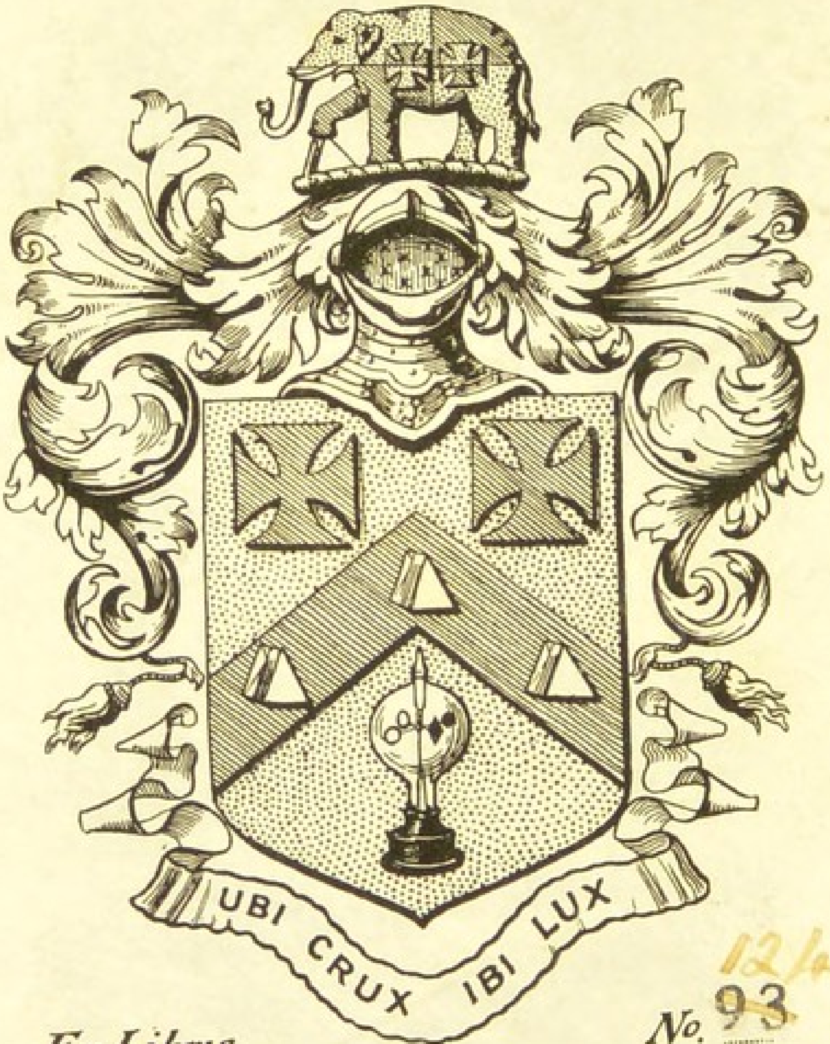
# CHEMICAL DIFFICULTIES
OF
# EVOLUTION

J. J. MACLAREN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# SOME CHEMICAL DIFFICULTIES

# OF EVOLUTION.

BY

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# PREFACE.

I HAVE endeavoured in the following pages to give persons who take an interest in the subject of Evolution, but who have not devoted any time to the study of chemistry, some idea of a few of the principal difficulties which the theory of Evolution, in the form in which it is generally put forward, presents to the chemical student.

Some of my readers will probably be surprised to find that these difficulties are so numerous and so formidable, and they have certainly not received that degree of attention from Evolutionists which their importance deserves.

In fact, it is startling to find, that in the nineteenth century, and in the very country where Graham, Williamson, Odling and so many other distinguished chemists have lived and worked, the speculations of a few naturalists, who have admittedly devoted no particular attention to the study of chemistry, should have been unhesitatingly accepted by a considerable portion of the educated public as the true solution of those most difficult and most obscure of all the problems which the chemistry of nature presents to us, namely, the origin and the mode of action of that mysterious power which we call life; and our surprise is certainly not lessened when we find that these speculations have been accepted without waiting for the opinion of the scientific chemists of the day, and that the faith of the believers is actually so strong that they have not hesitated to charge so bold and original a thinker, and so distinguished a philosopher, as Mr. Darwin, with being untrue to himself—nay, with want of moral courage—because he will not accept their supposed solution of these chemical problems as part of the body of established scientific truth.

I cannot help thinking that the present state of chemical science is in some degree to blame for the line which popular opinion has taken on this subject. Every work on chemistry which gives a full account of the principles which have been established, is filled, and necessarily filled, with a mass of repulsive-looking formulæ, and a wilderness of small details, which make it highly distasteful to the general reader, and which certainly render it difficult for him to pick out the special facts and to select the particular general principles which bear upon the subject of Evolution. I have therefore, in the following pages, endeavoured to collect these facts and principles, and to place them before my readers in a convenient shape, with the object of enabling those who have not devoted any time to chemistry to form a fair estimate of the difficulties which the Evolutionist has to meet before his theory can be ranked among the indisputable facts of science. I have purposely avoided the use of formulæ and of technical language as far as possible; and where the use of technical words could not conveniently be dispensed with, I have given definitions of the terms which will, I trust, make them both intelligible and useful to the general reader.

For the sake of greater simplicity I have divided the subject into three parts: in the first I have endeavoured to explain the nature of chemical action, where life is absent; in the second I have examined those more complicated cases where living beings take part in inducing the changes observed; and in the third I have attempted to point out the bearing of the principles explained in the first two parts upon the doctrine of Evolution and the views of Mr. Darwin, and to lay the difficulties which these principles raise fairly before my readers.

I have only, in conclusion, to remind those who have not made a study of chemistry that there is little or nothing novel in the chemistry which they will find in the following pages, and that the principles there stated are not mere speculations, but for the most part explanations founded on experiment and approved by the whole body of chemists; and, in fact, I have to ask the kind consideration of any chemical readers for that repetition of well-known facts and familiar principles which the plan of my work has imposed upon me. I have endeavoured to confine this repetition as far as possible to the first and second parts of my inquiry; and I would suggest that any such readers should pass over those parts, and turn at once to the third part, where I have discussed the theory of Evolution and the views of Mr. Darwin, with reference to the chemical compounds met with among the various forms of life.

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9, New Square, Lincolns Inn.
*March 2nd*, 1877.

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## CHAPTER I.

### INTRODUCTORY.

THE theory that all the forms of life which we find surrounding us have descended from a common ancestor, and that this common ancestor, this first of all living forms, was called into existence at a remote period of the world's history by the action of ordinary physical force on part of the non-living matter of which our globe consists, has lately attracted much attention, and has been accepted by a large number of persons.

That it has been so accepted is in great measure to be attributed to the views which Mr. Darwin has put forward with great force and ability in support of the position that the observed differences between species can in the main be accounted for by small variations perpetuated by descent, and preserved by the advantage they gave their possessors in the battle of life. Mr. Darwin, however, does not himself assert that all forms are descended from one, and that this form was called into existence by the action of ordinary physical force; these positions are "extensions" of Mr. Darwin's views, which, so far as the writer has been able to discover, have been obtained, not by making further experiments, but by framing theories from the facts which Mr. Darwin and his followers have collected and arranged in support of his views.

If now we take up one of the works in which these extended views are put forward, such as Hæckel's "History of Creation," two points will strike us as especially worthy of remark. (1) That our author professes to give a *complete* history of the origin and progress of life, to account for *all* the phenomena we observe among living beings, and to lay down an authentic pedigree for each living creature, which accounts for every peculiarity which this creature exhibits. (2) That in tracing the long chain of descent connecting the highest living being with the original form of life, the force of chemical attraction, and the laws which govern chemical combination, are referred to once, and once only, namely, where an appeal is made to the action of ordinary physical force to account for the production of the first living form. We are told that the appearance of this form was due to the production of a chemical compound, to which the names of "protoplasm" and "matter of life" have been given, and that the essentially living part of every creature, as distinguished from parts used for purposes of support, defence, and so on, is composed of this substance. When this has once been pointed out, the chemistry of life is entirely put on one side; we hear nothing of any differences between the chemical compounds met with among the various forms of life, nothing of any differences between the chemical results of the life of different forms of being; and the non-chemical reader might at least be pardoned for supposing that no such differences were met with in nature.

We need hardly say this is far indeed from being the truth. Many of the most important and essential parts of living beings, parts which are as absolutely necessary to the *continuance* of their life as the "matter of life" is to the existence of this life, differ extremely in chemical composition among different forms. Some of these compounds contain elementary substances which are altogether absent, not only from the other special compounds we have referred to, but actually from the "matter of life" itself. Others are marked by the possession of chemical properties so singular that the chemist is forced to consider them as among the most wonderful productions met with in the whole world of nature. And lastly, the occurrence of these special compounds is as marked and constant a point of distinction between different forms of life as any of those differences of shape and structure to which the author of the "History of Creation" devotes page after page.

It is plain, therefore, that in attempting to give any true and complete history of creation, the production and occurrence of these special chemical compounds, and the fact that they are respectively met with among some only of the forms of life, must not be left out of sight, and we propose in these pages to consider how far the arguments put forward by Professor Hæckel and the school to which he belongs satisfactorily account for the existence of these chemical compounds, and how far these "extensions" of Mr. Darwin's views are to be looked upon as of equal value with the position actually taken up, and the views put forward by that great inquirer into the facts which nature presents to us.

In reading the works of Professor Hæckel, or of any of the school of thinkers to which he belongs, we can hardly fail to be struck with the stress which is laid on the simplicity of structure of the lowest forms as compared with the higher forms of life. We are repeatedly told that the lowest forms are mere shapeless homogeneous lumps of the "matter of life," we are shown their extreme simplicity of form in powerful and effective contrast with the complexity of form exhibited by beings higher in the scale, and we are invited to believe that we have here reached something very simple indeed, and which does not require our further attention when we are considering the problems presented by the variety of the forms of life.

The sooner, however, we disabuse ourselves of the notion that these small shapeless lumps of the matter of life are really simple the better. Our author believes them to be so, merely because he has not examined them with sufficient minuteness. This cannot be done by the aid of the microscope, or of any dissecting instruments we are able to construct; it is necessary here to have recourse to chemistry to ascertain what the real nature of this apparently simple body is, and the results which chemistry gives are surprising indeed.

Chemical science has succeeded in proving that this "simple" body is really a building simple in outward form, but in fact composed of an enormous number of different blocks of the special building material which is called the "matter of life." But chemistry does not stop here, it further shows us that each of these blocks, so far from being homogeneous or simple, is really itself a most complicated piece of architecture, a highly finished and very elaborate building, composed of many different kinds of matter, and in which these different kinds are arranged and fitted together with a nice adjustment, with a skilful allowance for the different properties and qualities of the various distinct kinds of matter, and with a perfection of workmanship, which when studied cannot fail to excite our highest admiration.

