	0·5	0·56	0·13	0·73
Red clover hay	84·7	6·8	35·8	1·7	2·20	0·38	2·07
Alsike clover hay	90·3	8·4	42·5	1·5	2·23	0·67	2·34
White clover hay	90·3	11·5	42·2	1·5	1·81	0·52	2·75
Crimson clover hay	90·4	10·5	34·9	1·2	1·31	0·40	2·05
Lucerne hay	91·6	11·0	39·6	1·2	1·68	0·51	2·19
Clover silage	28·0	2·0	13·5	1·0	—	—	—
Lucerne silage	27·5	3·0	8·5	1·9	—	—	—
Grass silage	32·0	1·9	13·4	1·6	—	—	—
Maize silage	20·9	0·9	11·3	0·7	0·37	0·11	0·28
Potatoes	21·1	0·9	16·3	0·1	0·46	0·12	0·32
Mangolds	9·1	1·1	5·4	0·1	0·38	0·09	0·19
Turnips	9·5	1·0	7·2	0·2	0·39	0·10	0·18
Swedes	11·4	1·0	8·1	0·2	0·49	0·12	0·19
Carrots	11·4	0·8	7·8	0·2	0·51	0·09	0·15
Parsnips	11·7	1·6	11·2	0·2	0·44	0·20	0·18
Artichokes	20·0	2·0	16·8	0·2	0·47	0·14	0·26
Cabbages	15·3	1·8	8·2	0·4	0·43	0·11	0·38
Spurrey	20·0	1·5	9·8	0·3	0·59	0·25	0·38
Prickly comfrey	11·6	1·4	4·6	0·2	0·75	0·11	0·42
Acorns, fresh	44·7	2·1	34·4	1·7	—	—	—
Rape	14·0	1·5	8·1	0·2	0·36	0·15	0·45
Dried blood	91·5	52·3	0·0	2·5	0·77	1·35	13·50
Cows' milk	12·8	3·6	4·9	3·7	0·18	0·19	0·53
Separated milk	9·4	2·9	5·2	0·3	0·19	0·20	0·56
Butter-milk	9·9	3·9	4·0	1·1	0·16	0·17	0·48
Whey	6·6	0·8	4·7	0·3	0·18	0·14	0·15

hay about 60 to 65 per cent., in potatoes and carrots less than 50 per cent., in mangolds, turnips, and swedes about 25 per cent., while in some specimens of maize silage it may be as little as 12 per cent.

Albuminoid Ratio.—It is found in practice that the food of an animal may be varied considerably without any detriment to the well-being of the animal, providing the ratio of albuminoids to non-albuminoids in the food be kept within certain limits.

In order to get this ratio it is necessary that some definite carbohydrate be taken in which to express the non-albuminoids. Starch is the substance always chosen, and it becomes necessary, in order to express the fat and the other carbohydrates in terms of starch, to obtain the equivalents in heat-producing power of these other food constituents. This has been done (1) by burning weighed portions of the various materials in calorimeters and (2) by direct experiments upon animals placed in large respiration calorimeters and fed with known weights of the various food-stuffs.

As the mean of several experiments it may be taken that 100 parts of fat evolve as much heat as 230 parts of sugar, starch, or cellulose, or of protein.

To express the percentage of total non-albuminoids of a food, therefore, in terms of starch it is necessary to multiply the percentage of fat by 2·3 and add the product to the percentage of soluble carbohydrates. The albuminoid ratio thus becomes $\frac{\text{albuminoids}}{\text{carbohydrates} + (\text{fat} \times 2{\cdot}3)}$, the *digestible constituents* being taken in all cases. Suppose, for example, it is desired to calculate the albuminoid ratio, or nutritive ratio, as it is sometimes called, of red clover hay. From the table it appears that the digestible constituents are as follows:

	Per cent.
Protein	6·8
Carbohydrates . . .	35·8
Fat	1·7

The albuminoid ratio is:*

$$\frac{6\cdot8}{35\cdot8 + (1\cdot7 \times 2\cdot3)} = \frac{6\cdot8}{35\cdot8 + 3\cdot91} = \frac{6\cdot8}{39\cdot71} = \frac{1}{5\cdot84}.$$

$$1 : 5\cdot84$$

For the reasons already stated, unless the distinction between true albuminoids and amides is made in the analyses, the albuminoid ratio calculated from the "protein" (*i.e.*, the percentage of nitrogen × 6·25) may in certain cases—*e.g.*, roots, grasses, and silage—be very misleading. If the amides present are considered, the best plan is probably to class them with the non-albuminoids and consider them as about equal to half their weight of starch. With a ration consisting of several foods the calculation of the albuminoid ratio is somewhat more complex. Thus, if it is desired to calculate the albuminoid ratio of a ration composed of the following mixture:

Oat straw	10 lb.
Beans	2 "
Bran	2 "

First find the total digestible protein:

In the oat straw	$1\cdot2 \times \frac{10}{100}$	$= \cdot12$
In the beans	$22\cdot4 \times \frac{2}{100}$	$= \cdot45$
In the bran	$12\cdot2 \times \frac{2}{100}$	$= \cdot24$
		$\cdot81$

Next the carbohydrates:

In the oat straw	$38\cdot6 \times \frac{10}{100}$	$= 3\cdot86$
In the beans	$49\cdot3 \times \frac{2}{100}$	$= \cdot99$
In the bran	$39\cdot2 \times \frac{2}{100}$	$= \cdot78$
		$5\cdot63$

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* Digestible crude fibre should really be included in the calculation and be reckoned as of equal value to starch. It is of importance in fodder crops, and when it is taken into account the albuminoid ratio will be "wider," *e.g.*, about 1 : 7·7 in the example given.

Next the fat: In the oat straw . . $0{\cdot}8 \times \frac{10}{100} = {\cdot}08$

In the beans . . $1{\cdot}2 \times \frac{2}{100} = {\cdot}02$

In the bran . . . $2{\cdot}7 \times \frac{2}{100} = \underline{{\cdot}05}$

${\cdot}15$

$0{\cdot}15$ of fat $\times$ $2{\cdot}3 = 0{\cdot}34$ of carbohydrates
$\underline{5{\cdot}64}$
$5{\cdot}97$ total carbohydrates

$\therefore$ Albuminoid ratio $= 0{\cdot}81 : 5{\cdot}97$
$= 1 : 7{\cdot}37$

The albuminoid ratio in a ration most suitable for the food of animals depends largely upon the kind of animal and the condition under which it is living. The following are suggested as suitable for the various cases:

For very young animals the food should have an albuminoid ratio of about	1 : 4·0
For oxen at rest	1 : 11·0
" moderately worked	1 : 8·7
" heavily worked	1 : 6·0
For horses moderately worked	1 : 7·0
" heavily worked	1 : 5·5
For milch cows	1 : 5·0
For sheep, for wool-producing	1 : 8·0
For fattening cattle, sheep, or pigs	1 : 5·5

It is probable, however, that in the past, too much importance has been attached to the albuminoid ratio of rations, especially in the case of fattening animals. When *real* albuminoids only are considered, the albuminoid ratio of fattening rations may, with economy, be much wider than has hitherto been recommended. A study of many feeding trials shows that, provided sufficient proteid be supplied—and much less than was thought necessary, suffices—the increase of a fattening animal becomes proportional to the amount of digestible non-nitrogenous matter which it consumes. A general recognition of this fact would lead to much economy in the cost of fattening, for proteids are the most expensive constituents of food-stuffs.

Thermal Value of Foods.—Provided foods contain sufficient nitrogenous matter to replenish waste of muscular tissue,

&c., and to maintain the animal in health, it is possible to assess their relative values as sources of mechanical power when consumed by the animal by a determination of their heat-producing power. The amount of heat produced by the burning of 1 part by weight of the three classes of food constituents may be stated in terms of the weight of water which that heat would raise through 1° C. These are found to be:

Fat	9300
Protein	4100
Starch	4100
Amides (*e.g.*, asparagine)	3500

If it is desired to calculate the heat-producing or calorific power of a food, the proportions of the digestible constituents in 1 part by weight should be multiplied by their respective heats of combustion. The sum of these products will give the calorific power of the food when fed to animals—*i.e.*, the quantity of water which will be raised 1°C. in temperature by the heat evolved from 1 part by weight of the food consumed in the animal. Suppose, for example, we wish to calculate the calorific power of oats.

1 part by weight of oats contains	·092	part	digestible	protein
,, ,, ,,	·473	,,	,,	carbohydrates
,, ,, ,,	·012	,,	,,	fat

$$\text{Multiplying by the respective heats of combustion,} \left\{\begin{array}{rcrcr} \cdot092 & \times & 4100 & = & 377\cdot2 \\ \cdot473 & \times & 4100 & = & 1939\cdot0 \\ \cdot042 & \times & 9300 & = & 390\cdot6 \end{array}\right.$$

$$\text{The calorific power of oats thus is} \quad \overline{2706\cdot8}$$

Calculated in this way, the heat-producing powers of foodstuffs show great variation, maize being nearly 3500, while roots are very low, turnips being about 300.

In an animal, food is used chiefly in three ways:

1. To promote growth and increase.
2. To repair and renew tissue.
3. To furnish heat and energy.

The proportion used in these three ways varies greatly with the animal. Thus in young and growing animals, as also in fattening animals, kept quiet, the first will consume a larger proportion of the total food than in adult animals doing hard work. The proper quantity of food to be provided for an animal will therefore vary considerably with conditions.

As long ago as 1864, Wolff proposed certain feeding standards, which, with various modifications, have been largely used in framing rations. In order to eliminate the influence of the size of the animal, the proportions of the various food constituents to be supplied daily per 1000 lb. of body weight are given.

WOLFF'S FEEDING STANDARDS.

Per day per 1000 lb. live weight.

	Total organic matter.	Digestible food-stuffs.			Approximate fuel value in lb. of water raised 1° C.
		Protein.	Carbohydrates.	Fat.	
	lb.	lb.	lb.	lb.	
Ox, at rest	17·5	0·7	8·0	0·15	37,000
„ moderately worked .	24·0	1·6	11·3	0·30	53,500
„ heavily worked . .	26·0	2·4	13·2	0·50	68,500
Horse, moderately worked .	22·5	1·8	11·2	0·60	59,000
„ heavily worked .	25·5	2·8	13·4	0·80	74,000
Milch cow	24·0	2·5	12·5	0·40	65,000
Sheep, for wool, coarse .	20·0	1·2	10·3	0·20	49,000
„ „ fine . .	22·5	1·5	11·4	0·25	55,000
Fattening Cattle.					
First period	27·0	2·5	15·0	0·50	76,000
Second period	26·0	3·0	14·8	0·70	79,000
Third period	25·0	2·7	14·8	0·60	77,000
Fattening Sheep.					
First period	26·0	3·0	15·2	0·50	79,000
Second period	25·0	3·5	14·4	0·60	79,000
Fattening Pigs.					
First period	36·0	5·0	27·5		133,000
Second period	31·0	4·0	24·0		115,000
Third period	23·5	2·7	17·5		82,500

In the case of the milch cow the ration ought to vary with the milk-flow, or, better, with the amount of solids in the milk. According to Lehmann, the ration for cows should vary in accordance with the following table;

Milk per cow per day. *Lehmann's Standard for Cows of* 1000 *lb. live weight.*	Dry matter.	Digestible nutrients.			Fuel Value Calories, *i.e.*, kilos of water through 1° C.	Albuminoid ratio.
		Protein.	Fat.	Carbo-hydrates.		
	Lb.	Lb.	Lb.	Lb.		
Yielding 11 lb. of milk .	25	1·6	0·3	10	22,850	1 : 6·7
" 16½ " .	27	2·0	0·4	11	25,850	1 : 6·0
" 22 " .	29	2·5	0·5	13	30,950	1 : 5·7
" 27½ " .	32	3·3	0·8	13	33,700	1 : 4·5

Another point of importance in connection with foods is the supply of *sufficient mineral matter*, lime and phosphates particularly, for the requirements of the animal. Young animals especially are liable to suffer in development should their food be deficient in these constituents. Fortunately many of the concentrated foods—*e.g.*, oil-cakes—valued for their richness in nitrogen and fat, are also rich in ash constituents. Maize and rice are perhaps the worst foods in this respect.

Recent investigations show that the ratio of basic material to acid radicals in the ash of a food is of much importance. In cereals, for example, the amount of bases (lime and magnesia) is small compared with the amount of phosphoric acid, and there is reason to think that an exclusive cereal diet is not good for horses, &c., and may encourage certain diseases of the bones. From a study of the composition of bones of animals suffering from certain bone diseases, the writer has recently come to the conclusion that the diet of animals should contain at least as much lime as phosphorus pentoxide, or otherwise the proper nutrition of the bones is disturbed. The following table gives the ratio of lime to one of phosphorus pentoxide in certain food-stuffs:

Seeds.		*Forage.*	
Kaffir corn	0·02	Whole wheat plant	0·66
Maize	0·04	„ oat plant	0.77
Barley	0·06	Boer manna hay	0·94
Wheat	0·07	Natal blue grass hay	1·68
Oats	0·16	English meadow hay	2·27
Roots.		Cabbages	2·24
Potatoes	0·15	Red clover hay	3·60
Turnips	0·83	Lucerne hay	4·78

The seeds of all plants are thus relatively poor in lime and rich in phosphorus pentoxide as compared with the foliage, while even the whole plant, in the case of the cereals, contains far more of the latter than the former.

The importance of the diet being rich in ash constituents in connection with bone formation has long been realised, but the fact that it is the ratio of lime to phosphoric acid that is important has not hitherto been recognised. Thus, bran is widely regarded as being rich in "bone-forming" material, but from the point of view here expressed it should be very unsuitable for the development of bone, since analysis shows it to contain about 3·3 per cent. of its dry weight of phosphorus pentoxide, but only 0·3 per cent. of lime, *i.e.*, only 0·09 of lime to 1·0 of phosphorus pentoxide. Practical experience shows that animals fed very largely upon bran are prone to contract a curious bone disease known as "millers' horse disease" or "bran rachitis."

The feeding of horses and mules upon a diet exclusively composed of oat-hay or oat-hay and maize, a ration containing a great excess of phosphorus pentoxide over lime, is believed, by the writer, to be the main cause of the prevalence of a bone disease, "osteoporosis," in many parts of South Africa.

Another function of the ash constituents of food is the supply of certain substances required by the animal in secreting various digestive juices, *e.g.*, chlorine for the production of hydrochloric acid in the gastric juice, potassium compounds which are present in the saliva, gastric juice and other secretions. In some countries, these substances are deficient in the natural food available, and it is then found necessary, in order to preserve the health of animals, to supply them artificially in the form of "licks," which generally consist chiefly of common salt, often with a little sulphur and sometimes some compound of iron—*e.g.*, ferrous sulphate. With young ruminants, too, it has been found that a certain quantity of bulky food is essential, and that when entirely fed on rich, concentrated food containing a sufficiency of all necessary constituents they died.

The *proportion of water to dry food* required by animals is apparently greatest in cattle, smallest in sheep, while horses are intermediate in their demands. With sheep the ratio of water to dry matter is said to be about 2 : 1, with cattle about 4 : 1. When roots which contain more water than this are taken the economy of adding a little dry food in the shape of cake or meal to the dietary is obvious. With horses in France it was found that the ratio of water to dry food was 2·1 : 1 when at rest and 3·6 : 1 when working. With fattening oxen the ratio was found to be from 1·6 to 3·4 lb. of water to each pound of dry matter, the larger amount being consumed when the food was richest in protein. Cows will usually drink from eight to ten gallons of water per day, but much less if roots be taken.

Money Value of Food Constituents.—It would be convenient, if it were possible, to adopt, in valuing food-stuffs from analysis, a method similar to that already described in valuing manures—*i.e.*, to give to the albuminoids, fats, and carbohydrates "unit values," so that the value per ton could be computed. Such methods, however, are not completely successful, since some of the properties of food-stuffs—flavour, palatability, &c.—cannot be taken into account, and since animals are much more fastidious as to their food than are plants.

By taking the market prices (which are necessarily fluctuating) of large numbers of foods it has been estimated that the values of the digestible carbohydrates, fats, and protein are in the ratio 1 : 2·5 : 2·5.

In England digestible carbohydrates may be taken as worth approximately 1*s.* 3*d.* "per unit" per ton. Thus the digestible fat and protein become worth about 3*s.* 1½*d.* "per unit" per ton. To calculate the value per ton of a food-stuff the percentages of digestible fat and protein should be added together, their total multiplied by 2·5 and added to the percentage of digestible carbohydrates, thus giving the number of "food units." The food units multiplied by 1*s.* 3*d.* will then give the value. In practice, it will be found that if the total carbohydrates be taken as worth 1*s.* per unit, and the total fat and protein as worth 2*s.* 6*d.* per unit, the value per ton, calculated on this basis, will be roughly correct.

Manurial Value of Foods.—Another factor of importance in determining the relative values of foods is their effect in enriching the excreta of animals fed upon them, in the valuable manurial constituents—nitrogen, phosphates and potash. Many of the rich nitrogenous food-stuffs are rich too in phosphates and potash; oil-cakes, for example, have a marked effect upon the manure of animals fed upon them, especially if the animals are not growing rapidly or producing milk. A variable proportion of the nitrogen, a smaller proportion of the phosphates, but practically none of the potash is retained by the animal in order to build up new tissue; the remainder eventually finds its way into the excreta.

Great importance is rightly attached to the manurial value of food-stuffs consumed on the farm, but it would be well for the farmer to remember that combined nitrogen can often be more cheaply purchased in the form of nitrates or ammonium salts than as cake or other concentrated food-stuff.

Lawes and Gilbert made elaborate experiments upon the manurial value of the common feeding-stuffs when supplied to fattening sheep and oxen. Voelcker and Hall have published a revised table, embodying the results of Lawes and Gilbert. In this table it is assumed that half the nitrogen, three-quarters of the phosphoric acid, and all the potash are voided in the excrement, and that nitrogen is worth 12*s.* per unit per ton, phosphoric acid 3*s.* per unit, and potash 4*s.* per unit.

VALUATION PER TON AS MANURE.									
No.	Foods.	Nitrogen.			Phosphoric Acid.			Potash.	
		Per cent. in Food.	Value at 12*s.* per Unit.	Half of Value to Manure.	Per cent. in Food.	Value at 3*s.* per Unit.	Three-quarters of Value to Manure.	Per cent. in Food.	Value at 4*s.* per Unit, all to Manure.
			s. d.	*s. d.*		*s. d.*	*s. d.*		*s. d.*
1	Decorticated cotton cake	6·90	82 10	41 5	3·10	9 4	7 0	2·00	8 0
2	Undecorticated cotton cake	3·54	42 6	21 3	2·00	6 0	4 6	2·00	8 0
3	Linseed cake .	4·75	57 0	28 6	2·00	6 0	4 6	1·40	5 7
4	Linseed . .	3·60	43 2	21 7	1·54	4 7	3 5	1·37	5 6
5	Palm-nut cake .	2·50	30 0	15 0	1·20	3 7	2 8	0·50	2 0
6	Cocoanut cake .	3·40	40 10	20 5	1·40	4 2	3 1	2·00	8 0
7	Rape cake . .	4·90	58 10	29 5	2·50	7 6	5 8	1·50	6 0
8	Beans . . .	4·00	48 0	24 0	1·10	3 4	2 6	1·30	5 2
9	Peas . . .	3·60	43 2	21 7	0·85	2 7	1 11	0·96	3 10
10	Wheat . .	1·80	21 7	10 9	0·85	2 7	2 0	0·53	2 1
11	Barley . .	1·65	19 10	9 11	0·75	2 3	1 8	0·55	2 2
12	Oats . . .	2·00	24 0	12 0	0·60	1 10	1 5	0·50	2 0
13	Maize . . .	1·70	20 5	10 2	0·60	1 9	1 4	0·37	1 6
14	Rice meal . .	1·90	22 10	11 5	0·60	1 9	1 4	0·37	1 6
15	Locust beans .	1·20	14 5	7 2	0·80	2 5	1 10	0·80	3 2
16	Malt . . .	1·82	21 10	10 11	0·80	2 5	1 10	0·60	2 5
17	Malt culms . .	3·90	46 10	23 5	2·00	6 0	4 6	2·00	8 0
18	Bran . . .	2·50	30 0	15 0	3·60	10 10	8 2	1·45	5 9
19	Brewers' grains, dried	3·30	39 7	19 9	1·61	4 10	3 8	0·20	0 10
20	Brewers' grains, wet	0·81	9 9	4 11	0·42	1 3	0 11	0·05	0 2
21	Clover hay . .	2·40	28 10	14 5	0·57	1 9	1 4	1·50	6 0
22	Meadow hay .	1·50	18 0	9 0	0·40	1 2	0 11	1·60	6 5
23	Wheat straw .	0·45	5 5	2 8	0·24	0 9	0 7	0·80	3 2
24	Barley straw .	0·40	4 10	2 5	0·18	0 6	0 4	1·00	4 0
25	Oat straw . .	0·50	6 0	3 0	0·24	0 9	0 7	1·00	4 0
26	Mangolds . .	0·22	2 8	1 4	0·07	0 3	0 2	0·40	1 7
27	Swedes . .	0·25	3 0	1 6	0·06	0 2	0 1	0·22	0 11
28	Turnips . .	0·18	2 2	1 1	0·05	0 2	0 1	0·30	1 2

Compensation Value for each Ton of the Food Consumed.									
Last Year.		Last Year but one.		Last Year but two.		Last Year but three.		Foods.	No.
s.	d.	s.	d.	s.	d.	s.	d.		
56	5	28	2	14	1	7	0	Decorticated cotton cake	1
33	9	16	10	8	5	4	2	Undecorticated cotton cake	2
38	7	19	3	9	7	4	9	Linseed cake	3
30	6	15	3	7	7	3	9	Linseed	4
19	8	9	10	4	11	2	5	Palm-nut cake	5
31	6	15	9	7	10	3	11	Cocoanut cake	6
41	1	20	6	10	3	5	1	Rape cake	7
31	8	15	10	7	11	3	11	Beans	8
27	4	13	8	6	10	3	5	Peas	9
14	10	7	5	3	8	1	10	Wheat	10
13	9	6	10	3	5	1	8	Barley	11
15	5	7	8	3	10	1	11	Oats	12
13	0	6	6	3	3	1	7	Maize	13
14	3	7	1	3	6	1	9	Rice meal	14
12	2	6	1	3	0	1	6	Locust beans	15
15	2	7	7	3	9	1	10	Malt	16
35	11	17	11	8	11	4	5	Malt culms	17
28	11	14	5	7	2	3	7	Bran	18
24	3	12	1	6	0	3	0	Brewers' grains, dried	19
6	0	3	0	1	6	0	9	„ „ wet	20
21	9	10	10	5	5	2	8	Clover hay	21
16	4	8	2	4	1	2	0	Meadow hay	22
6	5	3	2	1	7	0	9	Wheat straw	23
6	9	3	4	1	8	0	10	Barley straw	24
7	7	3	9	1	10	0	11	Oat straw	25
3	1	1	6	0	9	0	4	Mangolds	26
2	6	1	3	0	7	0	3	Swedes	27
2	4	1	2	0	7	0	3	Turnips	28

CHAPTER X.

THE DAIRY.

Milk is a valuable agricultural product, and both it and the substances obtained from it are of considerable commercial and industrial importance.

Milk is the secretion of special glands in the mammalian female, adapted to the nourishment of the newly born animal.

The milk of different animals differs considerably in composition and properties. That of the cow is the most important.

The constituents of milk may be divided into the following:

Water.
Fat.
Albuminoids.
Sugar.
Ash.

The Fat of Milk resembles in chemical constitution the animal and vegetable oils and fats already described in chap. V.—*i.e.*, it consists of the glyceryl compounds of fatty acids. It differs chiefly in containing acid radicals of low molecular weight in addition to the heavy acids—oleic, stearic, palmitic, &c.—which are present in other oils and fats. Butter fat, like all natural oils and fats, is a complex mixture of glyceryl salts of various acids.

According to recent investigations, 100 grammes of butter fat yield 92·73 grammes of fatty acids, containing:

	Grammes.
Dihydroxystearic acid, $H.C_{18}H_{33}(OH)_2O_2$	0·38
Oleic acid, $H.C_{18}H_{33}O_2$	44·42
Stearic acid, $H.C_{18}H_{35}O_2$	3·40
Palmitic acid, $H.C_{16}H_{33}O_2$	14·83
Myristic acid, $H.C_{14}H_{27}O_2$	16·43
Lauric acid, $H.C_{12}H_{23}O_2$	5·01
Capric acid, $H.C_{10}H_{19}O_2$	1·19
Caprylic acid, $H.C_8H_{15}O_2$	1·16
Caproic acid, $H.C_6H_{11}O_2$	1·64
Butyric acid, $H.C_4H_7O_2$	4·27
	92·73

The proportions, however, are variable, but the important fact to notice is the occurrence in milk fat of the last three or four acids in the above list, mere traces of which are present in other fats. These acids differ from those of higher molecular weight in being volatile in steam. The proportion of volatile acids from butter fat varies from 7·5 to 9·7 per cent. of the fat, while in suet, for example, there is usually about 0·4 per cent. of volatile acids.

Butter fat also contains traces of a substance, *cholesterol*, $C_{26}H_{43}OH$, present largely in wool fat, and of *lecithin*, $C_3H_5(C_{18}H_{35}O_2)_2[HPO_4.N(CH_3)_3C_2H_4OH]$, present in certain seeds, especially peas and beans, and of a colouring substance of unknown composition known as "lacto-chrome." Milk fat melts at about 30° to 33° C., and has a specific gravity of ·930 at 15° C., at $\frac{37{\cdot}8^\circ}{37{\cdot}8^\circ}$ (molten) = ·9118, at $\frac{39{\cdot}5^\circ}{39{\cdot}5^\circ}$ = ·9113. Contraction occurs at the moment of solidification; hence solid milk fat is heavier, volume for volume, than the liquid fat at the same temperature. Milk fat, however, varies considerably both in composition and physical properties, being affected by the food, period of lactation, and other circumstances under which the cows are kept. It exists in milk in the form of minute globules varying in diameter from ·0016 to ·010 mm. In the milk of Jersey and Guernsey cows the average size of the globules is considerably larger than in the milk of Ayrshire, also in recently calved cows than in those far advanced in lactation.

When milk fat becomes rancid the chief changes are the hydrolysis of a portion of the fat into free acids and glycerol. Thus the butyric acid glyceride may decompose in this way:

$$C_3H_5(C_4H_7O_2)_3 + 3H_2O = C_3H_5(OH)_3 + 3HC_4H_7O_2.$$

The glycerol sometimes oxidises to acrolein, C_3H_4O, or acrylic acid, $C_3H_4O_2$. The free volatile acids give rise to the characteristic odour of rancid butter.

The Albuminoids.—Various views are held as to the character of the albuminoids present in milk, some investigators believing that there are only two, or, at the most, three, while others declare the existence of five or more. Two, casein and albumin, undoubtedly occur, and are the most important.

Casein is by far the most abundant. This substance is a white, amorphous body, tasteless and odourless, insoluble in water, alcohol, or ether, but soluble in dilute alkalies, and in solutions of carbonates or phosphates. It is insoluble in dilute, but dissolves in strong, acids.

Its composition is:

	Per cent.
Carbon	53·30
Hydrogen	7·07
Oxygen	22·03
Nitrogen	15·91
Phosphorus	0·87
Sulphur	0·82

Casein can be coagulated in two ways—by the addition of an acid, or by the action of an enzyme contained in *rennet*. With dilute acids the casein is coagulated unchanged and the curd is almost free from calcium compounds. With rennet, however, the casein is split into two compounds, one of which unites with the calcium salts (chiefly phosphate) present in the milk and forms a curd which entangles the fat; the other remains in solution in the whey, but can be coagulated by heating to 95° or 100° C. In the absence of calcium salts rennet will not curdle milk. The enzyme, known as *rennin*, *lab*, *chymosin*, or *pixine*, acts best at 35° and is destroyed at 70° C. It is found in the stomachs of many animals, especially in young ones, while enzymes possessing similar properties have been found in birds, fishes, many plants, and in the products of the action of certain bacteria.

Milk Albumin resembles blood albumin. It is in complete solution in milk, but coagulates and precipitates when the milk is heated to 72° C. It is readily precipitated by lead, copper, or mercury salts, or by tannin or alcohol. It resembles casein in composition, but contains about twice as much sulphur and no phosphorus.

Milk Sugar.—Lactose or lacto-biose occurs in the milk of all animals, but is not present in plants. It is usually combined with one molecule of water, as represented by the formula $C_{12}H_{22}O_{11} + H_2O$. This substance crystallises in large rhombic or monoclinic crystals, which lose water at about 130°. It possesses a faint sweet taste, and is very soluble in hot water. Milk sugar, like glucose, has strong reducing properties, precipitating metallic silver from ammoniacal silver nitrate or cuprous oxide from alkaline copper salts.

By the action of hot dilute acids it combines with a molecule of water and yields a mixture of glucose and galactose. isomeric bodies of the composition $CH_2OH(CHOH)_4.CHO$.

An enzyme known as *lactase* can bring about the same change.