We know how difficult it is found in practice to erect a building which is intended to be used for some exceptional purpose, if stone, metal, and wood are all employed in the structure.* Changes of temperature and other physical changes affect these substances differently, and it is found necessary to make allowance for these differences if we wish our building to be permanent. What then are we to think of an edifice where hundreds of portions of matter, among which are found at least five substances all differing extremely from one another in physical properties, are built up into a shape, in which each portion of matter forms an essential part of the whole, and is as it were a keystone of the edifice, and which is yet itself so perfect a specimen of workmanship that it can be used as one among almost countless millions of similar blocks in building up a structure which endures the ordinary alterations in surrounding physical conditions, without injury, and without becoming unfitted for the very special purpose of exercising those surprising chemical powers which we shall find form the real wonder of that which we call life ?

We shall scarcely be inclined to regard this structure as one of such simplicity that we need pay it no further attention; and we shall be the less inclined to do so when on trial we find that among the innumerable compounds which inorganic matter presents to us in nature, there is not one which even distantly approaches the complexity of structure and the elaborate architecture which the "matter of life" exhibits.

* Most of our readers will recollect the trouble which was caused by the unequal expansion of metal and stone under ordinary atmospheric conditions in the Holborn Viaduct, when it was first erected.

We propose in the following chapters, in the first place, to give a slight sketch of the manner in which the chemist conceives the substances, of which all the matter we see around us is composed, to be employed in building up any visible portion of such matter, and of the laws which govern the architecture of such buildings; we shall then examine how far, and under what conditions, these laws apply to the chemical products met with among living beings, and to the chemical actions which living beings effect by means of these products; we shall next compare the views which have been put forward to account for the phenomena of life; and we shall then consider how far the differences between the chemical products of living beings, when examined and estimated by the aid of the laws of chemistry, can be satisfactorily accounted for by those "extensions" of Mr. Darwin's views to which we have already referred; and lastly we shall inquire what is the bearing, if any, of these chemical points of difference, and of the laws of chemical combination generally, on Mr. Darwin's views themselves.

# PART I.

# CHEMICAL ACTION WHERE LIFE IS ABSENT.

## CHAPTER I.

### THE STRUCTURE OF MATTER—ATOMS AND MOLECULES.

LET us now see if we cannot gain some insight into the structure of the masses of matter which we find around us, and let us in the first place consider what facts we are already acquainted with, which may throw some light on the subject.

Three very familiar facts at once present themselves: these are, (1) that there are many different kinds of matter; (2) that matter is known to us in three very different states, the solid, the liquid, and the gaseous; (3) that the same kind of matter is frequently known to us in all three of these states.

This last fact clearly points to the conclusion that sensible portions of matter are possessed of structure of some sort. Such substances as ice, water, and steam are so unlike, that there must be some difference between them; and as we know that they are all really the same kind of matter under different forms, we can only attribute the visible differences which they present to differences in the manner in which any portions of these substances which our senses can perceive are put together.

Let us now examine the phenomena which are exhibited by a portion of some well-known substance in passing from the solid to the liquid, and from the liquid to the gaseous form, and let us select a piece of ice for our experiment. We will first employ ordinary mechanical force: we thus easily reduce the piece of ice to a powder, coarse at first, but gradually becoming finer, till at length we arrive at a degree of fineness beyond which we find we cannot get by ordinary mechanical means.

Here we remark that this fine powder shows properties which approximate to those shown by liquids, and which naturally lead to the idea that if we could go on making the powder finer and finer, we should ultimately obtain a liquid. Yet if we look at a particle of the powder through a microscope, we see at once that it is a piece of ice, differing in nothing but size from the piece on which we commenced our experiment.

Let us now call in to our aid the powerful force of heat, and apply this to our ice powder. This soon melts, and assumes the form of a liquid. But here we are at once struck by the fact, that though we have used a large quantity of heat force, the liquid is no higher in temperature than the ice powder was just before it melted. What then has become of the energy exerted by the heat force? There seems but one answer: it has been employed in altering the structure of the matter; in other words, in changing the ice powder into water. Now it is plain that the effect of the heat has not been simply to undo the work which we had previously effected when we reduced the ice to powder by mechanical means, and it is equally clear that the action of the heat has not been confined to separating the particles of the powder to a greater distance from one another. It is therefore certain that the energy of the heat has actually torn the particles of which the ice powder consisted into smaller fragments, and that the change in form is due to this subdivision of the particles of the pounded ice. It is almost unnecessary to add that the properties of the liquid entirely confirm this conclusion.

Let us now apply a greater amount of heat to the liquid we have obtained. This soon assumes the form of steam, and, just as before, we find the change accompanied by a great expenditure of heat force, without any corresponding increase of temperature. It is plain, therefore, that either the particles of which the water is composed have been further subdivided, or that the energy of the heat has been employed in increasing the distances between these particles. The sudden and enormous increase in bulk when the water was transformed into steam, the fact, which experiment proves, that while the external pressure remains constant every further increase in the amount of heat applied gives rise to a corresponding increase in the bulk of the steam, and above all, the fact that in each case of an increase of heat an increase of the external pressure on the steam will once more reduce it to the bulk it exhibited before the heat was increased, all point to the conclusion that the change in this case is due to change in the distances separating the particles of which the water consisted, rather than to any actual subdivision of such particles themselves.

We thus come to the conclusion that in passing from the ice powder to the water we have effected the utmost degree of subdivision of the actual particles of which the ice powder was composed, which the force of heat is capable of effecting; and here we remark the important fact that though we can effect a very considerable subdivision of the matter of which our original piece of ice consists, both by mechanical means and by the force of heat, this subdivision can only be carried to a certain extent, and that the limit is reached when we have reduced the ice powder to the form of water or steam.

Let us now avail ourselves of the powers of a third form of force. We will first reduce our piece of ice to the highest degree of subdivision to which the forces we have previously employed can bring it, by melting it, and we will then submit the water so obtained to the action of a galvanic current. The water is now once more transformed into the shape of gas. Let us collect this and examine it, and let us in the first place compare it, under like conditions of temperature and pressure, with the steam we previously obtained. It will at once be noticed that our new gas occupies exactly half as much space again as the steam did under similar external conditions. Experiment, however, shows us that our new gas behaves precisely as the steam did under changes of temperature and pressure, and we can therefore hardly believe that the increased space occupied by the new gas is due simply to increase in the distances separating the particles of which the water was composed, and it seems reasonable to conclude that the particles have themselves been subdivided by the action of the galvanic current. This naturally leads to the question whether there has been any other change. Is the matter of which the new gas is composed the same in kind as the matter of the ice, water, and steam? will it, when the action of the current is withdrawn, once more reproduce the water and the ice, as we know that the steam will when the heat is withdrawn?

We observe that gases are given off from both the positive and negative poles of the battery. Let us collect these separately, and let us then withdraw the action of the current. Unlike the steam, neither gas now reproduces the water or the ice; and what is still more surprising, if we mix them together they still fail to reproduce the water or the ice.

Again, on examining the portions of gas separately, and testing their properties by their action on a lighted match, we at once see that we have here two substances, which not only differ in kind from each other, but are both quite distinct in kind from the water or the steam from which they were derived.

We thus come to the conclusion, that in effecting a further subdivision of the particles of which the ice powder consisted, we have effected a change of kind, and have separated the matter of the ice into two distinct kinds of matter, each differing in properties from the matter of which ice, water, and steam are all alike composed. We have therefore proved that ice, water, and steam are in reality compound substances, and that we cannot go on subdividing the matter of the ice indefinitely without arriving at matter of a different kind. It is plain, too, that some portion of ice exists, which is so small that it cannot be subdivided without ceasing to be matter of the kind of which ice, water, and steam are all composed, and that the particles of which water and steam are made up are at least not far from being actually such small portions of the matter which cannot be subdivided without change in kind.

Even yet, however, we have not exhausted our experiment. On collecting and measuring the gases given off by the two poles of the battery separately, we shall find that one of these (to which the name of hydrogen has been given) always occupies double the space occupied by the other gas (to which the name of oxygen has been given), whatever be the quantity of water which the current may have transformed into gas; and further, on weighing the amount of the two gases, we shall find that the weight of the oxygen is invariably eight times that of the more bulky hydrogen.

Here we may remark that the balance shows that, throughout the experiment, the matter, whether in the shape of ice, water, steam, or mixture of hydrogen and oxygen gases, is never altered in weight; any suggestion, therefore, that change has been due, not to subdivision of the old matter, but to the introduction of new matter, may at once be put on one side.

To sum up the results of our experiment. The matter of which ice, water, and steam are all composed is susceptible of division to a very considerable, but not to an indefinite, extent. The smallest portion of this matter which remains unaltered in kind is composed of two substances, hydrogen and oxygen.

The proportions, both by weight and by volume, in which hydrogen and oxygen are present in any mass whatever of the matter of which ice, water, and steam are composed, are invariable. The weight of oxygen in a given bulk of ice matter is always eight times the weight of hydrogen in the same given bulk; and on the other hand, under fixed conditions of temperature and pressure, the volume of the hydrogen which can be extracted from the given bulk is always twice the volume of the oxygen which can be extracted from the same bulk.

Looking at these results, it is evident that in the course of our experiment there have been three very different stages in our subdivision of the ice-matter. In the first we merely broke the piece of ice into smaller pieces, each of which could again be broken up without change in kind; in the second stage we subdivided the matter into particles so small that these could not be again subdivided without change in kind; and in the third we succeeded in subdividing these particles, and arriving at the substances of which each particle was composed.

In the first two stages there was no change in kind, and such subdivision may fairly be called mechanical; in the third stage there was change in kind, and such subdivision is generally called chemical.

We may here observe that all efforts to subdivide the oxygen and hydrogen, and obtain matter of a different kind from either, have hitherto failed. And this naturally leads us to the question, what the true meaning is of those remarkable relations of weight and volume which we found to exist between the oxygen and hydrogen composing any given bulk of water. We will begin with the relation of the weights and we will see what light is thrown upon it by experiments on other bodies.

A long series of experiments on other kinds of matter has established the fact that the great majority of the substances surrounding us are compound, that is, can by proper means be separated into two or more substances of different kinds. Each of the substances obtained by the first operation of this kind can frequently be again divided into substances of different kinds, and so on; but in all cases known to us the progressive separation can only be carried a certain length: we soon arrive at bodies from which, like the oxygen and hydrogen of our experiment, no substance differing in kind can be extracted; and thus we finally come to the conclusion that every substance known to us is made up of one or more of these particular substances from which new kinds of matter cannot be separated, and which are called by chemists elementary bodies or elements. The number of these elementary bodies hitherto discovered is somewhat over sixty; some of these are extremely abundant, and form almost the whole of the matter which we see around us, others are so scarce as to be mere chemical curiosities; but in every case, whether the elements with which we are concerned are the commonest or the rarest, experiments on compounds give the following results:—

If we apply the test of the balance to the weight of the elements contained in different portions by weight of a compound of two elements, A B, we find that, whatever weight of the compound we may select for experiment, the proportion by weight of A to B in the substance is constant. If now we select portions of a compound of A with another element C for experiment, we shall find the same rule to hold good between the relative proportions by weight of A and C in the compound of these two elements; and what is still more remarkable, the proportion by weight in which A takes part in forming a compound with C is either the same as the proportion by weight in which A takes part in forming the compound with B, or bears a simple numerical relation to such proportion. Again, if there are two or more distinct substances composed of the elements A and B known to us, the proportions by weight of A and B in each of these compounds bear a simple numerical relation to the proportions by weight of the two elements in the most simple compound which they form.

A long series of experiments has proved that these relations of proportion by weight hold good, whatever the elements may be which can be obtained from the compound on which we experiment, and also whatever the number of different elements may be which take part in making up the compound substance.

Experiment has also proved that the weight of a portion of any compound is always the sum of the weights of the portions of the elements which united to form this portion of the compound. Thus, if weights $w$ and $w'$ of the elements A and B unite to form a compound C, the weight W of the portion of C formed will always be given by the equation $W = w' + w$.

Experiment on other bodies has thus shown us that the relations which we found to exist between the weights of the oxygen and hydrogen composing any given bulk of water are mere instances of a general law which applies to all elements and to all compounds. Let us see if we can give any explanation which will account for these wonderful facts. It will readily be seen that these relations of weight between the proportions in which the elements unite in producing the almost infinite number of different compound substances known to us would be the obvious and necessary consequence of the properties of the elements themselves, if the following suppositions as to the structure of compound bodies, and the manner in which they are built up out of the elements, were admitted.

(1) The smallest portion of an elementary body capable of entering into combination with other elementary bodies, and forming compound substances with them, is a definite mass of fixed and invariable weight in the case of each element.

(2) More than one such mass of any particular element frequently takes part in building up a compound substance.

(3) The only portions of elements which combine together are these small definite masses of a weight which is in each element fixed and invariable.

(4) All compound substances are produced by the aggregation of a greater or smaller number of such definite masses of elementary bodies.

(5) The smallest portion of a compound substance which can exist as such contains a definite portion of invariable weight of each of the elementary bodies which take part in producing the compound.

(6) Any visible mass of a compound substance is made up of an aggregation of such smaller portions of the compound substance.

(7) The nature and properties of a compound substance are affected by the nature and number of the small definite masses of the elements which combine together to produce the smallest portion of the compound which can exist as such.

These suppositions are in fact a statement of the well-known "Atomic Theory" which is generally received by chemists as accounting for the experimental facts we have been considering; and there can be little, if any, doubt that this is in truth that explanation of which we were in search.

The definite mass of invariable weight of an elementary substance which upon this theory is the portion which takes part in building up compounds is called the "atom" of the elementary substance. The smallest portion of the compound which upon this theory can exist as such is called the "molecule" of the compound. Its weight is evidently the sum of the weights of the atoms of which it is composed.

These definitions of the atom and the molecule show us that if we can accurately ascertain the smallest proportion by weight in which any particular element A enters into combination with other elements, and if we then proceed to compare this with the smallest proportion by weight in which hydrogen also enters into such combination, the ratio thus obtained will be identical with the ratio which the weight of the atom of A bears to the weight of the atom of hydrogen. Hence we have

$$\frac{\text{Smallest combining proportion by weight of A}}{\text{Smallest combining proportion by weight of hydrogen.}} = \frac{\left(\text{Weight of atom of A.}\right)}{\left(\text{Weight of atom of hydrogen.}\right)}$$

Experiment has shown us that hydrogen is the lightest of all known bodies, and the weight of its atom thus gives us a convenient unit of weight. Taking this then as our unit, the equation which we have written down gives us the means of calculating the weight of the atom of A in terms of the weight of the atom of hydrogen. These calculations have been made for the various elements, and the numbers which have thus been obtained are called the atomic weights of the elements; a table of these will be found in any modern work on chemistry, to which we refer the reader for further details.

The weight of a molecule, expressed in terms of the same unit of weight, is obviously the sum of the atomic weights of the elementary atoms composing it. The weight so expressed is called the equivalent or atomic weight of the molecule.

Having thus defined atoms and molecules, and explained how the chemist has succeeded in comparing their relative weights, let us return to our old experiment upon the piece of ice, and consider the bearing of those facts which led us to conclude that there was a limit beyond which we could not push the subdivision of the ice-matter without arriving at substances of a different kind, and that this limit was nearly, if not quite, reached when we had carried the subdivision so far that the ice had assumed the form of water or steam.

Experiment has shown that steam and all other gases possess some properties so remarkable, and which throw so much light on the question of the existence and nature of the molecule, that it will be convenient to notice these before we proceed further.

(1) If no chemical change takes place, an increase of heat causes no further change of form in the gas. If the external pressure remains constant, the only effect of increasing the heat is to increase the space occupied by the gas, which can in this way be reduced to the most surprising tenuity.

(2) When portions of two different gases are brought together, and no chemical change takes place, the space occupied by either gas is as a vacuum to the other. Each gas ultimately distributes itself over the whole space precisely as if the other were absent.

(3) If the pressure remains unchanged while the temperature is increased, the ratio of the resulting increase of volume to the original volume is in the same proportion to the increase of temperature, whatever the chemical nature of the gas may be upon which we are experimenting. Thus if V be the volume of any gas whatever, at a given pressure and temperature, V′ the volume of the same quantity of this gas at the same pressure, but at a temperature increased by $t$ degrees

$\frac{V'-V}{V} = a\,t$, where a is the same for all gases.

(4) If the pressure and temperature are kept con-

stant, the weights of any portions of the same gas are directly proportional to their respective volumes. If the temperature is kept constant, but the pressure varied, the volumes of the same portion of gas at different pressures are inversely proportional to the pressures.

(5) The weights of equal volumes of different gases, under like conditions of temperature and pressure, depend upon the nature of the different gases examined.

Lastly, the balance shows that if we take a given weight of any particular substance, this weight remains unchanged, whatever may be the change in the outward form of the substance; it is immaterial whether we pass from the solid to the gas, or from the gas to the solid, in either case, and under all conditions, the weight remains unaltered.

It is obvious from the first four of these properties that the condition of a body in the state of a gas is strikingly different from its condition when in the state of a fluid or a solid; the received explanation is as follows:—

(1) Every portion of a substance which is sufficiently large to be appreciable to our senses is mechanically built up of small particles of the particular substance we are examining; which are all of the same kind and of the same fixed weight. Such a small particle is called a molecule.

(2) The molecules of a substance when it appears in the state of a solid or a liquid are separated from each

other by spaces small in comparison with the size of the molecules themselves, and cannot move about or be displaced without being impeded or interfered with by the adjoining molecules.

(3) The molecules of a substance when it appears in the gaseous form are separated from each other by spaces large in proportion to the size of the molecule, and are so remote from each other that each molecule can be moved or displaced to a considerable extent without being impeded or interfered with by the adjoining molecules.

(4) Equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules. (Law of Ampère or Avogadro.)

The molecule of a compound body thus conceived is still a portion of the compound body possessing all the properties of the compound as such, and it must therefore contain a portion of each of the elementary substances which take part in forming the compound; and to this extent, and in the fact that it is of invariable weight in the case of each particular substance, it resembles the molecule, which the atomic theory led us to believe was the starting-point in the building up of sensible masses of the compound substances around us.

Two questions here present themselves: Is the molecule of a compound as defined by laws (1) to (4) identical with the molecule as defined by the atomic theory?

What is the atomic constitution or structure of the molecule, as defined by laws (1) to (4), in the case of the elementary bodies themselves?

Let us examine the phenomena exhibited when equal volumes of the two elementary gases, hydrogen and chlorine, taken under like conditions of temperature and pressure, are caused to act chemically upon each other.* In this instance we find that the whole of each gas present takes part in the chemical action, and that when this is completed the hydrogen and chlorine have altogether disappeared as such, leaving, as the sole result of the change, a new gaseous substance, which is a compound of the two elements, and has received the name of hydrochloric acid. If now we observe the compound gas formed when under the same conditions of temperature and pressure as those of each component gas previous to the experiment, we find that the hydrochloric acid occupies exactly double the space which was occupied by either of the component gases. Hence, by Ampère's law, there are just twice as many molecules of the compound as there are either of hydrogen or chlorine in the quantities of these gases used. But each compound molecule contains some portion, one atom therefore, at least, of hydrogen, and some portion, one atom therefore, at least, of chlorine. Hence there are at least twice as many atoms of hydrogen present in the volume of hydrogen used, as there are molecules; and since both atom and molecule of hydrogen are of constant weight,

* See Hofmann's "Modern Chemistry," pp. 152-3.

each molecule of hydrogen must contain two atoms at least. Similar reasoning proves that each molecule of chlorine contains two atoms at least.

Now by Ampère's law the weight of a fixed volume at a given pressure and temperature of any specified gas is directly proportional to the weight of the molecule of this gas. Hence, if we wish to compare the weight of the molecule of hydrochloric acid with the weight of the atom of hydrogen, or, in other words, to express the weight of the molecule of our compound in terms of the weight of the atom of hydrogen, we must compare the weight of any particular volume of hydrochloric acid with the weight of half the same volume only, at the most, of hydrogen. Making the comparison, we find that the volume of the compound weighs 36.5 times as much as the half-volume of hydrogen.

Let us now turn to the table of atomic weights which we shall find in any modern work on chemistry. The atomic weight of hydrogen is of course 1, and we see that 35.5 is given as the atomic weight of chlorine. Hence the weight of a molecule which contained one atom of hydrogen and one atom of chlorine, if expressed in terms of the atom of hydrogen as the unit of weight, would be 36.5.

It is therefore plain that the experimental results which showed us that the molecule of hydrogen contains more than one atom, and that the volume of hydrochloric acid weighs 36.5 times as much as the half-volume of hydrogen, will both be accounted for if we make the supposition that the molecule of hydrogen contains two atoms, and that the molecule of the compound (which we know contains some portion of each element) is built up of one atom of hydrogen and one of chlorine.