Milk sugar does not easily undergo alcoholic fermentation, but very readily suffers the lactic fermentation under the influence of certain micro-organisms. The change may be represented thus:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_4(OH).COOH;$$

but other products are simultaneously formed, and the reaction is doubtless much more complex. This change in the milk sugar is the cause of milk "going sour" when kept. The necessary lactic organisms are very abundant everywhere, especially in the neighbourhood of dairies, cow-houses, &c., and as they multiply, more and more lactic acid is produced. As milk is usually sold, the acidity is less than 0·2 per cent. lactic acid. When about 0·4 per cent. is present the milk acquires a sour taste, and when the amount reaches about 0·7 per cent., coagulation or curdling commences. After long keeping, as much as 2·0 per cent. of lactic acid may be present.

The Ash of Milk is white, and contains the basic mineral matter and salts of the milk, together with sulphates, phosphates and carbonates produced by the oxidation of the sulphur, phosphorus and carbon contained in organic constituents. Its amount in cows' milk is usually about 0·7 per cent.

It contains	from	22	to	27	per	cent.	of	potash.
,,	,,	10	,,	12	,,	,,	,,	soda.
,,	,,	19	,,	24	,,	,,	,,	lime.
,,	,,	1·8	,,	3	,,	,,	,,	magnesia.
,,	,,	traces	,,	0·2	,,	,,	,,	ferric oxide.
,,	,,	3·8	,,	4·4	,,	,,	,,	sulphur trioxide.
,,	,,	22	,,	27	,,	,,	,,	phosphorus pentoxide.
,,	,,	13	,,	16	,,	,,	,,	chlorine.

The lime and other bases in the milk are associated with the casein and citric acid. The latter substance appears to be a general constituent of cows' milk, being present usually to the extent of 0·1 per cent. Milk contains dissolved gases, chiefly carbon dioxide, nitrogen and a little oxygen. When fresh, oxygen and nitrogen are the chief, amounting to from 1 to 3 c.c. per litre, but on keeping, the oxygen diminishes and carbon dioxide appears, probably from fermentation of the milk sugar.

Cows' Milk. **Physical Properties.**— A white or yellowish-white, opaque liquor, with a sweet taste. Specific gravity varies, usually from 1·027 to 1·034. When fresh milk is quickly cooled and its specific gravity taken at once, then again after some hours, at the same temperature, a small but decided rise in density is observable, usually amounting to about 0·0005. This, which is known as Recknagel's phenomenon, has been explained in various ways. It has been ascribed to the presence of air bubbles in the quickly-cooled milk, which gradually escape; to a molecular change in the casein; and, lastly, which is more likely, to the fat globules, which are liquid at the temperature of the cow, not solidifying at once in cooling, but remaining for some time in a super-cooled liquid state. Since contraction occurs as the liquid solidifies, a gradual increase of density would result from the slow solidification of the fat globules. The maximum density of milk is at its freezing point, about - 0·4°C.

Milk expands when heated by about ·0002 for each degree C., while its specific heat is about 0·847.

Chemical Composition.—This varies considerably according to race, food, age, period of lactation, and even individuality of the cow.

The *mean* composition, according to many thousands of analyses, is in England:

Water	87·10
Fat	3·90
Sugar	4·75
Casein	3·00
Albumin	0·40
Citric acid	0·10
Ash	0·75
	100·00

But it must be remembered that these figures, being averages, imply the existence of many values, some above, some below them. As a rule the fat is most liable to variation, and the ash perhaps the most constant. In considering the variations in the composition of cows' milk it will be advisable to discuss in detail the influence of various circumstances.

1. *Period of Lactation.*—Immediately after calving, the first product of the udder, known as "colostrum" or "beestings,"

is a yellow liquid of strong, pungent taste, very different from normal milk. It is characterised by containing small clusters of cells known as "colostrum granules," varying from ·005 to ·025 mm. in diameter. The fat of colostrum has a higher melting-point than ordinary milk fat, and contains less butyric and other volatile fatty acids. Milk sugar is accompanied by glucose, and the ash is greater and much richer in phosphoric acid (up to 41 per cent. of its weight) and poorer in potash than that of ordinary milk.

Colostrum has been found to contain:

	Per cent.
Fat	1·8 to 4·6
Casein	2·6 „ 7·1
Albumin	11·1 „ 20·2
Sugar	1·3 „ 3·8
Ash	1·2 „ 2·3
Total solids	24·3 to 32·5
Specific gravity	1·059 to 1·079

After four or five days from calving the secretion becomes like normal milk, but the colostrum granules can usually be found in the milk for about fourteen days after calving. The milk during the first month after calving is generally rich in fat and total solids, and these diminish during the second month. After the second or third month the proportion of fat begins to increase, as does also the milk sugar, and this goes on as long as the cow continues to give milk. The average size of the fat globules diminishes with advancing lactation, but their number per unit volume increases. The proportion of volatile fatty acids in the fat has been found to diminish with advancing lactation.

The following table gives the average composition of the milk of seventeen cows (dairy shorthorns), arranged according to the month of lactation, embodying the results of about 700 analyses by the writer in 1900.

Period of Lactation.	Fat. Per cent.	Solids not Fat. Per cent.	Total Solids. Per cent.
First month . .	4·11	8·91	13·02
Second ,, . .	3·40	8·81	12·21
Third ,, . .	3·65	8·99	12·64
Fourth ,, . .	—	—	—
Fifth ,, . .	3·70	9·00	12·70
Sixth ,, . .	3·82	9·08	12·90
Seventh ,, . .	—	—	—
Eighth ,, . .	4·30	9·31	13·61
Ninth ,, . .	4·35	9·37	13·72
Tenth ,, . .	—	—	—
Eleventh ,, . .	5·48	9·65	15·13

2. *Food.*—The influence of the food of the cows upon the composition of their milk is a matter upon which many varied opinions are held. There appears to be a widespread belief that this influence is considerable, but all experimental evidence shows it to be very small. The quantity of milk is more affected than the quality by change of food. There appears, however, to be distinct evidence that a change from a ration of wide albuminoid ratio to one of narrow albuminoid ratio is, for a time, attended with the production of milk slightly richer in fat, but the change is apparently only transient; and even if the food with the high albuminoid ratio be continued, the milk, after allowance is made for the effect of advancing lactation, shows a tendency to return to its previous composition.

In any case, it appears that, provided cows are sufficiently fed, change of food has very little effect upon the composition of their milk.

Certain foods, however, affect the character of the fat in the milk; thus certain oil-cakes have been noticed to affect the properties of the butter—*e.g.*, melting-point, iodine value, and proportion of volatile fatty acids.

3. *Influence of Season.*—Winter milk is richest, summer milk poorest, while in autumn and spring it is of intermediate quality. This, however, may be partly due to influence of food and mode of life of the animals.

4. *Influence of Time of and Intervals between Milking.*—In most cases cows are milked twice a day, morning and evening. The intervals between the milkings are usually very unequal, the night intervals being generally the longer. Evening's milk is, under these circumstances, much richer in fat than that taken in the morning. With seventeen shorthorn cows, milked at 6 A.M. and 3 P.M., the author found as an average of 1700 analyses 3·2 per cent. of fat in morning's milk and 4·5 per cent. in evening's milk, the animals being stall-fed. In summertime, July to September, the same herd, milked at the same hours, gave an average of 2·69 per cent. of fat in the morning's milk and 4·03 per cent. in the evening. In a third series of experiments the numbers obtained were in the summer 2·97 per cent. of fat in the morning and 4·31 per cent. in the evening.

The yield of milk in the morning is considerably greater than in the evening, the ratio of one to the other being in the cases just cited approximately inversely as the ratio of the fat content.

If, however, cows are milked at equal intervals of twelve hours both the yield and the average fat content become approximately equal at the two milkings.

The author proved this by experiment with some of the cows of the herd just referred to.

The results were as follows:

	First Period. Intervals 15 and 9 Hours.		Second Period (4 weeks). Intervals $12\frac{1}{2}$ and $11\frac{1}{2}$ Hours.		Third Period. Intervals 15 and 9 Hours.	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Fat in milk of five cows per cent.	2·87	4·26	3·18	3·80	2·94	4·40
Yield of milk in lb.	98·7	66·1	81·6	68·8	77·6	56·2

But it was noticed that when the change from the usual intervals to the $12\frac{1}{2}$ and $11\frac{1}{2}$ intervals was made the proportion of fat in the morning's and evening's milk was at first little affected, but became more and more so as the practice of milking at the more nearly equal intervals was prolonged. Taking the figures for the last weeks of each period, the following are the results:

	Intervals 15 and 9 Hours.		Intervals 12½ and 11½ Hours.		Intervals 15 and 9 Hours.	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Fat per cent.	2·94	4·50	3·20	3·63	2·90	4·48
Yield in lb.	97·0	64·1	78·0	66·7	76·9	54·0
Ratio, fat	1 : 1·530		1 : 1·134		1 : 1·544	
„ yield	1·513 : 1		1·169 : 1		1·424 : 1	
„ interval	1·66 : 1		1·09 : 1		1·66 : 1	

The solids other than fat do not show this variation, but are practically the same in evening's and morning's milk. By milking three cows at intervals of six hours for four successive days the following average figures were obtained:

	Time of Milking.			
	5 A.M.	11 A.M.	5 P.M.	11 P.M.
Milk yield (lb.)	40·0	23·5	24·0	24·0
Percentage of fat in milk	2·8	3·6	3·5	3·0

The greater richness of the milk secreted during the day, and the large secretion between 11 P.M. and 5 A.M., will be noted. But it may be that the unequal intervals fifteen and nine hours to which the cows had been long accustomed had some effect upon their manner of secretion, and that this influence affected them for the four days of the experiment.

It is well known that the first milk drawn from the udder at milking time is very low in fat (sometimes 1·0, or even 0·5 per cent. has been observed), while the last portion ("strippings") is very rich (sometimes up to 10 per cent. fat). The "foremilk," too, contains very small globules of fat, while the "strippings" or "afterings" contain large globules.

5. *Influence of Breed.*—It is well known that the milk of certain breeds of cows—*e.g.*, Guernseys and Jerseys—is very rich in fat, while that of others—*e.g.*, Holderness and Holstein Friesians—is notoriously poor in fat.

The following table gives the composition of the milk of certain breeds, according to various observers:

Breed.	Fat.	Solids not Fat.	Total Solids.
	Per cent.	Per cent.	Per cent.
Jersey	5·6	9·7	15·3
Guernsey	5·1	9·5	14·6
Welsh	4·9	9·2	14·1
Sussex	4·8	9·3	14·1
Kerry	4·7	9·0	13·7
Red-polled	4·3	8·9	13·2
Devon	4·2	9·5	13·7
Shorthorn	4·0	8·8	12·8
Montgomery	3·6	9·0	12·6
Ayrshire	3·6	9·4	13·0
American Holderness	3·5	9·1	12·6
Holstein Friesian	3·4	8·9	12·3

Another important difference in the milks of various breeds is in the average size of fat globules. In any one sample of milk there are great variations in the size of these. The *average* diameters of the fat globules from milk of various breeds of cows during the whole period of lactation are, according to American experiments, as follows:

	Inch.	Millimetre.
Guernsey	$\frac{1}{9344}$	0·00270
Jersey	$\frac{1}{9631}$	0·00265
Devon	$\frac{1}{10370}$	0·00245
American Holderness	$\frac{1}{11274}$	0·00225
Holstein Friesian	$\frac{1}{12090}$	0·00210
Ayrshire	$\frac{1}{12446}$	0·00205

This has an important practical effect upon the speed at which the cream rises. The milk of the Channel Island breeds throws up its cream very rapidly and such cream is well suited for butter-making, while from the milk of Ayrshire cows the cream rises very slowly.

Morning's milk is said to have larger globules than evening's milk. The change from dry winter food to pasture in spring is said to increase the size of globules.

Milk with large fat globules, though preferable for butter-making, is not so well suited for cheese-making as that with small globules. The number of fat globules per cubic millimetre of milk has been estimated to vary from two to eleven millions.

6. *Other circumstances.*—But even when all known disturbing influences have been eliminated milk shows considerable variation. There is little doubt that even the *average* composition of the milk yielded by a cow is dependent upon the individuality of the animal, and the proportion of fat in the milk of any individual cow is often subject to enormous changes from one milking to the next, even when the conditions are, so far as is possible, kept constant. The writer suggested, some years ago, that probably these variations were due to changes in the mental condition of the animal—*i.e.*, her relative contentedness or otherwise with her surroundings, food, &c.—and though the hypothesis has given rise to some ridicule and amusement, he still adheres to the opinion. It is well known that sexual excitement, for example, has a marked effect upon both the composition and quantity of the milk secreted; it certainly seems probable that other mental influences should act in a similar manner, though perhaps in a different degree. Enjoyment of food, comfortable housing, freedom from fright or annoyance, say by insects or dogs, and other circumstances affecting the placidity of existence may very probably affect the physiological processes going on in the cow, and thus have an influence upon the composition and quantity of the milk secreted.

Milk of Other Animals.—The following table, compiled from various authorities, gives the average composition of the milk of other animals:

Animal.	Specific Gravity.	Fat.	Solids not Fat.	Sugar.	Casein.	Ash.
Woman	1·031	3·3	8·5	6·8	1·5	0·20
Ass		1·02	7·8	5·5	1·16	0·42
Goat		6·5	10·2	5·0	4·3	0·90
Ewe	1·040	5 3	12·4	4·2	7·1	1·00
Mare		1·7	8·6	6·0	2·2	0·40
Camel	1·042	2·9	10·2	5·7	3·8	0·66
Hippopotamus		4·5	4·5	4·4	Trace	0·11
Sow		4·6	11·4	3·1	7·2	1·10
Bitch	1·035	9·6	13·8	3·2	9·9	0·73
Cat		3·3	15·0	4·9	9·5	0·58
Rabbit		10·5	20·1	2·0	15·5	2·58
Elephant		19·6	12·6	8·8	3·1	0·65
Porpoise		48·5	13·1	1·3	11·2	0·57
Whale		43·7	7·7	—	7·1	0·46

A considerable difference in the behaviour of the casein of the milks of different animals when treated with rennet (the coagulating enzyme present in the stomach, especially of young animals) is observable. With cows' milk rennet gives a coherent, curdy precipitate; with human milk or asses' milk the precipitate is much more finely divided, and of course smaller in quantity. This fact has an important bearing upon the feeding of infants, who for this reason often have great difficulty in properly digesting cows' milk. It will also be observed from the figures given in the table that cows' milk differs from the natural food of the human infant in containing much more ash and albuminoids and much less milk sugar.

Preservation of Milk.—Fresh milk is an important article of diet, and it is a matter of great interest to be able to supply it in a cleanly and uncontaminated state to the consumer. This is rendered the more difficult by the fact that milk serves as an excellent medium for the growth of micro-organisms, which by their life-processes effect peculiar chemical changes in several of the constituents. Milk sugar is particularly liable to undergo decomposition, being changed into lactic acid by micro-organisms which are very widely distributed.