Similar reasoning leads us to infer that the molecule of chlorine also contains two atoms; but if this be the case, the original volume of chlorine used ought to weigh exactly 35.5 times as much as the original volume of hydrogen, and on testing this by our balance, we find that this is actually the relation between the weights of these volumes. We can hardly believe that this coincidence is accidental, and the hypothesis that the molecule of hydrochloric acid contains one atom of each of the component elements, and that each molecule of hydrogen and chlorine contains two atoms of the element, has therefore been generally adopted. Let us now analyse the hydrochloric acid, and ascertain what is the chemical composition of its molecule as defined by the atomic theory. We find that the proportion by weight in which the hydrogen is present, as compared with that in which the chlorine is present, is as 1 to 35.5, or, in other words, as the numbers are the atomic weights of these elements, that the molecule of hydrochloric acid, as defined by the atomic theory, also consists of one atom of hydrogen and one atom of chlorine, and we have therefore good reason for concluding that in the case of hydrochloric acid the molecule as defined by laws (1) to (4) is identical with the molecule as defined by the atomic theory.

A similar examination of the phenomena exhibited when other compounds, such as steam, are formed by the union of elementary gases, leads to precisely analogous results, and we are irresistibly led to the conclusion that the answers to our questions are—

(1) The molecule of compounds as defined by laws (1) to (4) is identical with the molecule of the atomic theory.

(2) The molecule of many elementary bodies is composed of more than one atom. Our experiment has shown us that each molecule of hydrogen and chlorine contains two atoms. Similar reasoning founded on experiment leads to the result that the greater part of the elementary bodies known to us, which can be examined in the gaseous state, form molecules consisting of two atoms of the element.

Cases are however known where the molecule of an elementary body contains three atoms, four atoms, and even six atoms, and cases are also known where it contains only one atom. The importance of these results will be better seen when we have discussed the phenomena of quantivalence, to which we shall presently ask the reader to turn his attention.

Here, however, we cannot help remarking how completely the results which we have obtained from the examination of the relations by weight between the proportions of oxygen and hydrogen in any given bulk of water, and of the properties exhibited by steam and other gases, agree with and explain those other remarkable relations which we found to exist between the proportions by volume in which oxygen and hydrogen are combined together to form water. Experiment has proved that the molecule of oxygen, like the molecule of hydrogen, contains two atoms, and consequently, by Ampère's law, any volume V of either of these gases contains $2\,n\,V$ atoms of the element (where $n$ represents the number of molecules of each gas present in the volume V). Now let us return to our experiment on the ice-matter, and let us suppose that we have decomposed such a quantity of water that the volume of oxygen produced is exactly V. Our experiment showed us that the volume of the hydrogen is always twice the volume of the oxygen obtained from the decomposition of any quantity of water; the volume of the hydrogen produced is therefore $2\,V$. Hence the whole number of atoms of hydrogen present is $2 \times 2\,n\,V = 4\,n\,V$. Let $w$ be the weight of an atom of oxygen, in terms of the weight of an atom of hydrogen, as the unit of weight. Then, since each atom and molecule has a fixed and invariable weight,—

Weight of whole amount of hydrogen = sum of weights of atoms of hydrogen present $= 4\,n\,V$;

Weight of whole amount of oxygen present = sum of weights of atoms of oxygen present $= 2\,n\,V\,w$.

Now if we look at a table of the atomic weights of the elements, we find the atomic weight of oxygen is 16, and the value of $w$ is therefore 16, if all the weights are estimated in terms of the weight of the atom of hydrogen. Hence the whole weight of hydrogen produced is to the whole weight of oxygen produced as $4\,n\,v$ to $2\,n\,v\,16$,

$$\text{or} \qquad \frac{\text{weight of hydrogen}}{\text{weight of oxygen}} = \frac{4\,n\,v}{2\,n\,v \times 16} = \frac{1}{8}$$

or the oxygen produced ought to be eight times as heavy as the hydrogen produced; but as our balance showed us, this is in very truth the relation between the weights of the oxygen and hydrogen obtained, and we see at once that those relations which we found to exist between the proportions by weight of oxygen and hydrogen in any given bulk of water, and those other relations which we found to exist between the proportions by volume in which the gases existed in the same bulk of water, are not isolated and unconnected properties of the water, but that both are really consequences of the one fact that the water is built up of molecules, each of which is in its turn built up of atoms of oxygen and hydrogen in a fixed and constant proportion.

Numerous other cases have been examined where the products of the decomposition of some substance into the elements of which it is composed are obtained in the condition of gas, and in all these cases the relations between the volumes of the elements obtained, and the weights of these volumes, show the same wonderful agreement with the theories we have stated, and it must be admitted that these coincidences place the truth of these theories beyond any reasonable doubt; but even here the evidence in their favour does not end; a third and totally distinct line of experiments leads substantially to the same conclusions.

It had long been known that equal weights of different substances under similar surrounding conditions required very different amounts of heat to raise them one degree in temperature, while equal weights of the same substances under the like conditions were invariably raised one degree in temperature by the same amount of heat, and this difference in the power of absorbing heat appeared to be in some way connected with the different nature of the substances operated upon.

Some philosophers who had studied the subject of heat, in a happy moment conceived the idea of examining how much heat was required to raise the temperature one degree in the case, not of equal weights of different substances, but of weights bearing the same ratio to one another as that which existed between the atomic weights of these substances.

The result obtained was, that, when these weights were taken, the amount of heat required to raise each substance one degree was constant; and the theoretical conclusion which has been deduced from this, and which is now, we believe, universally accepted by those who have studied the theory of heat, is that the substances surrounding us are built up of atoms and molecules in the same way as that in which we have been already led to conclude they were constructed by our examination of the proportions in which the elements combine, and of the peculiar properties of gases.

We must refer the reader for details of these experiments, and of the conclusions deduced from them, to works on heat or on molecular science; they are too abstruse for a work like the present. Here we need only refer to the value of the confirmation they have given to the theories which we have already stated.

We have thus seen that the chemist conceives matter as existing under two forms—first, the molecule, which may be defined as the smallest portion of any substance, elementary or compound, which is actually met with in nature as a separate portion of matter; secondly, the atom, which may be defined as the smallest portion of an elementary substance which is capable of entering into combination with other elements, and which the chemist believes to exist from the phenomena exhibited by molecules, though no actual direct evidence of its existence as a separate entity can be produced. And here we must ask the reader to place these conceptions of the "molecule" and the "atom" distinctly before his mind, and to note that chemists use these terms simply to express the results of actual experiment. These words do express the experimental result that substances which appear to us to be distinct kinds of matter unite to form the various material masses which we see around us; but they are not intended to express, and are not used as expressing, any theory as to the ultimate nature of matter, or as to the question whether matter is infinitely divisible or not. The molecule and the atom with which the chemist deals must be carefully distinguished from that hypothetical body, the ultimate indivisible "atom," with which some philosophers set out when they amuse themselves with building worlds, and which seems to have a vague likeness now to the molecule and now to the atom of the chemist. The two conceptions of the atom have in truth no other resemblance than the accidental one of identity of name; the chemist finds his atom in his balance, the philosopher finds his in his own imagination. Such an ultimate indivisible portion of matter may exist, but chemistry knows nothing of it, and is not in any way concerned with it. The science of chemistry does not depend upon the truth of any such supposition as to the nature of matter, but stands upon the firm ground of actual experiment with the balance, and, like astronomy, is really founded on the law of gravitation. In the following pages the word atom will be used in its strict chemical sense only, to denote that portion of matter which forms the basis of chemical combination.

The reader will probably ask, Has no attempt been made to ascertain the actual dimensions of the molecule of any substance, of water for instance? We answer, The attempt has been made; the undulatory theory of light has furnished the great physical philosophers of our time with a measuring rod which they have applied even to these almost inconceivably minute bodies. Sir William Thompson, of Glasgow, tells us that in his opinion the diameter of a molecule of water lies somewhere between the $\frac{1}{250,000,000}$ and the $\frac{1}{500,000,000}$ of an inch; and in order to give us some idea of the degree of coarse-grainedness of a drop of water, Sir William adds that if we conceive a drop of water as large as a pea to be magnified to the size of the earth, each molecule being magnified to the same extent, the magnified structure would be more coarse-grained than a heap of small lead shot, but less coarse-grained than a heap of cricket balls. (See Cooke's "The New Chemistry," pp. 34, 35.)

Now we know that our best microscopes will but just make lines drawn 112,000 to the inch, appreciable to our eyes. No wonder then that in dealing with protoplasm the microscope and the dissecting needle have alike failed to give the operator any real insight into the true molecular structure of the matter on which he was experimenting, and that the evolutionist, having arrived at the simple lump of protoplasm, thought he had arrived at something so simple, so without structure, that he need not investigate further, and that he might choose this body as the starting-point, the foundation-stone, as it were, of his theory.

No wonder, on the other hand, that the chemist does not here go with the evolutionist, and that he fails to see that the molecule of protoplasm, which analysis shows him is one of extraordinary complexity, containing in all probability hundreds of atoms, all built up into one marvellous structure, is so simple and so completely known to us, that we can safely take it as the starting-point of a theory, and found elaborate arguments on the basis of the simplicity of this body.

It is true, we have no means of estimating the actual size of a molecule of protoplasm, as we have not been able to obtain this body in a condition fitted for such experiments, but Ampère's law clearly points to the conclusion that all molecules are at least comparable in size, and there can be no doubt that the molecule of protoplasm is far too small to be rendered visible by any microscope we can construct.

## CHAPTER II.

THE ATOMIC STRUCTURE OF MOLECULES—QUANTIVALENCE — MOLECULAR EQUILIBRIUM — CAUSES OF CHEMICAL CHANGE.

So far we have established the fact that the substances we see around us are built up of molecules, and that each of these molecules is in its turn built up of atoms. It still remains to consider whether we can ascertain anything with regard to the manner in which the atoms of the different elementary bodies take part in building up molecules. Until a comparatively recent period this subject was one of great obscurity, but very considerable light has of late been thrown upon it by the study of those remarkable properties of the atoms which chemists comprise under the general term quantivalence, and to which we will now ask the reader to turn his attention.

If we examine more minutely than we have hitherto done into the manner in which atoms of different kinds unite in building up molecules of compound substances, we find at once that for the purposes of what for want of a better term may be called the architecture of molecules all atoms do not play equal parts. For instance, an atom of oxygen goes as far in completing the building up of any molecule in which it takes part as two atoms of hydrogen or of chlorine. Similarly an atom of boron goes as far in completing the building as three atoms of hydrogen or chlorine, and so on; and in the same way in breaking up or altering the molecules by removing some of the component atoms, and replacing them in the molecule by others of a different kind, we find that in the new structure when complete an atom of oxygen has taken the place architecturally of two atoms of hydrogen or chlorine, an atom of boron of three atoms and so on. The bodies of highest architectural value known to us can take the place of as many as six atoms of hydrogen or chlorine. Such bodies can take the place of three atoms of a body such as oxygen, and of two atoms of a body such as boron ; and similar relations exist between the architectural values of all the elements whose atoms can replace more than one atom of hydrogen in a molecule. Experiment has proved that no atom has a lower architectural value than the atom of hydrogen, and this element has therefore been chosen as the standard of reference.

It must be kept in mind that this difference in value for what we have called architectural purposes has nothing to do with the relative power of the chemical attractions between elements of different kinds. For instance, it by no means follows that because an atom of oxygen, in combining with some particular substance, goes twice as far towards completing a compound molecule as an atom of chlorine does in combining with the same substance, that the attraction of oxygen for this substance is double that of chlorine. On the contrary, the results of innumerable experiments show that this power of taking a greater or less share in the building up and completing a compound molecule out of elementary atoms of different kinds is independent in the case of each element of the intensity of the whole chemical attraction which this element can exert upon other elements, and that the architectural value of the atom of each element is either a constant quantity or follows a very simple law of variation, whatever may be the nature of the compound molecule in the building up of which the atom takes part.

Experiment shows that an atom capable of doing the work in molecular architecture of six atoms of hydrogen may also be found in the architecture of another molecule of a different kind doing the work of four atoms of hydrogen only, or even of two only, but is never found doing the work of five or three atoms or one atom of hydrogen. Similarly experiment shows that an atom capable of doing the work in molecular architecture of five atoms of hydrogen may in other molecules of a different kind be found doing the work of three atoms or of one atom of hydrogen, but is never found doing the work of four or two atoms. Similar relations are found to exist between the relative architectural powers of all atoms capable of doing the work of more than one atom of hydrogen, when their values in completing a molecule are compared.

The maximum amount to which the single atom of any element can do the work of atoms of hydrogen in building up and completing compound molecules is called the quantivalence or the maximum quantivalence of the element, and the particular amount of architectural work which the single atom may be doing in any particular molecule is called the active quantivalence of the atom in the particular case.

The laws governing quantivalence as deduced by experiment may be stated as follows:—

The (maximum) quantivalence of each element is a constant quantity.

The active quantivalence of an element in the molecules of any particular compound is a constant quantity.

The active quantivalence of an atom of any element in any molecule whatever is either the maximum quantivalence of the element or a quantivalence less than the maximum by 2, 4, etc., that is, decreasing from the maximum in an arithmetical progression where the common difference is 2.

It is usual to call elements monatomic, diatomic, triatomic, etc., as their maximum quantivalence is 1, 2, 3, etc., that is, as they possess the architectural power of taking the place of 1, 2, 3, etc., atoms of hydrogen. An element or atom having a higher quantivalence than 1 is also called a multivalent atom.

If we suppose the manner in which an atom of hydrogen or any other monatomic body takes part in building up a molecule to be represented by a single clamp or bond of connection, by means of which the atom of the monatomic body holds on to the other atoms making up the molecule, and in other elements represent each increase of quantivalence, that is, each power of doing the work of an atom of a monatomic body in completing the structure of a molecule, by the addition of another clamp or bond for each atom of a monatomic body which the single atom of the particular element under consideration can replace in molecular architecture when at its maximum of quantivalence—*e. g.* representing an atom of hydrogen as $\bigcirc-$ an atom of oxygen as $-\bigcirc-$ an atom of boron as $-\overset{|}{\bigcirc}-$ and so on—and if we make the further assumptions (1) that each clamp or bond in any atom can only unite or attach itself to one clamp or bond of another atom, and (2) that atoms can only unite by these clamps or bonds, it will be seen that atoms connected by our hypothetical clamps or bonds would give rise to molecules precisely identical in chemical composition with those which we find actually existing in nature, provided we confined our comparison to molecules in which all the component atoms are at their maximum of quantivalence. If, however, we make the further supposition with regard to our hypothetical bonds, that (3) in multivalent atoms two clamps or bonds belonging to the *same* atom are capable at times of uniting or attaching themselves to one another, and thus become for the time unavailable under (1) for the purpose of hooking on to other atoms, it is equally evident that atoms connected together by our hypothetical bonds would give rise to molecules precisely identical in chemical composition with those actually existing in nature, even when we extend our comparison to any molecule, whatever may happen to be the active quantivalence of any of the atoms composing it.

Let us now examine into the relations between the atoms composing the molecules of different substances, on the supposition that the actual molecules are replaced by molecules built up of atoms which are connected by hypothetical bonds governed by the laws (1) (2) and (3).

Experiment on innumerable substances has shown that for all compound molecules with which we are acquainted the following remarkable laws hold good:—

(A) The integrity of every complete molecule depends on the multivalence of one or more of its atoms, and no such molecule exists unless its parts are bound together by these atomic bonds or clamps.*

(B) No element exists in combination with any of its bonds or clamps disconnected.†

It will be observed that we have made no supposition as to the nature of the chemical forces acting between two atoms, or the manner of action,

* Cooke, "The New Chemistry," p. 244.

† Frankland's "Lecture Notes for Chemical Students," pp. 18, 19.

or direction, or arrangement of these chemical forces: all that we state is that the result of experiment shows that atoms connected by hypothetical bonds governed by laws (1) (2) and (3) would build up compound molecules precisely identical in composition with those met with in nature.

What then is the real meaning of the remarkable results (A) and (B)?

The molecule is really held together by chemical forces, or, as they are sometimes called, chemical affinities, as to the mode of action of which we know little or nothing, and not by bonds or clamps. Let us however make the supposition that (3) is actually represented in nature by the law that in multivalent atoms a portion of the chemical force which the atom can exert may be, and not unfrequently is, at times employed in counteracting or balancing other parts of the chemical force of the same atom, whilst at other times the whole force of the atom is engaged in dealing with other atoms—or, what some may perhaps consider more probable, that the disposition of the chemical forces in a multivalent atom at its maximum of quantivalence is analogous to the disposition of magnetic force in a magnet, with one or more consequent poles, and that decrease in quantivalence is due to the disappearance of some of these consequent poles, and subsequent increase to their reappearance. If either of these suppositions be admitted, it appears to the writer that (A) and (B) translated into the ordinary language expressing relations of force may be expressed by the following law:—

In every molecule the chemical forces exerted by the several atoms composing the molecule are in equilibrium amongst themselves.

It must, however, be constantly kept in mind that this law is only a law of general application upon the supposition as to the suppression or change of force in a multivalent atom referred to above. In molecules therefore which contain multivalent atoms not acting at their maximum of quantivalence, it is plain that if from any cause whatever this latent quantivalence were called into activity, the molecule might become capable of entering into combination and aiding in the formation of a new and more complex molecule, as a whole, and without disturbing the atoms already united with the multivalent atom. It is thus possible that molecules of this particular class may under certain circumstances appear to possess chemical energy, and in some sense to play the part of atoms, and such instances do probably actually occur, and, as we shall subsequently see, must be taken into account in considering some complex cases of chemical action.

So far we have considered the phenomena of quantivalence as observed among compound molecules only; but the remarkable results which we have already considered, and which proved that the molecules of the greater part of the elements are composed of more than one atom, lead us to think that the law which we have already stated, and which we shall in future call the law of molecular equilibrium, is one which applies to all molecules.

Five forms of molecule are known amongst elementary bodies.

(*a*) Molecule composed of two atoms. This is the most usual form, and to it all the known molecules of monatomic elements belong.

(*b*) Molecule composed of three atoms. As far as the writer is aware, only one such is known—ozone, a molecule composed of three atoms of a diatomic element ($3 \times 2 = 6$).

(*c*) Molecule composed of four atoms. Certain pentatomic elements have molecules of this form ($4 \times 5$ or $3 = 20$ or $12$).

(*d*) Molecule composed of six atoms. A form of sulphur appears to have molecules of this type ($6 \times 6$ or $4$ or $2 = 36$ or $24$ or $12$).

(*e*) Molecule composed of one atom only. The only known instances among the elements are diatomic bodies.

Hence it is obvious that if the actions between the atoms were represented by our hypothetical clamps, the relations (A) and (B) would in every case hold between the atoms of the known molecules of the elements; and we may therefore, by the same course of reasoning as before, conclude that the law of molecular equilibrium applies to the molecules of the elements as well as to the molecules of compounds.

The fact that all the molecules met with in nature are in a state of chemical equilibrium, so far as relates to the atoms composing them, naturally leads us to inquire whether this equilibrium is equally able to resist disturbance in all cases. It is plain that the power of resistance will vary if the intensity of the chemical force exerted between any two atoms depends in any degree upon the nature of these atoms; and when we turn to actual experiment, we find the clearest proof that the nature of the atoms does affect the intensity of the chemical action between them. If, for example, we examine the results obtained by combining the atom of some selected element with the atoms of the various other elements known to us, we meet with most surprising differences in the intensity of the chemical action which takes place: with some elements the action will be extremely violent, with others it will be almost imperceptible, and we find all sorts of gradations between these two extremes.

It follows that the force which tends to retain any given atom of a particular molecule in its position as a constituent part of that molecule will, in some degree at least, depend upon the nature of the atom or atoms with which it is united to form the molecule, and consequently that the stability of the molecule, that is, the degree of force which it will be necessary to exert to displace any given atom from its position in the structure, will also, in some measure at least, depend upon the nature of the various atoms making up the molecule.

Theory, therefore, would lead us to expect that we should meet with molecules of very various degrees of stability, and we need hardly say that experiment entirely confirms this conclusion. It is perhaps not too much to say that molecules are met with of every degree of stability, from those whose equilibrium scarcely any force which we can apply will disturb, to those which are so unstable that it is scarcely possible to guard them from disturbing causes which suffice to break them up.

We shall see the full importance of these facts if we consider what is meant by the term "chemical change," and to what causes its occurrence is really to be attributed.

The terms chemical change or chemical action are generally applied to those cases where new bodies differing in kind from those originally present are produced as the result of the change or action, while the terms molecular change or molecular action are applied to those cases where the result does not present us with any new body differing in kind; but it is obvious that the distinction really is, that in cases of chemical change there is some rearrangement of atoms which gives rise to new molecules, and thus adjusts and balances the chemical forces exerted by the several atoms which take part in the action, while in cases of molecular change there is no such rearrangement: the former may be said to depend on the motion of atoms, the latter on the motion of molecules only as distinguished from atoms.