In the udder, under normal conditions, milk is free from micro-organisms, but, unless special precautions are taken, in a short time after milking it becomes highly charged with them. The micro-organisms find their way into the milk from the air, the hands of the milker, the teats and hair of the cow, and, too often, from the vessel in which the milk is collected.

Milk, as drawn from the cow, is at a temperature highly favourable to the multiplication of the micro-organisms, and the number present after any given time is largely dependent upon the temperature at which the milk is stored. Thus milk stored for fifteen hours at 15° C. was found to contain about 100,000 bacteria per cubic centimetre; another portion, stored for the same period at 25°, contained 72,000,000 organisms per cubic centimetre; while a third sample, kept at 35°, contained 165,000,000 per cubic centimetre.

The micro-organisms which find their way into milk are of various kinds; generally the lactic organisms predominate, so that, usually, the first evidence of change is the production of lactic acid—*i.e.*, the milk becomes "sour." As the quantity of lactic acid increases the casein is coagulated, and the milk is said to "curdle." This generally occurs when the amount of lactic acid reaches about 0·7 per cent., or with less acid if the milk be heated.

Other bacteria also sometimes find their way into milk, some of them dangerous to the health of the drinker. Outbreaks of typhoid, cholera, diphtheria, diarrhœa and other diseases have been traced to contaminated milk. Tuberculosis has also been proved to be conveyable by milk. Milk, too, has a great aptitude to absorb gases and vapours, and, in consequence, readily acquires odours and flavours from the air.

The necessity of perfect cleanliness in the cow-house and dairy is thus evident, if the milk is to be kept sweet and pure.

But it is impracticable to keep milk free from access of micro-organisms, especially such widely distributed ones as the lactic bacteria.

The methods to be adopted in preserving milk are, therefore, based upon either the destruction of the micro-organisms which have entered it or the prevention of their growth.

The second of these methods, the prevention of the growth of the micro-organisms, cannot be done perfectly, but if the temperature of the milk can be kept low the growth is slow and the milk will keep for some days. Rapid cooling after milking is of great importance, as multiplication of the micro-organisms goes on very quickly in warm new milk.

In order to destroy the organisms which have gained access to milk recourse may be made to either of two methods:

1. Sterilisation by heat.
2. The use of antiseptics.

To effect complete sterilisation—*i.e.*, the destruction of all bacteria and their spores—by heat requires a high temperature (about 115° C.), which can only be applied to milk under pressure, and unfortunately this produces undesirable chemical changes in the milk. Some of the sugar is turned brown, the albumen and a portion of the calcium citrate are precipitated, a peculiar burnt or cooked flavour is imparted and the casein becomes less readily coagulable by rennet. The fat rises more slowly and a very small quantity of richer cream is obtained.

In order to avoid these disadvantages a modified process known as *Pasteurisation* is often substituted for sterilisation. The milk is heated to only 60° or 80° C., whereby its flavour is hardly affected and the active bacteria are killed, though the spores are not. It fortunately happens that the micro-organisms to which the souring of milk is due—*viz.*, the lactic bacteria—do not readily form spores, so that Pasteurised milk will usually keep sweet and good for some days. Occasionally, however, spore-forming bacteria are present in milk, and it may happen in such cases that the milk very soon curdles, and even putrefies, after Pasteurisation. A case of this kind recently came under the writer's notice near Pretoria, the injurious organisms being *Bacillus subtilis* and allied species. The trouble arose from the very dusty condition of the kraals in which the cows were milked, and after Pasteurisation the milk did not keep as well as un-Pasteurised milk, becoming curdled without the formation of acid. In this case the destruction of the lactic organisms was apparently complete, and in their absence the spores of *Bacillus subtilis* multiplied more rapidly than if they (the lactic organisms) had been present, and thus led to the coagulation of the casein without souring. In some cases the coagulum redissolved on further standing, but the milk soon became repulsive in appearance and flavour.

Fortunately, as most of the pathogenic organisms likely to occur in milk do not form spores, Pasteurised milk is generally safe from risk of conveying contagion.

The most satisfactory method of distinguishing sterilised or Pasteurised milk from fresh milk is by a determination of the soluble albumin. In fresh milk this amounts to about 0·4 per cent., while in milk heated to about 70° C. only about 0·25 per cent. will remain, and if the milk be heated to 80° C. the whole of the albumin is coagulated and precipitated.

Fresh milk also contains an enzyme, which with paraphenylene diamine, $C_6H_4(NH_2)_2$, and hydrogen peroxide gives a blue colour. In Pasteurised milk this enzyme is largely destroyed, while in sterilised milk it is entirely absent.

Preservation by Antiseptics.—By adding various substances to milk the growth of the micro-organisms can be greatly impeded, so that the milk becomes sour much more slowly. The amounts of the antiseptics added, however, can never be sufficient to destroy pathogenic organisms, and thus render milk safe from a hygienic standpoint. Moreover, it is probable that the presence of antiseptics in milk renders it less digestible.

The chief "preservatives" used are:

1. Boric acid, HBO_3, or borax, $Na_2B_4O_7.10H_2O$.
2. Salicylic acid, $C_6H_4(OH).COOH$.
3. Formaldehyde, $H.CHO$.
4. Sodium carbonate, Na_2CO_3.
5. Glycerine, $C_3H_5(OH)_3$.
6. Benzoic acid, $C_6H_5.COOH$.
7. Beta-naphthol, $C_{10}H_7OH$.

No. 4, sodium carbonate, is not a true preservative, since it does not prohibit the activity of the lactic acid organisms, but, indeed, rather favours their action. However, by neutralising the lactic acid as fast as it forms it postpones the curdling of the milk. Its presence is readily detected by ashing some of the milk and adding hydrochloric acid, when an effervescence will show the presence of carbonates.

The favourite preservatives are formaldehyde and boric acid.

Formaldehyde is a gas, very soluble in water. A solution containing 40 per cent. of real formaldehyde is commercially known as "formalin," and is the origin or source of many commercial milk preservatives. These substances usually contain from 1 to 6 per cent. of real formaldehyde in water, and they are generally added in the proportion of about 1 ounce to 10 gallons of milk. The milk thus receives 1 part of the real preservative to from 20,000 to 50,000 of milk. Even in these small proportions the preservative power is remarkable, but this increases greatly as the quantity added is increased; thus 1 part of formaldehyde in 50,000 of milk extended the time required for curdling from 36 hours to 66 hours, the milk being kept at 20° C. 1 part in 20,000 extended the time required for curdling to 96 hours, while 1 in 10,000 required 5½ days, 1 in 5000 10½ days, and 1 in 2500 kept the milk from curdling for 55 days. It is very doubtful whether formaldehyde is as efficacious in destroying pathogenic germs as it is in preventing the lactic fermentation.

Formaldehyde may be detected in milk by adding to a small quantity of the milk an equal volume of strong hydrochloric acid containing about 2 per cent. of a 10 per cent. solution of ferric chloride. The mixture is heated gradually to the boiling-point, when a violet colouration is produced if formaldehyde be present. Pure milk slowly becomes brown under this treatment. 1 part of formaldehyde in 250,000, it is said, can be detected by this test.

Boric acid and *borax* have long been used for preserving milk in hot weather. They are not nearly so effective as formaldehyde, and have to be added in much larger proportions; thus 1 part of a mixture of boric acid and borax added to 2000 parts of milk had scarcely any preservative action at 20°, 1 in 1500 extended the period before curdling from 36 to 66 hours, 1 in 1000 to 72 hours, and 1 in 500 to 96 hours.

Boric acid can be detected by ashing the milk (best after addition of lime), acidifying with a little dilute hydrochloric acid, and immersing in the liquid a strip of turmeric paper. On drying, the paper turns red if boric acid be present, and on moistening with very little caustic soda, takes a greenish-black colour.

The other preservatives are rarely used.

PRODUCTS DERIVED FROM MILK.

The following substances must be very briefly considered here:

Cream.
Skimmed milk.
Butter.
Condensed milk.
Milk powder.
Cheese.
Whey.

Cream.—The fat, being specifically lighter than the aqueous portion of milk (sp. gr. of fat at 15° = 0·930, that of the rest of the milk about 1·036), tends to rise to the surface. The resistance to the motion of the small globules is large, while their buoyancy is small; consequently the rise of the fat is a slow process, slower in milk possessing very small globules—*e.g.*, the milk of Ayrshire cows—quicker in milk with large fat globules—*e.g.*, Jersey or Guernsey milk.

The fat, however, in any case, does not separate completely from the aqueous portions. The globules simply become more crowded together near the surface than they are lower down in the body of the milk. The upper layer on milk which has stood at rest for some time is known as cream, and is very variable in composition, according to the state of accumulation of the fat globules. There is, however, a fairly sharp line of separation between the cream and the rest of the milk. Cream can be separated from milk by gravitation, or by substituting for gravitation the much greater force produced by rapid rotation.

There are two methods employed in the former, *viz.*:

Shallow setting.
Deep setting.

By the former the milk is placed in shallow vessels to a depth of from 2 to 4 inches, cooled to about 15·5° C., and kept at that temperature for twenty-four or thirty-six hours. The cream layer is then removed, either by means of a shallow spoon-like vessel, known as the skimmer, or sometimes by running off the milk into another vessel through a hole at the bottom of the creaming pan.

By the deep-setting system the milk, while still warm, is placed in cylindrical vessels, usually about 8 to 12 inches in diameter and 15 to 20 inches deep, which are then immersed in ice-cold water. Under these conditions the creaming will be practically complete in twelve hours.

The explanation of the effectiveness of deep setting is somewhat difficult. Since fat expands and contracts with changes of temperature more rapidly than water, the effect of cooling upon milk would be to lessen the difference in specific gravity between the fat and water, and on that account would make the rise of the cream slower. To ascribe, as has been done, the effect to the difference in conductivities for heat of fat and water, and to assume that the fat globules remain at a higher temperature than the watery liquid surrounding them, is absurd. Neither is it due to a change in the viscosity of the milk, for this is much greater at low than at high temperatures.

The two causes which are probably most influential are the setting up of gentle convection currents in the milk during the time the temperature is falling, and the fact that the fat globules remain liquid for some time after cooling, and while liquid are of lower specific gravity than when solidified. The milk in contact with the cooling wall of the can contracts, becomes heavier, and sinks slowly to the bottom, the warmer and therefore lighter milk rising in the central portion of the can and flowing outwards near the surface towards the walls, and again sinking. Thus a slow circulation takes place, nearly all the milk rising in the centre, flowing outwards, and sinking down near the walls. The fat globules are thus brought in turn near the surface, and all the time, by virtue of their levity, they tend to accumulate there, the very gentle currents produced by convection not being sufficient to drag them down.

The effect of super-cooling the liquid fat has already been alluded to in the explanation of Recknagel's phenomenon (p. 187).

Separators.—By imparting very rapid rotation to milk, the magnitude of the centrifugal force thus set up may be made immensely greater than the force of gravity. Consequently the separation of the heavier portion of the milk from the lighter part takes place much more quickly. The construction and details of the various forms of separators cannot be described here, but they all depend upon the general principle that by rotating milk, previously warmed so as to become more mobile, at the rate of several thousand revolutions per minute the aqueous portion of the milk accumulates near the walls of the vessel furthest from the axis of rotation, while the fat globules tend to accumulate on the inner surface of the revolving mass—*i.e.*, near the centre. By providing suitable outlets the skimmed milk can be directed into one channel, and the cream into another, and by adjustment of the size of one of these openings, thick or thin cream can be obtained at will.

Composition of Cream.—Cream varies enormously in composition, the proportion of fat varying from as low as 10 per cent. to as high as 60 or 70 per cent. By shallow setting a product containing from 15 to 40 per cent. of fat is usually obtained; at low temperatures about 20 per cent. of fat is present. With the separator almost any desired proportion of fat may be obtained. Usually the amount of the "solids not fat" in the aqueous portion of the cream is slightly higher than in milk, due probably to a slight loss of water by evaporation during setting, though possibly also to the fat globules holding around them by surface attraction a layer of liquid slightly richer in casein, &c., than the rest of the aqueous portion of the milk.

In Devonshire "clotted cream," prepared as it is by heating the milk during setting, the amount of evaporation of the water is probably considerable. Such clotted cream usually contains about 58 per cent. of fat, 34 per cent. of water, and about 8 per cent. of solids not fat.

Although the specific gravity cannot conveniently be determined directly if the cream contains more than 30 per cent. of fat, yet, according to Richmond, the proportion of fat can in most cases be calculated from the specific gravity, thus:

$$F = 32{\cdot}0 - 0{\cdot}892\frac{G}{D},$$

where F = per cent. of fat,
G = lactometer reading (*i.e.*, specific gravity × 1000 − 1000),
D = true specific gravity.

Separated cream is always thinner in consistency than skimmed cream of the same fat content, and is sometimes thickened by the addition of "viscogen," made by mixing 2½ parts of cane sugar, 1 of quicklime, and 8 of water. About 1 oz. of the clear solution will thicken a gallon of cream.

Skimmed Milk varies in composition according to the more or less complete removal of the fat.

Skimmed milk from hand-skimming usually contains about 0·6 per cent. of fat, but may contain as much as 2 per cent. Separated milk usually contains from 0·05 to 0·15 per cent. of fat. In consequence of the removal of fat the percentage amounts of the other constituents are slightly higher than in the original milk. Thus milk of the average quality given on p. 187 might be expected to yield with a good separator skimmed milk of about the following composition:

Water	90·54
Fat	0·10
Sugar	4·94
Casein	3·11
Albumin	0·42
Citric acid	0·10
Ash	0·79
	100·00

Skimmed milk contains a valuable amount of food-stuffs, and should be utilised on the farm for feeding pigs or in other ways. Separated milk, though poorer in fat, has the advantage of being sweet and of keeping better; by the addition of cod-liver oil it has proved successful in calf-rearing.

Butter.—When cream or milk is agitated for some time the fat globules coalesce and butter separates out in irregular masses, which consist of almost continuous fat, very few of the original globules remaining. The spherical globules visible in butter under the microscope consist of minute drops of butter-milk or water enclosed in the fat.

Churning is a purely mechanical process: the fat globules collide, adhere, and the large, irregular masses thus formed in turn knock against each other or against other fat globules and cohere. Portions of the aqueous liquid, butter-milk, are enclosed in the masses of fat. During the "working" of the butter the butter-milk is more and more pressed out.

The best temperature for churning depends upon the melting-point of the fat in the particular sample of cream churned. Thus when cotton-cake has been used as food for the cows the melting-point of the butter-fat is raised, and churning should be done at a higher temperature. So, too, with "ripened" or sour cream a slightly higher temperature than with sweet cream is suitable. From 8° to 18° C. (46° to 65° F.) is the greatest range usually employed, and in most cases from 10° to 15·5° C. is chosen (50° to 60° F.). Churning takes place more readily at the higher temperature, but the resulting butter will not be so free from casein nor the butter-milk so free from fat as when the operation is done at a lower temperature.