Now, as we have seen, all substances occur in nature as molecules composed of atoms, whose mutual chemical attractions balance each other. Hence any rearrangement of the atoms to obtain a balance of chemical forces can only become necessary when some force external to the molecule comes into action, and destroys the balance previously existing; and this leads us to the important conclusion that chemical change is in every case due to the action of external disturbing force in some form or other.

Modern science has proved that all the known forms of physical force are really manifestations of one and the same agent, or in other words, that the special form of physical force which causes any observed phenomenon, however it may be manifested, or in whatever manner it may act, is commensurable and comparable with, and may even by proper means be transformed into, other known kinds of physical force.

It does not of course follow that forms of force, which we are unable to compare directly with or to transform into any known form of physical force, may not be capable of affecting the balance which exists between the chemical forces exerted by the atoms which build up a molecule; but it is at least plain that we may expect to find not only chemical force, but all the known kinds of physical force, disturbing the chemical equilibrium of molecules, and that in considering the causes of any observed chemical change we must take into account the possible effects of physical force not manifested in the form of chemical affinity.

# CHAPTER III.

## MODE OF ACTION OF CHEMICAL FORCE.

THE fundamental conception of the atomic theory is that chemical force is exerted between the atoms themselves, but beyond this we have not hitherto made any inquiry into the nature or mode of operation of this form of force. As with other forms, the action observed is no doubt due to some mode of motion which in this case affects the atoms themselves, but the actual nature of this movement is at present involved in some obscurity, and some difference of opinion exists among chemists themselves. We shall not ask the reader to enter upon these somewhat abstruse questions, but we may here state that it is considered highly probable that the force should be classed among those which are known as "polar" forces, and which give rise to phenomena both of attraction and repulsion, and that it may thus best be compared with those forms of force which are known as magnetism and electricity.

There is also considerable ground for believing that the phenomenon of multivalence exhibited by the atoms of so many elements is really due to the fact that the multivalent atom is capable of exerting chemical force in several directions, or in several of the positions it occupies in the course of the movement which gives rise to the phenomena of chemical activity; the number of these directions or positions corresponding in each case with the maximum degree of quantivalence which the atom is able to exhibit. We can thus readily understand how it happens that active quantivalence varies by differences of 2, 4, etc.; for it is plain that if the force exerted in one direction or in one position is equal and opposite to that exerted in another direction or in another position, the ultimate result will be the same as if no force had been exerted in either direction or in either position.

Again, it by no means necessarily follows that the force which a multivalent atom is capable of exerting in each direction or at each position is identical, it may well be that such forces are at the most arranged in pairs, and that the forces belonging to one pair may be very different from those belonging to other pairs. All this is at least possible, and it agrees well with some remarkable experimental results which appear to show that in some cases, as for instance in phosphoric pentachloride ($PCl_5$), some pair or pairs of the atoms united with the multivalent atom are less firmly held than the remaining atoms. In other cases it may well be that the force exerted by the multivalent atom in each direction or in each position is identical, and carbon is perhaps an element in which this is the case.

This view of the nature of the force exerted by a multivalent atom also agrees well with the experimental facts, that change in quantivalence appears never to occur except in cases where the influence of surrounding or adjoining atoms plays an important part in producing the chemical change observed, and that the active quantivalence exhibited by an atom forming any particular molecule appears to be determined solely by the chemical nature of the atoms which are for the time being in a position to exercise chemical influence on the special atom whose powers we are examining.

Here, too, we should note in passing that these experimental results, and the theory of the nature of the action of a multivalent atom which agrees so well with them, alike point to the conclusion that when we are considering under what circumstances chemical change is likely to take place, we may neglect change in quantivalence, except where we are dealing with the action of chemical force.

Lastly, experiment clearly proves that distance is a material element in the action of chemical force. Molecules when separated by a great interval frequently appear to exert no chemical influence on each other, while if the very same molecules be brought into close proximity violent chemical action immediately takes place. Here, however, we must recollect that we have reason to believe that the actual bulk of a molecule is extremely small, and the terms "distance" and "proximity" must be understood with some reference to the size of a molecule. It even appears to be probable that chemical force is exerted by atom upon atom, only at distances comparable with the magnitudes of the atoms and molecules themselves.

These theoretical considerations furnish us with the means of applying an experimental test to the law of molecular equilibrium. If this law be really a law of nature, it is obvious that the relative position of each atom with respect to the other atoms united with it in the molecule, and also the nature of the directions or positions in which the multivalent atoms present are exerting their chemical force on the atoms composing the molecule, will or may affect the equilibrium of the molecule. Theoretically then we may expect to meet with molecules which consist of precisely the same number of atoms of each of the several elements which take part in forming them, but whose molecular equilibrium will vary greatly in stability, owing either to a different arrangement of the atoms themselves as to relative position, or to difference in the directions or positions in which the same multivalent atoms are exerting chemical force, in the two molecules.

Consequently theory leads us to expect that molecules will be met with in the course of actual experiment, which will be precisely identical as to the number and nature of the atoms composing them, but which will yet behave very differently when exposed to the same disturbing influences.

Let us look now to the results of actual experiment;

not only do we meet with cases of this kind, but we find that the instances known to chemists are actually so numerous, that express words, "isomeric," "metameric," have been formed to denote those compounds which, though absolutely identical as to the nature and number of the atoms composing them, yet differ widely in properties when we expose them to the action of identical disturbing influences.*

The remarkable phenomena of "isomerism" thus strongly confirm the truth of the law of molecular equilibrium, and we will now proceed to consider in what cases chemical change may be expected to take place, on the supposition that, so far as relates to the atoms composing it, every molecule is in chemical equilibrium.

Bearing in mind the important fact, which we have already noticed, that this view compels us to attribute all chemical change to the influence of force external to the molecule itself, and remembering the remarks already made as to the essential identity of all forms of force, and as to the probable nature of the phenomena of quantivalence, we see that chemical change may be expected to take place under three classes of circumstances.

(1) Where chemical force alone comes into play.

This class may be divided into two sub-classes.

(A) Where molecules of different substances are

* For further information on the interesting subject of isomerism, the reader should consult an admirable paper by Mr. Muir, in the *Philosophical Magazine* (v.), vol. ii., p. 161.

brought so near together by external force, that the chemical affinities mutually exerted between atom and atom of the various elements present in the molecules are brought into action, and these affinities are such that a rearrangement of the atoms present, and taking part in the reaction, must be effected to obtain a molecule or molecules in which the internal chemical actions and reactions between the atoms composing it or them will be in equilibrium.

(B) Cases where the action depends on change in the active quantivalence of one or more multivalent atoms.

This may occur either (*a*) where molecules of different kinds are brought into proximity by external force, and the effect of the approach of the atoms forming the strange molecule is to give rise to a change in the active quantivalence of some multivalent atom, and thus to cause a disturbance of equilibrium which has to be adjusted by a rearrangement of some at least of the atoms present; or (*b*) where the atoms which satisfy a part of the active quantivalence of some multivalent atom present in the molecule are united to this atom by an affinity so feeble that they cannot resist the force of some external impulse, but are detached by it from their connection with the multivalent atom, whose active quantivalence then falls by reason of its partial self-satisfaction, and a rearrangement of the atoms present becomes necessary to obtain equilibrium under the conditions of a lower active quantivalence exhibited by the multivalent atom in question.

(2) Where chemical force does not come into play at all in the first stage of the change, but the molecules of some particular substance are broken up under the influence of external force manifested in some other form.

(3) Where both chemical force and forces of other kinds come into play simultaneously, and the effect produced is due partly to one form of force, and partly to the other or others.

Excellent examples of chemical change coming under the first of these heads are afforded by the rearrangement which takes place between the atoms forming the molecules of water and the atoms forming molecules of the oxides of various metals, when these last are placed in contact with water; for instance, if a molecule of potassic oxide ($K_2O$), is placed in contact with a molecule of water ($H_2O$), a rearrangement of atoms takes place, and as the result *two* new molecules, each composed of KHO (hydric potassic oxide), are produced.

Another example coming under the same head, but where the change is due to change in quantivalence, is presented to us by bringing a molecule of ammonia ($NH_3$) into contact with a molecule of hydrochloric acid (HCl); a new molecule ($NH_4Cl$), ammonic chloride, often called sal-ammoniac, is immediately produced, in which chemists consider that all the monatomic atoms are directly united with the multivalent atom of nitrogen which, though triatomic in $NH_3$, now suddenly, under the influence of the molecule of HCl, becomes pentatomic, and gives rise to a rearrangement of the atoms present, the molecule of HCl being completely broken up.

Another example depending upon change in quantivalence is given by the formation of ammonia ($NH_3$) and free hydrogen (HH) from the amalgam of ammonium obtained by pouring a solution of ammonic chloride upon an amalgam of mercury and sodium. In this case the slightest external impulse appears to be sufficient to detach the mercury from its connection with the pentatomic nitrogen of the ammonium; the active quantivalence of the nitrogen then falls to three, and the amalgam is broken up,* giving rise on the one hand to free mercury, and on the other to molecules of ammonia and free hydrogen in the proportion of two molecules of ammonia ($NH_3$) to one molecule of free hydrogen (HH), as the result of the rearrangement of atoms which takes place.

To this first class also we may in one sense refer the innumerable reactions between molecules of different kinds when these have been set in motion by the forces of heat, electricity, surface attraction etc.; and thus extended, it is the class to which the greater part of known chemical changes belong.

The second class may be illustrated by such changes as the decomposition of mercuric oxide by heat, the decomposition of water by an electric current, and others of a similar kind.

* $2\,Hg.\,n\,NH_4\,m = 2\,m\,NH_3 + m\,(HH) + 2\,n\,Hg.$

To the third class belong certain remarkable reactions which were formerly included under the name of catalytic actions. A good example is afforded by the decomposition of potassic chlorate, under the combined influence of heat and of the chemical force exerted by atoms of manganese present in adjoining molecules of manganic dioxide, at a far lower temperature, in other words, with a much smaller expenditure of heat force, than when the decomposition of the chlorate is effected by heat alone.

Modern experiments render it highly probable that analogous cases also occur where the combined influence of physical attraction, and of the chemical force exerted by certain atoms present, effects decompositions which the chemical force exerted by the atoms alone would be unable to effect.

These examples will, we think, sufficiently illustrate the nature of the cases in which chemical change ordinarily occurs, and here we should note that if we confine our attention to those cases of chemical change where no complication is introduced by the presence of a living being, we shall find on trial that every case of true chemical change known to us, almost innumerable as these cases are, is unquestionably due to disturbing influences which bring it within one or other of the classes we have specified.

We have already defined chemical change as change depending on the motion of atoms, and molecular change as change depending on the motion of molecules as distinguished from atoms; but it is obvious that in every case of molecular change there is some displacement of the atoms forming a molecule, with respect to the positions which these occupy relatively to the atoms forming adjoining molecules, and we may reasonably expect to find cases in which there will be considerable difficulty in ascertaining whether the change which has taken place is an instance of true chemical or ot molecular change. We have seen that molecules containing multivalent atoms not acting at their maximum quantivalence may possess some degree of chemical energy as molecules, and we may easily conceive cases where a true chemical change has taken place, but which from another point of view might be accurately described as a motion of molecules only; we ought not therefore to be surprised if we meet with cases where it appears almost impossible to say with precision whether the observed change is a case of true chemical or of molecular change, and in truth the chemist meets with hosts of such cases. We might refer to examples among the numerous hydrates which appear to have a perfectly definite composition; to numbers of cases where the presence of some particular substance in solution has the power of causing some other substance, generally insoluble in the particular solvent employed, to enter into solution also; and to a vast number of other instances; but we do not think it necessary to take up space by a detailed examination of them: we will merely ask the reader to note that one of the greatest difficulties in examining a complicated chemical problem arises from our imperfect means of ascertaining the point at which molecular change ends and true chemical change begins, and that in many, we might perhaps say in all, complicated cases this difficulty is so great, that, in the present state of our knowledge, we cannot hope to give that complete explanation which a mathematician would call the solution of the problem, but must be content to obtain some general idea only of the nature of the changes which give rise to the phenomenon we are considering.

## CHAPTER IV.

### THE STRUCTURE OF SENSIBLE MASSES OF MATTER.

It will be observed that we have not hitherto made any reference to the laws which govern the grouping of molecules into the sensible masses of matter which we find around us. This is a vast subject, and is at present involved in almost impenetrable obscurity. Even in the case of such definite bodies as crystals, the laws which cause the molecules of any substance to group themselves into a special crystalline form may practically be said to be absolutely unknown. We have reason to believe that the forms of these bodies are due to attractions and repulsions exerted between the molecules while the crystal is being formed, but what the precise attractions and repulsions are still remains to be discovered. And when we turn from crystals to those bodies which do not appear to possess any definite form, or to organized bodies such as a plant cell or a grain of starch, we find our ignorance even more complete. It is hardly too much to say that nothing whatever is known of the laws which determine the formation of such masses.

Some points, however, which relate to the differences of form presented by the masses into which molecules of different kinds are aggregated, are so important that we cannot fairly examine the problems which the chemical actions of living beings present without taking the facts into consideration.

If we examine the forms into which molecules of various kinds are collected when they build up masses of matter perceptible to our senses, we find two very distinct types of construction.

One of these comprises those bodies which are known by the name of crystals; these are distinguished by being all more or less hard, by having a fixed definite outline, bounded, roughly speaking, by mathematical planes, and their lines of intersection, and by the symmetrical arrangement of the molecules about certain axes or lines of direction.

The other type comprises those more or less soft shapeless masses with which we are familiar in the case of such substances as jelly, gum, etc. Such masses cannot be said to possess any fixed or definite form, or to have their molecules arranged symmetrically about any particular lines of direction, and the shape which they do assume under any particular circumstances appears to be due to the action of gravity, or some external force or pressure upon their comparatively soft and yielding substance.

When the molecules of a substance group themselves into structures of the first type, the substance is classed as a crystalloid; when, on the other hand, the structure belongs to the second type, the substance is classed as a colloid (glue-like body).

It must not, however, be assumed that the structure of colloid masses is more simple than that of crystals. There is good reason to believe that the structure of colloids is in reality extremely complicated, and that it appears to us to be wanting in definition merely from our ignorance of the real nature of this type of construction.

The differences between these two classes of substances are very marked, and appear to affect their chemical as well as their physical properties in a most striking manner. As we might naturally expect, these differences seem to be intimately connected with the structure of the molecules themselves; and as experiment has proved that the plastic compounds, such as protoplasm, which living beings produce, are colloids, the peculiarities which such bodies present become of importance in examining the chemical actions which living beings give rise to.

Colloids, like crystalloids, are met with among the compounds with which mineral chemistry has made us acquainted, as well as among those products which are undoubtedly due to the action of living beings; but wherever met with, the colloid class presents one striking peculiarity. Crystalloids are met with among compounds of elements of all kinds; colloids, on the other hand, are met with only among compounds where one at least of the component elements has a high degree of quantivalence.

Again, it is a well-known experimental fact, that some multivalent elements show a marked inclination to form molecules by as it were stringing together a number of atoms of the element, and completing the molecule by filling up unoccupied spaces with atoms of other elements, either as connecting links, or to complete the equilibrium of the molecule. Now it is very remarkable that all the colloids known occur among compounds where elements are present which in some degree exhibit this peculiar propensity to accumulate in the same molecule. For instance, this characteristic is well marked in silicon, in iron, and in aluminium, and each of these elements affords us examples of compounds which are colloids. In no element, moreover, is this propensity to accumulate in the same molecule so strikingly marked as in carbon; and in strict analogy with the phenomena presented by the other elements, it is among the compounds of this element that we most frequently meet with colloids.

Further, crystalloïds are met with, such as chloride of sodium,* whose molecules present a very simple atomic constitution; colloids, on the other hand, invariably have molecules which are distinguished by considerable complexity of atomic structure, and by the accumulation of more than one atom of some multivalent element in the same molecule. In addition to these experimental facts, we have already seen that theory leads us to believe that molecules which contain multivalent atoms not acting at their maximum

* Common salt.

quantivalence are likely under suitable conditions to exhibit some degree of chemical energy, and we should therefore naturally expect to meet with such molecules among those substances where a number of atoms of the same multivalent element appear to be to a greater or less extent in chemical union with one another. Lastly, it seems not improbable that such complicated molecules as those presented by the colloids may be larger than the comparatively simple molecules of such crystalloids as water or chloride of sodium, and may thus be unable to pass through openings which present no obstacle to a crystalloid molecule. These considerations will, we think, enable us in some measure to understand the strange peculiarities which colloids exhibit. Among these we may specially note—

(1) Marked instability of form as compared with crystalloids. This is frequently so great, that the slightest disturbing cause seems sufficient to produce some change in the physical state of the colloid.

(2) Marked tendency to form complicated hydrates with water, and generally to give rise to changes where it is extremely difficult to say whether the phenomenon is a case of chemical or of molecular change.

(3) Inability to undergo diffusion through solutions, as compared with crystalloids.

This last property is so important, that we may notice it a little more in detail. It is well known that if an aqueous solution of a crystalloid be brought into contact with a mass of pure water, and sufficient time be allowed, the particles of the crystalloid will ultimately diffuse themselves uniformly through the whole mass of fluid present. If now for the water used in this experiment we substitute masses of some hydrated colloid, precisely the same thing takes place, and it is found that the jelly-like substance of the colloid offers no permament obstacle to the gradual diffusion of the crystalloid. Let us, however, repeat our experiments with a solution of a colloid instead of the crystalloid we previously employed. We find a striking diminution of the power of diffusing even into pure water; but when we test the power of one colloid to diffuse through another, we find that this is absolutely nil. Even a very thin septum of colloidal matter, which has no apparent influence on the diffusion of crystalloids, presents an insurmountable barrier to other colloids, and the two classes of matter can thus be readily separated. This strange property appears like the others to depend upon the special character of the molecule of colloids, and the separation of the two classes of bodies by its means is frequently accompanied by chemical changes of the most surprising character. An example taken from one of the experiments made by the celebrated chemist, Graham, will illustrate this, and will perhaps best give the reader some idea of the complicated chemical actions we may expect to meet with where we are dealing with colloids.*

* See Graham's original papers in the *Philosophical Magazine* for 1862 (iv.), 23, pp. 223, 290, 368, to which the reader should refer for further information on the subject of colloids.

Ferric oxide ($Fe_2O_3$) is insoluble in pure water, but is readily dissolved by a solution of ferric chloride ($Fe_2Cl_6$). When a portion of such a solution was separated from a mass of pure water by a colloid partition formed by a sheet of moistened parchment paper, Graham found that hydrochloric acid (HCl) gradually diffused out into the pure water, while ferric oxide in a colloidal state was left in solution on the other side of the parchment paper partition.

This appears a most extraordinary phenomenon; but if we consider it carefully in connection with the character of the elements which alone seem to give rise to colloid compounds, it will not be found so unintelligible. We have called the body which is left undiffused, ferric oxide, but its precise composition in the colloidal state has never been ascertained, and there can, we think, be little doubt that its real composition is far more complicated, though it may well be that the proportion of atoms of iron to atoms of oxygen in its molecule is still as two to three. It is plain that the solution of the ferric oxide is due in some way or other to the presence of the molecules of ferric chloride, and we can hardly doubt that in the solution ultimately obtained the molecules of the two ferric compounds and those of water are all brought into close proximity. Possibly some chemical change may take place when the ferric oxide is dissolved, but at the least some kind of molecular adhesion between the molecules of water and those of the two ferric compounds must occur, and it seems not improbable that the atoms needed to form a molecule of hydrochloric acid are thus brought within close proximity to one another. Now we must remember that oxygen has a powerful affinity for iron, and that chlorine has a powerful affinity for hydrogen: we have also reason to believe that iron, though acting as tetratomic only in the ferric compounds, is really a hexatomic element, and we know that it shows considerable tendency to accumulate in the same molecule. Lastly, experiment shows that hydrochloric acid is a highly diffusible body, which, if formed, would be strongly attracted by the water contained in the moistened colloid septum. It can therefore hardly be considered as unintelligible that some change in the chemical equilibrium should occur at the surface of the parchment paper where all these disturbing causes co-exist, and that a rearrangement of the atoms present should be effected, as one result of which hydrochloric acid is formed and immediately removed by diffusion, while the other product of the action, a highly complicated compound of oxygen and iron, united probably as a hydrate with a considerable quantity of water, remains behind by reason of its inability as a colloid to diffuse through the parchment paper partition.

We have chosen this example partly because it well illustrates the difficulty of ascertaining with precision where chemical change begins and molecular change ends in a complicated case; for, in the present state of our knowledge, it is, to say the least, very difficult to decide whether the disappearance of the solid ferric oxide in the solution of ferric chloride is due to chemical combination or to mere molecular solution, and it is this very uncertainty which makes it impossible to gain anything more than a general idea of the changes which take place, and which end in producing the colloidal oxide of iron.