Freshly separated cream is sometimes churned, but it is generally admitted that the best flavour and aroma in butter can only be obtained by the use of properly ripened cream—*i.e.*, cream to which the lactic organisms have either gained access spontaneously or, as is preferred in modern practice, have been added in the form of a "starter" of sour skimmed milk or some pure culture of the lactic organisms. The degree of "ripeness" which is probably best corresponds to about 0·5 per cent. of lactic acid; but the acidity most suitable depends to some extent upon the flavour desired in the butter. If the cream be over-ripe the casein present may be completely coagulated, and on churning is found as white specks or flakes in the butter, thus spoiling its appearance, and also rendering it liable to contract unpleasant flavours and rancidity on keeping.

Salt is usually added to butter, serving both as a condiment and as a preservative, the proportion varying from a mere trace up to 6 or 7 per cent.

Composition of Butter.—The main constituent is, of course, fat, but in addition water, casein, milk sugar, and ash are also present.

The amount of fat is usually about 80 to 86 per cent., water about 11 or 12 per cent., casein from 0·6 to 1·5 per cent., salt from 0·1 to 4·0 per cent. Salt butter often appears to be wetter than fresh butter, but is generally lower in water content.

"Pickled" butter is made in Ireland by warming and kneading it in brine, when the resulting butter often contains a high proportion—16 to 20 per cent.—of water.

By the present Sale of Butter Regulations (British) it is unlawful to sell butter containing more than 16 per cent. of water.

So-called "milk-blended" butters, prepared by kneading butter in milk, usually contain an excessive quantity of water and a high proportion of casein.

In America rancid butter is sometimes converted into what is known as "renovated," "process," "boiled," "aerated," or "sterilised" butter. This is done by melting the butter, separating the fat from the casein, water, &c., blowing air through the fat to remove the unpleasant smell, and then churning the liquid fat with milk until an emulsion is formed. This is quickly cooled in ice, and a granular mass is obtained. This is then "worked," salted, and made up as butter.

"Oleo-margarine," "Margarine," or "Butterine."—This product, which is intended as a substitute for butter, is made by churning so-called "oleo oil" with lard, milk, sometimes a little butter, and occasionally cotton-seed oil or pea-nut oil, in a warm state, quickly chilling the mixture, salting, "working," and treating it like butter, colouring-matters—*e.g.*, annatto—being sometimes added.

The "oleo oil" is made from beef fat by melting, carefully clarifying, and allowing it to stand at a temperature of about 30° C. The semi-solid mass which results is then separated by a press into solid stearin and a liquid composed of olein and palmitin.

Pure butter can be distinguished from "renovated" butter and from margarine by its behaviour when heated, say in a test-tube or basin, over a flame. Pure butter "boils" quietly, but with much frothing or foaming, while "renovated" butter and margarine bump and splutter violently, but do not froth.

The chief reliable chemical difference between genuine butter and margarine is in the proportion of volatile fatty acids present.

Butter-milk varies in composition; in general it resembles skimmed milk, but is usually sour. It contains from 0·3 to 3·5 per cent. of fat, 4 to 5 per cent. of sugar, 3 to 4 per cent. of albuminoids, and 0·7 to 0·8 of ash. It finds a limited use in the kitchen, but the greater part is employed as food for pigs.

Condensed Milk and Milk Powder.—Though the preparation of condensed milk forms no part of the work of the farm or dairy, it may be of interest to explain briefly the character and method of preparation of this and similar products.

Condensed milk is prepared by boiling milk in vacuum pans until its volume is diminished to about one-third or one-fourth of the original. In many brands cane sugar is added in large proportion, whereby the product keeps better, even after the tins are opened. In other brands, often known as "evaporated cream,"* no cane sugar is added. The composition of such products varies considerably, the fat especially being liable to great fluctuation. The following analyses may be taken as typical:

	Sweetened.	Unsweetened.
Water	25·7	71·7
Fat	10·7	8·1
Proteids	8·5	8·7
Milk sugar	11·9	9·9
Cane sugar	41·9	—
Ash	1·3	1·6
	100·0	100·0

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* The term "cream" cannot now be legally used for such products.

Milk powder is made by evaporating milk in thin layers in a current of warm air and scraping off the film. So far as the writer can ascertain, the yellowish-white powder which is sold as dry milk contains less fat in proportion to the other constituents than would be present in the residue from whole milk.

Cheese is produced from milk by the coagulation of the casein, which carries down with it almost all the fat, leaving the albumin and sugar in the whey. This curd is separated from the whey as fully as possible, pressed and allowed to "ripen."

The coagulation of the casein is usually effected by the action of rennet, but it may be produced by acids—*e.g.*, by the lactic acid resulting from the action of the lactic organisms on the milk sugar. This is sometimes done in the preparation of cream cheese. The curd and whey produced from whole milk by rennet have approximately the following composition:

	Curd.	Whey.
Water	50·0	92·94
Fat	26·7	0·35
Sugar	2·3	5·10
Casein	20·0	0·46
Albumin	Trace	0·46
Ash	1·0	0·69
	100·00	100·00

Rennet acts most rapidly at a temperature of about 39° or 40° C. (102° to 104° F.), and then gives a firm and hard curd, while in cooler or hotter milk—up to 50° C. (= 122° F.)—the curd formed is soft.

Soft cheeses are made by coagulating the milk at 25° to 30° C. (77° to 86° F.), and always contain much moisture.

Hard cheeses result when the curd forms in milk at about

35° C. (95° F.). Some of the better qualities of hard cheese are made from enriched milk—*i.e.*, from a mixture of milk and cream—others from whole milk, others from a mixture of whole and skimmed milk, while some poor, horny cheeses are made from skimmed milk.

It would be beyond the scope of the present volume to attempt to describe the varieties of cheese and their methods of manufacture.

The practice usually followed is to "ripen" the milk—*i.e.*, to impart the necessary acidity, often corresponding to about 0·2 per cent. lactic acid—by adding to it a "starter" consisting of sour milk or a pure culture of lactic organisms, then to add the necessary amount of rennet, the milk being previously warmed to the proper temperature. When coagulation occurs, which should be in from twenty to forty minutes, the temperature is raised to the optimum temperature, about 37° or 38° C., and kept at that for some time, usually one or two hours. The whey is then run off, the curd stirred and cut, and lastly broken in a mill, salted and pressed into moulds. The cheeses are then ripened at a temperature of 15° to 20° C.

During ripening many changes of complex character occur; the sugar is converted into lactic acid, water evaporates and the casein is converted into more digestible nitrogenous bodies of the nature of albumoses and peptones. These changes, according to one view, are produced by the lactic organisms, while another theory ascribes them to enzymic action, the enzyme being probably mainly *galactase*, which is said to be present in all milk, and possesses the power of peptonising casein.

Whatever may be the cause of the change, there can be no doubt that in well-ripened cheese a considerable portion of the casein is converted into albumoses, peptones, amides and even ammonia. In most analyses, however, the whole of the nitrogen present is expressed as being present as casein, though in fully ripened cheese perhaps not more than 14 or 15 per cent. is actually present in that form. Pasteurised milk or sterilised milk cannot be used in cheese-making.

The average composition of various cheeses, according to American analyses, is given in the following table:

	Water Per cent	Casein. Per cent	Fat. Per cent	Sugar. Per cent	Ash. Per cent
Cheddar	34·4	26·4	32·7	2·9	3·6
Cheshire	32·6	32·5	26·0	4·5	4·3
Stilton	30·4	28·9	35·4	1·6	3·8
Edam	36·3	24·1	30·3	4·6	4·6
Roquefort (sheep's milk)	31·2	27·6	33·2	2·0	6·0
Swiss	35·8	24·4	37·4	—	2·4
Brie (cream cheese)	50·4	17·2	25·1	1·9	5·4

In some of the American States "standards" of fat content for various classes of cheese were, some few years ago, established by special law.

Thus "full cream" cheese must contain at least 32 per cent. of milk fat, "three-fourths cream" cheese at least 24 per cent., "one-half cream" cheese not less than 16 per cent., "one-fourth cream" cheese at least 8 per cent. of fat. All cheeses containing less than 8 per cent. of milk fat must be labelled "skimmed milk cheese."

In some cases cheese is adulterated by the addition of foreign fat—*e.g.*, lard—and such cheese is generally known as "filled cheese."

The characteristic ingredient of cheese is casein, but the commercial value depends rather upon the percentage of fat present than upon the richness in casein. Stilton cheese is made from milk enriched with cream; Cheddar, Cheshire, Wensleydale, Gorgonzola and Gruyère are made from whole milk; while Parmesan, Gloucester and Edam are made from partially skimmed milk.

English cream cheese is usually made without rennet, and varies greatly in composition—water from 20 to 55 per cent., fat from 40 to 80 per cent., casein from 3 to 19 per cent.

Whey.—As already stated, whey contains almost all the milk sugar originally present in the milk, together with small quantities of albumin, casein, fat and ash constituents.

It is usually utilised as food for pigs, but sometimes in the manufacture of milk sugar.

CHAPTER XI.

MISCELLANEOUS.

In this chapter a description will be given of various substances used on the farm which do not come under the category of the materials discussed in the preceding chapters.

The subjects to be dealt with are numerous and diverse, so that no attempt can be made to attain any continuity or logical order.

For convenience we may consider in turn the chemical nature of the substances used as

I. Disinfectants and antiseptics;
II. Fungicides;
III. Insecticides;
IV. Plant poisons; and, lastly, those used for
V. Other purposes.

I. **Disinfectants and Antiseptics.**—A real disinfectant is a substance which destroys the micro-organisms (and their spores) which give rise to putrefaction, disease, or other chemical changes. An antiseptic is a body which prevents their growth, but may or may not destroy them. All disinfectants are thus antiseptics, but all antiseptics are not disinfectants.

A great many substances act as disinfectants in strong solution, but obviously only those which by their presence in relatively small quantity act destructively on micro-organisms are worthy of consideration under this heading.

Powerful disinfectants are found among chemical compounds of very different types, and no perfectly satisfactory method of correlating chemical and physical properties with germicidal action is known. The following classification is perhaps one of the best suggested :

1. Free acids or salts of acid reaction retard the growth of micro-organisms.

2. Soluble salts of many heavy metals—*e.g.*, mercury and copper—precipitate albuminoids. Such compounds probably act upon the protoplasm in the organisms

3. Such salts or other substances—*e.g.*, charcoal—by rendering albuminoids insoluble, may deprive the bacteria of food, and thus kill them by starvation.

4. Reducing agents—*e.g.*, sulphites, ferrous salts—remove oxygen from the medium, and thus destroy aerobic organisms —*i.e.*, those which require oxygen.

5. Oxidising agents—*e.g.*, chlorine, ozone, hydrogen peroxide, permanganates — destroy by oxidation both the bacteria and their food, and thus form the most perfect disinfectants.

6. Some metallic salts are assimilated by bacteria, and the metal is deposited within their tissues. In this way gold and silver salts act as disinfectants, provided they are present in sufficient quantity.

7. Some substances act as germicides for no apparent chemical reason. To this class belong boric acid, the borates, and some of the aromatic compounds.

By a disinfectant we usually mean a substance used for killing noxious micro-organisms in substances which are not used for food, while an antiseptic is used to arrest putrefactive changes without rendering the substance to which it is applied injurious to animals.

A large number of substances possessing disinfecting properties exists, and new ones are continually being introduced. On the farm disinfectants are chiefly used for destroying the risk of infection after outbreaks of contagious diseases. The following are among the most important substances which can be used for this purpose.

Bleaching Powder, or "chloride of lime," $Ca(OCl)Cl$. This substance may act in two ways:

1. By evolving hypochlorous acid, $HClO$, which is a powerful oxidising agent and readily destroys putrescible matter and bacteria. The liberation of hypochlorous acid is effected by the carbon dioxide of the air:

$$2Ca(OCl)Cl + CO_2 + H_2O = 2HClO + CaCl_2 + CaCO_3.$$

2. By evolving chlorine, which is a powerful disinfectant. The evolution of chlorine occurs when bleaching powder is acted upon by any acid—*e.g.*, dilute sulphuric acid:

$$Ca(OCl)Cl + H_2SO_4 = CaSO_4 + H_2O + Cl_2.$$

If a building is to be disinfected by means of chlorine about 2 lb. of bleaching powder for each 1000 cubic feet of space should be placed in an earthenware bowl or vessel, and then a previously cooled mixture of 1½ lb. of oil of vitriol and a gallon of water poured upon it, and the windows and doors closed as quickly as possible. This will yield gas enough to form nearly 0·5 per cent. of the atmosphere in the room, and this is sufficient to kill micro-organisms, though possibly some spores may escape destruction.

Sulphur Dioxide, SO_2, is a much-used disinfectant. It gives rise to the well-known smell of burning sulphur, and is soluble in water, forming a solution of sulphurous acid, H_2SO_3. It is a strong reducing agent, and acts upon many organic substances, producing colourless compounds, and is therefore often used for bleaching wool, straw, &c. By strong pressure it can be liquefied, and liquid sulphur dioxide, under a pressure of three or four atmospheres, is now commercially obtainable in glass siphons or in metal cylinders. In this form it can very conveniently be used for disinfecting purposes, but the gas is usually made by burning sulphur in air. The sulphur should be either in the form of "candles"—*i.e.*, short cylindrical cakes provided with a wick—or roll sulphur, which can be readily set on fire if placed in metal dishes just previously moistened with the very inflammable carbon disulphide. About 1 lb. of sulphur to each 1000 cubic feet of space will probably be the most suitable quantity to use for fumigation.

Carbon Disulphide, a very volatile and inflammable liquid of offensive odour, gives off a vapour which is very poisonous both to animals and to micro-organisms, but its readiness to catch fire and its explosibility when mixed with air render it too dangerous for use on the large scale. Its temperature of ignition is so low—about 150° C., that a glowing splint or a burning cigarette is sufficient to ignite a mixture of its vapour with air.

The above are gaseous disinfectants, and are thus readily brought into contact with the material to be disinfected. Many liquid preparations are in use for disinfecting purposes, some of them volatile, and therefore giving off disinfecting vapours.

Phenol, C_6H_5OH, or "carbolic acid," and *Cresol*, $C_6H_4(CH_3)OH$, contained in coal-tar or wood-tar, have long been used as disinfectants. Pure phenol is a colourless, crystalline substance, melting at 41° C. and boiling at 182° C. Often, however, it is used in the form of a liquid (a hydrate), and is soluble in about fifteen times its weight of water.

With alkalies phenol forms salts, "carbolates," which are much more soluble in water, and are readily decomposed by acids (even by carbonic acid), yielding free phenol again. Many of the "disinfecting" powders of commerce consist of some indifferent powder, silica, silicates, or sometimes of lime or magnesia, to which about 15 per cent. of phenol has been added.

Creasote is a mixture of cresol, $C_6H_4(CH_3)OH$, xylenol, $C_6H_3(CH_2)_2OH$, and other members of this series, and is largely used for preserving timber.

Lysol is an alkaline (potash) compound of tar oils and fat. It is soluble in water, and owes its disinfecting powers mainly to cresol.

Wood Creasote is obtained from wood-tar, and contains phenol, cresol, guaiacol, $C_6H_4(OCH_3)OH$, and creosol, $C_6H_3(CH_3)OCH_3OH$.

"*Formalin,*" the commercial name for a 40 per cent solution of formaldehyde, H_2CO, in water, is a very powerful disinfectant. Formaldehyde is a gas, and from strong solutions, if exposed, it escapes into the air. A solution of 1 part of this substance in 10,000 of water will prevent the growth of many micro-organisms, while 1 in 100 gives absolute sterility.

Formalin is too expensive to be used for true disinfecting purposes, but is largely used for the prevention of decay in food materials.

The above, though used in the liquid or solid form, are volatile, and to some extent exert a disinfecting action upon substances near but not actually in contact with them.

The following substances, used as disinfectants, are non-volatile, and only affect those substances with which they or their solutions actually come into contact:

Potassium Permanganate, $KMnO_4$, or the sodium salt, $NaMnO_4$, and the manganates—*e.g.*, K_2MnO_4—are extremely powerful oxidising agents, and soon destroy organic matter and micro-organisms. Solutions of these salts are the active ingredients in "Condy's Fluid."

Zinc Chloride, $ZnCl_2$, is a caustic and deliquescent solid. A strong solution (about 50 per cent.) constitutes "Burnett's Disinfecting Fluid," and is often used as a wood-preservative.

Copper Sulphate, "blue vitriol," or "blue-stone," $CuSO_4.5H_2O$, is sometimes used as a disinfectant, but is somewhat expensive.

Mercuric Chloride, "corrosive sublimate," $HgCl_2$, is a very efficient disinfectant, but is very poisonous. It is largely employed in surgical operations.

As antiseptics, several substances, in addition to those described under "Disinfectants," are employed:

Boric Acid, or *Boracic Acid,* H_3BO_3, is a sparingly soluble, crystalline, solid substance, almost devoid of taste. It is often employed as a preservative of food-stuffs—*e.g.*, milk, cream—and in surgery.

Borax, $Na_2B_4O_7.10H_2O$, is used for similar purposes, and sometimes as a poison for cockroaches.

Salicylic Acid, $C_6H_4(OH).COOH$, is also sometimes added as a preservative to milk, cream, canned fruits, fruit syrups, &c.

II. **Fungicides.**—A fungicide is a plant poison—in fact, a disinfectant—but used under such conditions that while destructive to the low forms of plant-life—the fungi—it does not injure the higher plants. In fact, a fungicide might be defined as a differential plant poison, strong enough to kill some forms of plant-life, but too weak to destroy others.

A fungicide is usually employed to destroy micro-organisms which are liable to attack cultivated plants, and may be applied to the seed, stem, or foliage, as the case requires. Amongst the substances used as fungicides the following are the most important:

(*a*) *Copper Salts.*—These salts are, when in solution, very injurious even to the higher plants. The starting-point of nearly all copper fungicides is copper sulphate, or "blue vitriol," $CuSO_4.5H_2O$. This is a blue crystalline substance of specific gravity 2·28, readily soluble in water to a blue solution.

100 parts of water at 0° C. dissolve 31·6 parts of the salt.
" " 10° " 37·0 " "
" " 20° " 42·3 " "
" " 100° " 203·3 " "

A 2 per cent. solution of the salt has a specific gravity of 1·0126, a 4 per cent. solution 1·0254, and a 6 per cent. solution 1·0384.

A solution of copper sulphate has long been used for "pickling" seed wheat for the prevention of the fungoid diseases *smut*, *rust* and *bunt*. A common practice is to thoroughly wet each quarter of wheat with 2 gallons of water in which 2 lb. of "blue vitriol" has been dissolved.

The grain is dressed with this liquid about twenty-four hours before sowing. The spores of the fungi which may be on the grain are thus destroyed, and the thin film of soluble copper sulphate which remains on the wheat is converted, probably mainly by the calcium carbonate of the soil, into insoluble compounds soon after sowing, and before the wheat germinates. If this conversion of the copper into insoluble compounds did not occur the wheat would probably be killed by the treatment. In America the grain is soaked for twelve hours in a solution of 1 lb. of copper sulphate in 24 gallons of water, and then for five minutes in lime-water.

Copper sulphate is also employed for spraying the foliage of plants for the prevention of fungoid diseases. For this purpose a solution not stronger than 1 lb. of the salt in 20 gallons of water should be used, or the leaves will be injured.

Copper sulphate has also been used for the destruction of certain cruciferous weeds, especially charlock. If barley or oats are badly infested with this plant it is found that if the whole field be sprayed with a 2 or 3 per cent. solution of sulphate of copper, using about 40 gallons to the acre, provided the charlock plants are not above two or three inches high, their leaves blacken, and they die, while the oats, barley, or clover are not injured.

It is difficult to explain why the charlock should be killed, while the cereal is uninjured, but it may be due to plasmolysis (see chap. v., p. 78) occurring more readily in the one case than in the other. But copper sulphate is too corrosive in its effect on foliage to be very suitable as a fungicide for many plants, and a much more generally used substance is copper hydroxide, CuH_2O_2, or really basic copper sulphate, *i.e.*, a compound of 4 or 5 molecules of copper hydroxide with one of copper sulphate, applied in suspension in water.

This is largely used under the name of *Bordeaux mixture*, and is made as required by the action of slaked lime upon sulphate of copper:

$$\underset{\text{Copper sulphate}}{CuSO_4} + \underset{\text{Lime}}{CaH_2O_2} = \underset{\text{Copper hydroxide}}{CuH_2O_2} + \underset{\text{Calcium sulphate}}{CaSO_4}$$

Various strengths have been recommended—usually from 12 to 30 lb. of copper sulphate to 100 gallons of water, and from 8 to 20 lb. of quicklime. Of the pure substances, 239 parts of sulphate of copper require only 56 parts of quicklime, but in practice, as the lime is never pure and portions of it never dissolve, much more lime has to be employed. The mixing of the lime and copper sulphate must always be done in the cold, and there should always be a slight excess of lime. This can be ascertained by filtering the muddy blue liquid and testing it for dissolved copper or lime. The simplest plan for the former is to immerse a piece of polished steel—a knife blade, for example—in the liquid for a few minutes. If there be excess of copper sulphate a stain of metallic copper will appear on the steel. To show excess of lime in the solution the easiest plan is to breathe on the surface, when the carbon dioxide in the air from the lungs will form a thin scum of carbonate of lime.

A much-used formula is:

Copper sulphate	6 lb.
Quicklime	6 „
Water	50 gallons.

Each of the solid constituents should be dissolved in 25 gallons of water, and then thoroughly mixed together. The mixture should be used as soon after its preparation as possible, since it must be remembered that the effective ingredient, copper hydroxide, or rather basic copper sulphate, is in suspension, not in solution.

It has recently been shown that the active substance in Bordeaux mixture is not copper hydroxide, but some basic copper sulphate—(several are known to exist, *e.g.,* $4CuO.SO_3$ $5CuO.SO_3$ and $10CuO.SO_3$)—which subsequently on exposure to air absorbs carbon dioxide and again forms sulphate, which being soluble, exerts its fungicidal action—

$$4CuO.SO_3 + 3CO_2 = 3CuCO_3 + CuSO_4.$$

Other copper preparations used as fungicides are:

Eau Céleste, ammonio-copper sulphate, $CuSO_4.4NH_3.H_2O$, made by adding ammonia to a solution of copper sulphate. This yields a magnificent blue solution. The usual proportions are copper sulphate 5 lb., ammonia (strong) 6 or 7 pints, water 100 gallons.

Ammoniacal Copper Carbonate, made by dissolving 10 ounces of copper carbonate in about 6 pints of strong ammonia and diluting to 100 gallons with water. A deep blue solution.

In the latter two preparations the copper is in solution, and the liquids have the advantage of not discolouring the fruit and foliage so much as Bordeaux mixture.

Mercuric chloride, $HgCl_2$, "corrosive sublimate," is an extremely powerful poison both to animals and plants. It has been used as a fungicide against bunt in wheat, and for other purposes. A very dilute solution suffices—about 1 lb. in 50 gallons of water. Its violent poisonous qualities render it necessary to take every precaution in dealing with this substance.

Formaldehyde, H_2CO, used in the form of a solution in water, "formalin," containing about 40 per cent. of the real substance. It is an excellent fungicide and disinfectant, and is being more and more used; but as it is also a violent poison to plants it has to be used with care.

A solution containing 0·1 per cent. of the real substance—*i.e.*, about 1 quart of formalin to 100 gallons of water—has been recommended as effective for destroying fungi and their spores on grain, clover seed, &c. An hour's immersion of the seed in this solution is recommended. As a preventative of scab in potatoes, immersion of the "sets" for an hour in a solution containing 1 pint of formalin in 30 gallons of water is said to be effective. This solution would contain 0·167 per cent. of the real formaldehyde.

III. **Insecticides.**—By this term is understood a substance which can be used to kill insects or creatures similar to insects. The destruction may be accomplished in three ways:

(A) By poisoning the food eaten by the insects, or by absorption through their skin.
(B) By poisoning the air breathed by the insects.
(C) By suffocating the insects by stoppage of their breathing apparatus.

(A) Poisoning the Food.

Under Class A large numbers of chemical compounds may be included; in fact, nearly all which are poisonous to the higher animals are fatal to insects.

Among those most largely used for the purpose of destroying objectionable insects are the following:—

Arsenic.—This substance is never used in the pure elementary state, but in the form of its oxide, arsenious oxide, As_2O_3, or some compound containing this. Indeed, in common language "arsenic" or "white arsenic" is generally used to designate what the chemist would call arsenious oxide. This is a heavy white substance, not readily soluble in water, but dissolving easily in alkalies—*e.g.*, caustic soda or sodium carbonate solution, when the arsenious oxide is converted by the soda into sodium arsenite, or arsenite of soda.

Arsenious oxide is used as a vermin poison, and is fatal to most forms of animal and plant life. Certain low forms of vegetables, however, can develop in presence of considerable quantities of arsenic. This is the case with many moulds. But to higher plants arsenical solutions are quickly fatal, even when highly diluted.

In very small doses arsenic acts as a tonic upon animals, and confers by continued use an immunity to doses which under ordinary conditions would be sufficient to cause death. The administration of arsenic in small doses often produces a plumpness and sleekness of the skin, but is attended with the danger of setting up chronic poisoning.

As an insecticide both for animal and plant parasites arsenical compounds are largely used. They enter into the composition of many dips for sheep, cattle, &c.

Arsenic in Dipping Compositions.—In these the arsenic is usually in the soluble form of sodium arsenite. Though in many commercial dips other substances are also present, in the majority of arsenical dips the efficiency depends upon the amount of arsenic alone.

In South Africa particular interest attaches to the destruction of ticks on cattle and sheep, because of the transmission of disease by ticks. According to Lounsbury's experiments in Cape Colony,* it appears that to ensure the killing of *all* ticks the solution must contain about 1 lb. of arsenious oxide in 30 gallons of water—*i.e.*, 0·33 per cent.—though for practical purposes 1 lb. in 40 or 45 gallons (0·25 to 0·22 per cent.) is considered by him to be sufficient.

A preparation reported to be efficient in Queensland contains 1 lb. in 50 gallons—*i.e.*, 0·2 per cent.

In the same paper Lounsbury concludes that the addition of tar or soap to the arsenical dips has little or no effect upon their poisonous qualities.

He also gives a table from which it may be inferred that two well-known arsenical dips, Demuth's and Alderson's, contain about 11 and 46 per cent. of arsenious oxide respectively, and that when diluted in accordance with the makers' directions—viz., 1 lb. to 6 gallons and 1 lb. to 14—they yield a liquid containing arsenious oxide in the proportions of 1 lb. to 65 gallons and 1 lb. to 30 gallons respectively.

He also states that " Scrub exterminator," crude arsenite of

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* *Cape Agricultural Journal*, March 1905, p. 390.

soda, contains about 66 per cent. of arsenious oxide.* If diluted so as to contain about 1 lb. of arsenious oxide in 40 or 50 gallons of water it forms a thoroughly efficient destroyer of ticks.

Later, in the same journal, a dip containing

Arsenite of soda	5 lb.
Aloes	12 ounces
Soft soap	5 lb.
Water	100 gallons

is recommended. The aloes are merely added to render the dip distasteful, so as to lessen the risk of the animals drinking it. This dip contains about 0·3 per cent. of arsenious oxide.

The soft soap is thought to increase the effect upon the ticks by keeping the wool moist for a longer time after dipping, and for long-wooled sheep it is recommended that the soap be omitted.

If the animals are dipped in too strong an arsenical solution, or too frequently, poisoning through absorption of the arsenic by the skin may ensue. This is apparently most likely to occur with long-haired or long-wooled animals. Thus it occurs more readily with sheep than with cattle or horses. It is also said to be more likely to occur if the animals be dipped or sprayed while hot.

It is unnecessary, perhaps, to emphasise the need of care in using so poisonous a substance as arsenic, but every precaution should be taken to prevent animals drinking the dip, or licking or eating anything with which the arsenical preparation has been in contact.

Arsenic compounds are also largely used for the destruction of insects injurious to plants or vegetable products. Thus arsenious oxide is now strongly recommended for poisoning white ants. The most successful plan of using it for this purpose is to vapourise a mixture of sulphur and arsenious

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* My experience is that commercial arsenite of soda frequently contains about 56 per cent. of arsenious oxide.

oxide in a suitable apparatus, and force the vapours by means of a pump into the ants' nest. The vapour of arsenious oxide is intensely poisonous, and as it cools it impregnates the workings and their contents with a sublimate, which would be fatal to any insect which might escape the effect of the fumes and afterwards eat of the stores within the nest. An apparatus designed for performing this operation has been constructed. The material supplied with the machine consists of about 11 per cent. of sulphur and 89 per cent. of arsenious oxide, intimately mixed together. Arsenic, generally as sodium arsenite, is the basis of many preparations for the destruction of ants or preserving wood, &c., from their attacks.

Another important use of arsenic is for poisoning locusts. The plan adopted is to spray the grass or other vegetation in the neighbourhood of a swarm of "voet-gangers" with a solution containing

Arsenite of soda	1 lb.
Sugar	1 lb.
Water	8 to 12 gallons

The grass so sprayed, if consumed by the locusts, soon poisons them, or, if not, it quickly dies and dries. If eaten by cattle or sheep soon after spraying injury might result, but after a few showers of rain the arsenic is to a great extent washed off into the soil. Even if no rain falls the danger of cattle eating the poisoned grass is not great, as after a few days the grass dies and withers, and, except under stress of hunger, would be rejected by the animals. The poisoned insects are often eaten by poultry, locusts, birds, &c., and though they contain considerable quantities of arsenious oxide (in one sample we found 0·219 per cent. in the dried insects) they do not appear to do much harm to the birds. Nevertheless animals should be kept from access to the sprayed locality until after several showers, and the poisoned insects should be supplied in small quantities only, if at all, to poultry, &c., as there is undoubtedly some risk of poisoning, for arsenic is not a substance which is readily eliminated from the carcass by decomposition, as some poisonous substances are.

The arsenite of soda employed for this and other purposes may be prepared by boiling "white arsenic"—*i.e.*, arsenious oxide—with one-third of its weight of caustic soda or four times its weight of sodium carbonate (washing soda) and water until it dissolves; or it may more conveniently be procured already prepared in the form of a white solid.

About 9 ounces of "white arsenic" is equivalent to 1 lb. of sodium arsenite.

The sugar in the above formula is intended to make the poisoned material more attractive to the insects, and aids also in increasing the quantity which adheres to the grass or other vegetation.

Arsenic is also used for the destruction of caterpillars, grubs, &c., particularly on fruit-trees. In this case the use of arsenious oxide, arsenite of soda, or other readily soluble compound is excluded, because of the injury which such substances produce on the foliage.

Several almost insoluble compounds of arsenic are therefore employed, the following being the favourites:

Paris Green, "Schweinfurth's Green," or "Emerald Green."—An impure arsenite and acetate of copper, usually containing from 30 to 50 per cent. of arsenious oxide (in combination), but of very variable composition. Often a portion (2 per cent. or more) of its arsenic is in a soluble form. The best samples for spraying are those which contain the least soluble and the most insoluble arsenic. It is used in suspension in water, and applied by means of a spray pump, usually at a strength of 1 part of the solid in 2000 or 3000 of water. Obviously, to ensure good results the liquid must be kept in constant agitation, otherwise the Paris green will settle to the bottom. The injury to foliage due to the presence of soluble arsenic may be prevented by the addition of an equal weight of lime.

London Purple.—A mixture of arsenite of lime with colouring matter, obtained as a by-product in the manufacture of certain coal-tar dyes. It, like Paris green, is very variable in composition, but usually contains from 30 to 50 per cent. of arsenious oxide, of which often a considerable proportion is soluble in water. It is used in the same manner as Paris green, but unless lime be also added it is even more liable to injure foliage.

An arsenite of lime can be made by dissolving arsenite of soda in water, diluting largely, and then stirring in milk of lime containing about ten times the weight of lime as of the arsenite of soda taken. The lime is in large excess, but does no harm.

Lead Arsenate, which is insoluble in water, and therefore does not injure foliage, is very valuable as a spraying material. It can be bought ready prepared, or can be made as required from "sugar of lead" (*i.e.*, acetate of lead) and arsenate of soda —11 ounces of the former and 4 ounces of the latter, dissolved in separate portions of water. When mixed they give a fine white precipitate of arsenate of lead, which, when suspended in 150 gallons of water, can be sprayed on trees without fear of injury. Arsenate of lead is supplied either as a paste (usually containing about 12 per cent. arsenious oxide) or in powder. The former gives the better results.

Scheele's Green.—Copper hydrogen arsenite is also sometimes used for spraying. Like lead arsenate, it is very slightly soluble in water, and therefore has but little injurious action on foliage. It is, however, not often used as an insecticide.

Caution as to Use of Arsenical Preparations.—Arsenic compounds are so poisonous to man and the higher animals that it is of the utmost importance that they be used with care. Every precaution should be taken to prevent access of any of the arsenical solutions to foods, water, &c., which may afterwards be consumed by animals. The lethal dose of arsenious oxide depends very largely upon the individual; for man it has been given as probably 1 or 2 grains, for a horse perhaps 30 grains, for a cow 10 or 15 grains, for a dog about 1 grain. Authorities, however, differ very greatly as to the lethal doses. In readily soluble form—*e.g.*, sodium arsenite—it is much more powerful than as the oxide. As antidotes, emetics should be given, followed by a dose of recently precipitated ferric hydrate, prepared, as required, by adding ammonia or carbonate of soda to a solution of ferric chloride ("perchloride of iron"). Milk, eggs, olive oil, and barley-water are also useful.

Other poisonous substances sometimes used as insecticides are:

Carbolic Acid, phenol, C_6H_5OH (see p. 214). This is a violent poison, both to animals and plants, and as an insecticide has to be used with care, in order to avoid injury to vegetation.

On dormant fruit trees a wash containing about 1 lb. of the crude acid, 2 or 3 lb. of soft soap, and 2 gallons of water is sometimes used to destroy boring insects. A solution of carbolic acid is also sometimes used for preventing the attacks of insects—*e.g.*, the warble fly on cattle.

On account of its poisonous action on plants, it is probably not safe to use solutions stronger than 0·5 or at the most 1 per cent. It should not be allowed to touch the foliage.

Alkaline Sulphides.—These are very effective insecticides, but are also poisonous to the roots of plants and corrosive to foliage.

"Sulphide of potash," or "liver of sulphur," is really a mixture of sulphide and polysulphides of potassium, and is used in solution for spraying trees at a strength of from 2 to 4 per cent. More largely used is the sulphide of calcium, generally prepared, as required, by boiling lime and sulphur with water. The resulting yellow liquid contains in solution a mixture of various sulphides of calcium, and often some free lime.

This "lime and sulphur" wash or dip is largely used both by the horticulturist for the destruction of scale and other insects on trees and by the sheep-farmer for killing insect parasites, especially scab, on his animals.

There are many formulæ recommended, according to the particular plant and kind of insect to be dealt with. Thus a mixture for fruit trees is made by boiling 10 lb. of quicklime with 20 lb. of sulphur in about 20 gallons of water for about two hours, then mixing this with 40 gallons of water in which 30 lb. of lime and 15 lb. of common salt have been dissolved. This wash must only be used in winter, when the leaves are off.

For scab in sheep the so called "lime and sulphur dip" has some strong partisans, especially in Cape Colony. However it may be prepared (and the variations in the proportions of lime, sulphur, and water appear to be very great; thus, to 100 gallons of water quantities of lime varying from 4½ lb. to 20 lb., and of sulphur from 15 to 25 lb., are recommended by various correspondents, and the ratio of lime to sulphur varies from 1 : 1 to about 1 : 5), there can be little doubt that the dip is injurious to wool. All alkalies and alkaline sulphides have a strong caustic action on such organic substances as hair and wool, as is evidenced by the use of calcium sulphide in strong solution for removing hair, both for toilet purposes and also, on the larger scale, from skins prior to tanning. But, if the injury to the quality of the wool can be excused, there appears to be strong evidence in favour of the efficacy of the dip as a remedy for and preventative of scab.

It is of importance, however, to understand the principles of its preparation. As already stated, the really active ingredient is the calcium sulphide and polysulphide, though the free sulphur doubtless would be useful, especially as a preventative of re-infection. This free sulphur, however, can only be applied to the wool if the dip is well stirred during the operation of dipping, since it is quite insoluble in water, and this practice is rarely followed. When lime is boiled with sulphur the reaction results in the formation of calcium sulphide and calcium thiosulphate, as indicated by the equation:

$$\underset{\text{Lime}}{3CaO} + \underset{\text{Sulphur}}{4S} = \underset{\substack{\text{Calcium}\\\text{sulphide}}}{2CaS} + \underset{\substack{\text{Calcium}\\\text{thiosulphate}}}{CaS_2O_3}.$$

The calcium monosulphide, CaS, can, however, dissolve an additional quantity of sulphur, to form, finally, calcium pentasulphide, CaS_5, thus:

$$CaS + 4S = CaS_5.$$

So the maximum amount of sulphur which can be dissolved by boiling with lime and water is indicated by the equation:

$$3CaO + 12S = 2CaS_5 + CaS_2O_3.$$

Taking atomic weights $Ca = 40$, $O = 16$, $S = 32$,

$$3(40 + 16) = 168 \text{ lime.} \qquad 12 \times 32 = 384 \text{ sulphur.}$$

168 parts of pure lime can thus bring about the solution of 384 parts of sulphur—*i.e.*, 1 part by weight of lime suffices to dissolve 2·28 parts of sulphur, or 1 lb. of sulphur requires 0·4375 lb. of pure lime. Now ordinary lime is never pure; the proportion of real lime present varies from as low as 50 per cent., or even lower, to as high as 98 per cent., or higher. Hence those recipes which give lime to sulphur in less proportion than 1 to 2, even if the lime be of good quality, must leave a large proportion of the sulphur undissolved. With the usual qualities of lime the amount of sulphur in excess will be still greater, and when, as is generally recommended, the liquid is allowed to settle and only the clear portion used for dipping much sulphur is wasted. It is, on the other hand, desirable to avoid excess of lime in the dip, otherwise the injury to the wool becomes greater. The proper proportions of lime and sulphur to use will depend greatly upon the purity of the former. If the lime be white, freshly burnt, and slakes with considerable heat when water is added, it is probably fairly pure, and 1 part of lime to about 2½ parts of sulphur will be about the right proportion. But if "blue lime" be used, and especially if it be partly "air-slaked"—*i.e.*, has been kept for some time—equal weights of lime and sulphur will probably be better. In any case it will be safer to see that there is at the end of the boiling a *little* sulphur

undissolved, as this makes it less likely that there is excess of lime in the liquid.

Of course, in preparing 100 gallons of the dip the lime should be treated with only about 5 to 10 gallons of water, heated to boiling, the sulphur added in fine powder little by little, and the whole boiled for about two hours, or until most of the sulphur has disappeared. The strong solution of calcium sulphides and thiosulphate is then diluted to 100 gallons with water.

The dip should be used as soon after preparation as possible, as it absorbs carbon dioxide and oxygen from the air and the calcium sulphide and pentasulphide are decomposed. Many users have obtained better results by using the dip at a temperature of about 100° to 110° F. (38° to 43° C.). Each animal should remain at least two minutes in the dip.

Hellebore (*Veratrum album*).—The root of this plant contains several alkaloids, of which veratrine, $C_{32}H_{49}NO_9$, protoveratrine $C_{32}H_{51}NO_{11}$, and jervine, $C_{26}H_{37}NO_3$, are poisonous to animals. It is occasionally used as an insecticide, either in the dry, finely powdered state, often mixed with flour, or in water—about an ounce to 3 gallons of water. It is efficacious against leaf-gnawing insects, and is not so poisonous to animals or man as the arsenites.

Insect-powder is the finely powdered flower-heads of a plant Two species of plant are used—*Pyrethrum roseum*, the product from which is known as Persian or Caucasian insect-powder, and *Pyrethrum cinerariæfolium*, which yields Dalmatian insect-powder, or "buhach," as it is called in California. The Dalmatian product is said to be more effective than the Persian. It can be used dry, often mixed with three times its weight of flour, or in aqueous or alcoholic solution, also in fumigation. The substance can be used to destroy aphides, house insects of various kinds, and, especially by fumigation, for driving away mosquitoes and flies. For spraying solution 1 ounce of the powder is mixed with 2 or 3 gallons of water. A little alcohol is sometimes first added to the powder, and the mixture then diluted with water. Additions of ammonia and of soap to the liquid are sometimes made, and are said to increase efficiency. For fumigation the powder is scattered on hot coals or on a hot metal plate; this, of course, can only be effective in a closed space.

Several other vegetable products—*e.g.*, quassia chips—are used as insecticides, but their importance is not sufficient to justify detailed description here.

Other insecticides are substances which are more commonly used as disinfectants or antiseptics. To this category belong many coal-tar products—carbolic acid, Lysol, Izal, Jeyes' disinfectant, creasote, and many others.

Quicklime, calcium oxide, CaO, is sometimes used for killing snails, slugs, caterpillars, &c. It is only effective for this purpose when fresh and unslaked, and is best applied as fine powder, dusted on to the slugs or caterpillars. Lime-water, too, is useful as a destroyer of many caterpillars and worms. Lime will only dissolve in water to the extent of about 0·13 per cent.—*i.e.*, a gallon of water will only dissolve about one-fifth of an ounce of quicklime. Lime-wash—*i.e.*, about 2 lb. of lime to the gallon of water—is also used as a remedy against scale insects, being applied to the bark of trees.

(B) For Poisoning the Atmosphere breathed by the Insects

the principal substances used are the following:

Carbon Disulphide, CS_2, "bisulphide of carbon," a colourless, heavy, very refractive liquid, possessed of a strong, disagreeable odour recalling that of rotten cabbage. When perfectly pure, however, it has a pleasant, ether-like smell. Carbon disulphide is very volatile, and its vapour is very inflammable, becoming ignited, when mixed with air, at temperatures much lower than those required to set fire to most combustibles. A mixture of air and carbon disulphide vapour is very explosive, and may be ignited even by a glowing pipe or cigar. The vapour is heavy, and very poisonous to animals, including insects. On this account its vapour is particularly well adapted for killing subterranean insects or larvæ. It is often used for destroying ants. One or two ounces of the liquid poured down the holes, which should then be covered, will evolve a poisonous vapour which may penetrate into all parts of the nest.

It can also be used for the destruction of weevils in mealies or other grain. For this purpose the grain is placed in bins or tanks, sufficient carbon disulphide is either poured on to the grain or placed in a vessel on the top, and the bin or tank closely covered.

Insects on low-growing shrubs or trees may be destroyed by surrounding the trees with boxes to enclose the heavy vapour given off from a small quantity—half an ounce to an ounce—of the liquid placed in a saucer.

Sulphur Dioxide, SO_2 (see p. 213), cannot be used to destroy insect pest on plants, but is often employed for the destruction of bugs, cockroaches and other household insects.

Tobacco Smoke, or, better, the fumes from tobacco extract, is often used as an insecticide in greenhouses, &c.

Hydrocyanic Acid, HCN, "prussic acid," is a gas with a curious and characteristic, though not strong, odour. It is intensely poisonous to animals, but as, in small quantities, it is not fatal to plants *in the dark*, it can be and is extensively used for the destruction of insect pests on shrubs and trees.

The gas is made as required by the action of diluted sulphuric acid upon potassium cyanide. The reaction is:

$$\underset{\substack{\text{Potassium}\\\text{cyanide}}}{KCN} + \underset{\substack{\text{Sulphuric}\\\text{acid}}}{H_2SO_4} = \underset{\substack{\text{Potassium acid}\\\text{sulphate}}}{KHSO_4} + \underset{\substack{\text{Hydrocyanic}\\\text{acid}}}{HCN.}$$

Fairly pure cyanide is now easily obtainable (98 per cent. potassium cyanide), and ordinary oil of vitriol is suitable for the purpose. Before use the acid should be diluted with about one and a half or twice its volume of water. The proportions to use are about one part by weight of potassium cyanide to one and a half parts of sulphuric acid and two or three parts of water. The water should be placed in a glass or earthenware vessel, the sulphuric acid poured gradually in, with continuous stirring, and lastly, when all is ready, the cyanide should be dropped in, and the building or tent at once vacated.

For trees a tent made of canvas, rendered gas-tight by treatment with boiled linseed oil, is used to retain the gas, and the fumigation done at night. Usually from thirty to forty minutes' exposure to the gas is sufficient. The greatest care should be taken in dealing with such intensely poisonous substances as potassium cyanide and prussic acid. Caution to avoid breathing air containing the acid is particularly necessary. This method is also very successful in ridding houses, mills, &c., of insect pests of all descriptions. For trees the amount of cyanide to use is from 10 to 25 grams—*i.e.*, from $\frac{1}{3}$ to $\frac{7}{8}$ ounce—per 100 cubic feet of air space, depending upon the kind of trees. For buildings about 1 ounce per 100 cubic feet will generally be sufficient.

(C) The so-called Contact Poisons.

These are intended particularly for sucking insects, which, deriving their food from the interior of the host plant or animals, cannot be killed by poisoning their food. They, therefore, are destroyed either by clogging the breathing pores by some liquid or solid, or in some cases, perhaps, by absorption of the poison through the skin. Soap of any kind, and particularly potash or soft soap, is effective, being usually applied in from five to twenty times its weight of water.

Resin soaps are also employed, being made as required by boiling resin with caustic soda or potash solution, or with sodium carbonate (washing soda) solution. Generally some fish-oil or tallow is also used. Thus a common wash is made by taking:

Resin	20 lb.
Fish-oil	$\frac{1}{2}$ to 1 gallon
Caustic soda	8 lb.

These are placed in a boiler with a few gallons of water and heated to boiling, cold water gradually added, and the boiling kept up for about two hours, until there are about 30 gallons and all is dissolved. Then dilute to 100 gallons with soft water. Sometimes potash is substituted for soda, and tallow for fish-oil, and occasionally petroleum is also added. If the potash and soda are equally pure, 56 parts of potash are equal to 40 of soda.

Paraffin or petroleum emulsion is also very effective. It can be made with either soap solution or sour milk. For the former 1½ lb. of soap are dissolved in 2½ gallons of hot water, then 5 gallons of paraffin are added, and the whole violently agitated by a spray pump until an emulsion is formed. 1 gallon of the emulsion is then diluted with from 9 to 12 gallons of water.

The effect of the soap is merely mechanical, and the petroleum is not in any sense dissolved, but merely broken up into minute droplets and suspended in the water.

1 gallon of sour milk to 2 gallons of paraffin may also be emulsified, and afterwards diluted with water before spraying.

Some of the substances described under (A) also act as contact poisons, being probably absorbed by the insect through the skin. This is often the case with arsenic dips, calcium sulphide, sulphur, &c., when used for blood- or sap-sucking insects.

IV. **Plant Poisons.**—These are sometimes useful to kill weeds. A large number of substances act as poisons to plants. Among those which have been most largely used are the following:

Arsenic and Arsenite of Soda.—These have been described under "Insecticides." About 1 lb. of arsenious oxide or 1½ lb. of arsenite of soda to 10 gallons of water is the strength often used. If arsenious oxide be used it should be dissolved by boiling with water and about 2 lb. of soda. It should be applied in dry weather, and care be taken to keep cattle off the treated vegetation.

Salt.—Hot brine—1 lb. of salt to 1 gallon of water—is useful for killing weeds on paths, &c.

Calcium Sulphide (or any soluble sulphide—*e.g.*, fresh "gas-lime") is a powerful plant poison. For this purpose it is advisable to use excess of lime, so as to save waste of sulphur. 2 lb. of sulphur, 10 to 20 lb. of quicklime, and 10 gallons of water, boiled for an hour or two, are suitable quantities to use.

Sulphuric Acid.—Oil of vitriol, diluted with about 30 parts of water, will kill weeds. Care must be taken that the acid does not come into contact with iron vessels or be spilt on clothing, &c.

Carbolic Acid, Phenol.—An ounce of the commercial acid to a gallon of water will kill plants as well as insects.

All these substances render the soil barren for some time afterwards. With heavy rains, however, they will soon wash out. Additions of lime to the soil would cure the acidity due to sulphuric acid.

An example of a differential plant poison is afforded by the so-called "lawn sand" used for ridding lawns of daisies and plantains. The essential ingredient in lawn sand is sulphate of ammonia, and if it be applied in sufficient quantity—about 4 oz. per square yard—it will be found that broad-leaved plants, daisies, plantains, &c., are turned brown and killed, while the grasses, though, perhaps, at first slightly injured, soon recover and grow vigorously.

APPENDIX

Specific Gravities.—The most rational method of expressing the specific gravity of a solid or liquid is in terms of water—*i.e.*, by a number which expresses the ratio of the weight of any volume of the solid or liquid to that of an equal volume of water at a specified temperature.

This plan is always adopted for solids, but for liquids for technical purposes various empiric scales are employed.

In England Twaddle's hydrometers are often used for liquids heavier than water.

These are so constructed that the relationship between true specific gravity and degrees Twaddle is

$$d = \frac{\frac{n}{2} + 100}{100}, \text{ or } n = 200(d - 1),$$

where d = true specific gravity and n = degrees Twaddle.

The determinations are assumed to be made at 15·5° C. (60° F.).

Other hydrometers, based upon purely arbitrary and empiric systems, are also in use in various branches of industry, and it is to be regretted that they do not give way to a more rational method of expression of density.

Thus Baumé's hydrometer, for liquids heavier than water, is so constructed that it sinks to 0° in pure water and to 10° in a 10 per cent. solution of common salt, both at 17·5° C., and the scale is continued in a uniform manner down the stem.

For liquids lighter than water a Baumé's hydrometer is constructed so that in a solution of 1 part by weight of common salt in 9 parts by weight of water it sinks to 0°, while in pure water it sinks to 10°, the scale being extended further up the stem.

The following formulæ connect degrees Baumé with true specific gravity:

	For Liquids Heavier than Water.	For Liquids Lighter than Water.
At 12·5° C.	$d = \frac{145 \cdot 88}{145 \cdot 88 - n}$	$d = \frac{145 \cdot 88}{135 \cdot 88 + n}$
At 15° C.	$d = \frac{146 \cdot 3}{146 \cdot 3 - n}$	$d = \frac{146 \cdot 3}{136 \cdot 3 + n}$
At 17·5° C.	$d = \frac{146 \cdot 78}{146 \cdot 78 - n}$	$d = \frac{146 \cdot 78}{136 \cdot 78 + n}$

Other empiric scales are also in use. The relationships to real specific gravity of some of the principal ones are given below:

	For Liquids Heavier than Water.	For Liquids Lighter than Water.
Brix, at 12·5° R. (15·62° C.).	$d = \frac{400}{400 - n}$	$d = \frac{400}{400 + n}$
Balling	$d = \frac{200}{200 - n}$	$d = \frac{200}{200 + n}$
Gay-Lussac, at 4° C.	$d = \frac{100}{100 - n}$	$d = \frac{100}{100 + n}$
Beck, at 12·5° C.	$d = \frac{170}{170 - n}$	$d = \frac{170}{170 + n}$
Cartier, at 12·5° C.	$d = \frac{136 \cdot 8}{126 \cdot 1 - n}$	$d = \frac{136 \cdot 8}{126 \cdot 1 + n}$

d = true specific gravity.
n = degrees of the various hydrometers.

Thermometer Readings.—Though in modern science the Centigrade thermometer is coming more and more into general use, the much less convenient Fahrenheit and Reaumur scales are still often employed in ordinary life.

The relationships between the three scales is simple, it being only necessary to remember that the interval between the melting-point of ice and the boiling-point of water under a barometric pressure of 760 mm. of mercury is divided into 100° on the Centigrade, 180° on the Fahrenheit, and 80° on the Reaumur thermometers; and that while the scales commence at the lower temperature on the Centigrade and Reaumur thermometers, on the Fahrenheit instrument it begins at a point 32° below the melting-point of ice.

Hence

$$^\circ\text{C.} = \tfrac{5}{4}\,^\circ\text{R.} = \tfrac{5}{9}\,(^\circ\text{F.} - 32),$$

$$\text{or}\quad ^\circ\text{F.} = \tfrac{9}{5}\,^\circ\text{C.} + 32 = \tfrac{9}{4}\,^\circ\text{R.} + 32,$$

$$\text{or}\quad ^\circ\text{R.} = \tfrac{4}{5}\,^\circ\text{C.} = \tfrac{4}{9}\,(^\circ\text{F.} - 32).$$

On the continent of Europe many thermometers are graduated on one side in Centigrade, on the other in Reaumur degrees. With such an instrument an easy way of obtaining the temperature in Fahrenheit degrees is to add the readings in Centigrade and Reaumur degrees together, and then add 32.

Units of Length, Area, Volume, and Weight.—Our British system of weights and measures is absurdly cumbrous, complex, and inconvenient, and it is to be hoped that the whole of the civilised world will eventually resort to some simple and rational method of expressing lengths, areas, volumes, and weights. In agriculture, perhaps more than in other branches of commerce, English units are inconsistent, for there are such anomalies as selling grain nominally by volume (bushels and quarters) and then fixing definite weights, which necessarily differ with various products, for these volumes, and which are so arbitrary that they differ in various parts of the country.

Then even in our weights there are peculiar anomalies; *e.g.*, the hundredweight is 112 lb. in England, though usually

100 lb. (as its name implies) in America, South Africa, and other places.

The metric system, which is gradually gaining in popularity is free from many of the objections of our British units, and has the great advantage that the various units are connected together in a simple and uniform manner.

It is unnecessary to give here the fundamental units and method of decimal multiples and sub-multiples of the metric system, but the connection between metric and British units may be useful.

Units of Length.

1 centimetre = 0·393708 inch.
1 metre = 39·3708 inches = 3·2809 feet = 1·0936 yards.
1 kilometre = 3208·9 feet = 1093·63 yards = 0·62138 mile.

Or

1 inch = 2·53995 centimetres.
1 foot = 0·30479 metre.
1 yard = 0·91438 metre.
1 mile = 1·609315 kilometres.

Units of Area.

1 square metre = 1550 square inches = 10·764 square feet = 1·196 square yards.
100 square metres (1 are) = 1076·4 square feet = 119·6 square yards = 0·0247 acre.
10,000 square metres (1 hectare) = 11,960 square yards = 2·4711 acres.

Or

1 square inch = 6·45137 square centimetres.
1 square foot = 9·290 square decimetres = 0·0929 square metre.
1 square yard = 0·8361 square metre.
1 acre = 0·40467 hectare = 4046·7 square metres.

Units of Volume.

1 cubic centimetre (c.c.) = 0·061 cubic inch.

1 cubic decimetre (1 litre) = 61·028 cubic inches = 1·76 pints = 0·22 gallon.

1 cubic metre (1 kilolitre or 1 stere) = 61,028 cubic inches = 35·317 cubic feet = 1·308 cubic yards = 220·09 gallons = 27·512 bushels.

Or

1 cubic inch = 16·3862 cubic centimetres.

1 cubic foot = 28·3153 litres = 6·24 gallons.

1 pint = 567·93 cubic centimetres.

1 gallon = 4·54346 litres = 277·274 cubic inches.

1 cubic yard = 0·7645 stere or 764·513 litres = 168·49 galls.

1 bushel — 36·3477 litres.

Units of Weight.

1 gramme = 15·43235 grains = 0·035274 ounce avoirdupois.

1 kilogramme = 35·2739 ounces avoirdupois = 32·1507 ounces troy = 2·2046 pounds avoirdupois.

1000 kilogrammes (1 tonne) = 2204·621 pounds avoirdupois = 0·98420 ton.

Or

1 ounce avoirdupois = 28·3495 grammes.

1 ounce troy = 31·1035 grammes.

1 pound avoirdupois = 453·593 grammes.

1 pound troy = 373·242 grammes.

1 hundredweight = 50·802 kilogrammes.

1 ton = 1016·05 kilogrammes.

On the Continent crop yields are usually expressed in kilogrammes per hectare, which is approximately equal to $\frac{9}{10}$ of English pounds per acre.

In South Africa lengths, volumes, and area are usually expressed in Cape or Dutch measures.

Length.

The Cape foot = 1·033 English feet.
The Cape rood = 12 Cape feet = 12·396 English feet.
1 English mile (5280 English feet) = 5111·3 Cape feet = 425·944 Cape roods.
Approximately 1 Cape foot = $1\frac{1}{30}$ English feet.
1 English foot = 0·96786 Cape foot.

Area.

1 Cape square foot = 1·067 English square feet.
144 Cape square feet = 1 Cape square rood.
600 Cape square roods = 1 Cape morgen.
86,400 square Cape feet = 1 Cape morgen.
1 Cape morgen = 2·11654 English acres.
= 10244·054 square yards.
= 92196·486 English square feet.
1 acre = 0·47247 morgen = 283·48 Cape square roods.
1 square mile = 302·38 morgen.
1 hectare = 2·471 acres = 1·1675 morgen.

Volume.

1 muid = 3 bushels = 24 gallons.
1 Dutch gallon = ·7895 English gallon.
= 6·316 English pints.
1 English gallon = 1·2666 Dutch gallons.
1 leaguer = 16 anker = 152 Dutch gallons = 126½ English gallons.

Weight of a Bushel of Grain, &c.

The following are the approximate weights of a bushel (8 gallons, or 4 pecks, or 2219·7 cubic inches) of various grains of average density:

Wheat	63 lb.	(varies from 60 to 65 lb.)
Oats	42 ,,	(,, ,, 35 ,, 48 ,,)
Barley	55 ,,	(,, ,, 52 ,, 59 ,,)
Rye	54 ,,	

Mealies (maize)	60 lb.
English beans	66 „
Peas	64 „
Lucerne seed	61 „
Russian linseed	53 „
Bombay and La Plata linseed	52 „
Buckwheat	48 „
Sorghum	45 „
Castor beans	46 „
Pea-nuts	22 „

A bushel of the following substances weighs approximately the number of pounds stated:

Salt	65 lb.	Turnips	45 lb.
Lentils	63 „	Brewers' grains, wet	40 „
Potatoes	56 „	Bran	17 „
Cotton-seed meal	51 „	Malt culms	14½ „
Mangolds	45 „	Chaffed hay	8 „
Swedes	45 „	„ oat straw	5 „

In South Africa, farm produce is often sold per 100 lb., and the usual "ton" is the "short ton" of 2000 lb. Grain and potatoes are usually sold per bag or "muid" of 3 bushels.

A bag of mealies	is reckoned as	200 lb.
„ Kaffir corn	„ „	203 „
„ wheat	„ „	200 „
„ barley, oats or potatoes	„ „	163 „

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