Another reason for choosing this example is, that the oxide of iron thus obtained is almost a typical colloid exhibiting all the special peculiarities of the class in a very marked manner. For instance, it is exceedingly unstable in form, passing with extreme ease from a soluble modification to an insoluble one, which presents the appearance of a jelly-like solid. It appears to have a wonderful power of retaining water in some more or less feeble form of union, and it is absolutely incapable of passing through a colloid partition by diffusion. It appears, in truth, to be as perfect a colloid as any of the colloid bodies met with among the products of life, and it is certainly a very remarkable and very instructive fact, that mineral chemistry should present us with a compound which exhibits in perfection some of the most puzzling physical peculiarities which distinguish the plastic products of living beings, but never shows the slightest trace of the peculiar properties included under the term "life." A more striking proof that life is not the mere result of the mechanical condition in which protoplasm and such bodies are met with could scarcely be given, though we shall perhaps hardly see what an important advance has thus been made, until we come to discuss the phenomena presented by the chemical action of living beings.

## CHAPTER V.

### INFLUENCE OF TIME AND MASS IN PRODUCING CHEMICAL CHANGE.

ENOUGH, we think, has now been said to show how greatly the colloidal form, in which protoplasm and other important products of life occur, adds to the difficulty of giving any complete explanation of a chemical change in which such bodies appear to be concerned, and also to prepare the reader for the extraordinary complexity which we shall find is a characteristic feature of the chemical compounds which are formed when molecules are brought within the sphere of action of living beings.

Before, however, we consider this action, some important general points which appear to affect the chemical action both of colloids and crystalloids remain to be noticed.

Among these we must specially note that in all cases in which masses of sensible magnitude are caused to act chemically upon one another, some length of time always ensues before the whole of the chemical action between the masses has taken place and on looking to the extent of the action effected in any given time in such cases, we find that the mass of each body present has had a marked influence on the actual result which has been obtained at any stage.

Let us now consider how far these observed facts agree with the results which theory would lead us to expect. We have already stated that experiment gives us reason to believe that the chemical force exerted by atoms on one another is only called into play at distances comparable with the size of the molecules and the atoms themselves: we have come to the conclusion that, in cases where molecules of different kinds are brought within the sphere of the mutual chemical action of the atoms composing them, chemical change is due to disturbance of the equilibrium previously existing between the atoms of which these several molecules were composed, and we also know that all the sensible masses of matter employed in our experiments are built up of molecules.

Now it seems, at least, not improbable that if more than one molecule of substance A were brought into such close proximity to a molecule of substance B that the atoms composing the several molecules of A were all to some extent within the range of the mutual affinities between these atoms and the atoms composing the single molecule of B, an effect might be produced upon this last molecule which would not occur if the molecules of A were present in smaller number. If so, we might well conceive that where masses of two substances were brought into contact, some period of time, were it more or less, would elapse before all the molecules which would ultimately be subject to chemical action were brought within the influence of the forces of chemical affinity, and we might also well suppose that under such circumstances the whole amount of chemical change which would ultimately take place would be in some degree at least influenced by the whole number of distinct molecules—in other words, by the mass—of each substance present.

Let us test this view by carefully examining some specific instance in which the influence of mass is conspicuous. A very common case of chemical action, which moreover, if not previously investigated, might possibly embarrass us in our examination of the chemical action of living beings, will give us an excellent opportunity of doing this. The action we refer to is that of one compound in solution upon another compound also in solution, where chemical change takes place when the two solutions are mixed.

Let us suppose the solutions to be solutions of the compounds A B and C D respectively, and that the effect of chemical reaction between A B and C D is to give rise to the new compounds A D and B C. We might take some of those compounds which are known as "salts," and in which the whole or part of the hydrogen existing in the molecules of such bodies as sulphuric or tartaric or phosphoric acid is replaced by some metallic element, A and C standing for the metallic elements, and B and D for the compound masses (or radicals, as they are frequently called,) which when united to the metallic elements are capable of forming a complete molecule; but as it is found that the results are the same in either case, let us, for the sake of simplicity, suppose A, B, C, and D, to be all elementary substances, and let us suppose that portions of the solutions have been mixed, and that reaction has taken place. The following is the result, as found by actual experiment:—

(1.) If neither A D nor B C is insoluble, and all the products of the reaction remain in solution, the effect of mixing the solutions is to produce a fluid containing all the four compounds, A B, C D, A D, and B C, and these will be found in the mixed solution in proportions depending partly on the respective attractions of A, B, C, and D, for each other when all are present together, and partly on the quantities of A B and C D respectively present in the mixed solution at the time when the reaction takes place.

(2.) If one of the compounds produced, say A D, is insoluble, the first result of the mixture is the same as before; but in this case the portion of A D formed is immediately removed by gravitation from the solution, and a further reaction takes place, as the result of which a fresh portion both of A D and B C is formed, depending on the amount of A B and C D left unaltered by the first stage of the reaction. This new portion of A D is again removed by gravitation; fresh reaction, giving rise to a further production of A D, takes place, this portion of A D is again removed by gravitation, and so on, until the whole of the A or the D present is removed in the shape of A D.

(3.) In both cases the products A D and B C are invariably found to conform to the law of molecular equilibrium.

(4.) After the reaction has been completed, no further disturbance in the mixed solution appears to take place.

(We have of course assumed throughout that none of the compounds A B, C D, A D, and B C, has any action on the solvent.)

Unfortunately our knowledge of the laws governing solution (which, it must be remembered, is in most cases a "molecular" as distinguished from a true "chemical" change) is very slight, and it is almost impossible in consequence to examine these remarkable results theoretically with any great degree of minuteness. It is known that the result of attempting to dissolve one body in another, where no chemical action takes place between them, is greatly influenced by the chemical nature of both the body dissolved and the solvent. It is also known that temperature greatly affects the result, and that it is also in many cases (as, for example, with certain forms of sulphur) affected by the molecular structure of the mass operated on, quite apart from its chemical nature; but the laws on which these influences depend may be said to be wholly unknown. Experiment, however, shows that the molecules of the dissolved body are in all cases tolerably uniformly distributed through the mass of the solvent, but beyond this little or nothing is known with regard to the position in the solution of the molecules of the dissolved body with respect to each other, or with respect to the molecules of the solvent.

We have, however, a much greater knowledge of the relative positions which the molecules occupy in the case of substances which are mixed in a gaseous condition; and where gases are caused to react on each other, it is in all cases probable, and in some cases certain, that several molecules of one substance are associated with a single molecule of another in effecting specific chemical changes; for example, when we form water by exploding a mixture of oxygen and hydrogen gases, we know that at least *two* molecules of hydrogen are associated with *one* molecule of oxygen in every reaction which gives rise to molecules of water. It seems not unreasonable to suppose that something of the same kind may take place when substances in solution react upon each other, and it is at least probable that several molecules will contribute something towards effecting each chemical change which results in the production of a new molecule, and consequently that the relative number of molecules of the two substances in solution present in any given space will or may affect the actual result which is obtained when the two solutions are mixed. Now we have seen that the molecules of A B and C D are tolerably equally distributed through the respective solutions of these substances, and it follows that after the solutions have been thoroughly mixed, the number of molecules of A B and C D, and therefore also the number of atoms of A, B, C, and D, present in any given space will depend upon the total number of molecules, that is, in effect, the mass, of each of the substances A B and C D present in solution. Hence it is at the least highly probable, theoretically, that the extent to which the molecular equilibrium of A B and C D will be disturbed, or in others words, the amount of reaction between A B and C D in the mixed solution will depend partly upon the mutual affinities of A, B, C, and D, when all are present, and partly upon the respective masses of A B and C D employed. Further, as the space occupied by the molecules of any compound such as A D must be filled up by something, if this compound is removed from the solution, we can see that it is probable, on theoretical grounds, that such removal would bring fresh molecules within the sphere of action of the chemical affinities exerted by the atoms composing these and the adjoining molecules, and thus give rise to further chemical change, so long as anything continued to be removed from the solution.

Results similar to those obtained by mixing compounds in solution are also obtained by fusing together two compounds which react on each other when in a melted state; volatility here having the same influence on the result as insolubility has in the case of solutions; and it is plain that the same considerations which theoretically explained the results of the experiments on mixed solutions will equally explain the results of the experiments on the mixture of fused compounds.

On the whole, therefore, we think we may fairly say that experiment and theory here agree at least as closely as we have any right to expect, and that while we keep the law of molecular equilibrium in mind, we need not embarrass ourselves by attributing any occult or unknown influence to mass or time in the production of any observed chemical change.

## CHAPTER VI.

### SURFACE ACTION.

It is well known that the presence of bodies in the state which we call "living" gives rise to chemical change among the molecules which are submitted to their influence, and that this is especially conspicuous in those cases where the living being is in a state of growth or increase. It might be urged that we are acquainted with cases in mineral chemistry where the mere presence of certain bodies, which themselves undergo no change, appears to give rise to chemical action, and that the action of living beings might be somewhat of the same kind. Let us therefore, in accordance with the method we have proposed, briefly examine those cases where no living being takes part in the action, but where we find chemical change induced under certain circumstances by the mere presence of various bodies which themselves remain unaffected.

Such changes are of two kinds, the one where the concurrent chemical attraction of the atoms of the foreign body, aiding the mutual chemical attractions between the atoms composing the molecules which are affected, assists in breaking up the existing molecules, although itself insufficient to permanently attract and fix any of the atoms set free; the other where the action of the foreign body must be attributed to causes quite distinct from the force of chemical attraction. Cases of the first kind are merely cases of ordinary chemical action, and require no special examination but cases of the second kind present some remarkable phenomena which we shall shortly notice.

It is well known that many solid bodies under suitable circumstances possess the power of attracting molecules of substances in the state of gas, and causing these molecules to adhere to the surface of the solid. In certain cases this adhesion is followed by chemical action between the adherent molecules, and this is the action to which we ask the reader to turn his attention. The action of finely divided platinum on a mixture of gases affords an excellent example. It is found that when mixed gases are passed over finely divided platinum, chemical action very frequently takes place: for instance, if a mixture of hydrogen and oxygen be brought into contact with the finely divided platinum, chemical action takes place, and water is formed; so if ammonia and air be brought into contact with the finely divided metal, nitric acid and water are produced; and if in the last experiment the vapour of alcohol be substituted for the ammonia, a series of compounds due to the gradual oxidation of the alcohol is produced, and we ultimately obtain acetic acid and water, the usual ultimate results of oxidizing alcohol by other methods.

Many other examples might be given, but these, we think, will be sufficient. In all cases the intensity of the action depends on the amount of surface exposed by the platinum within a given space: as the extent of surface increases, so does the intensity of the action. In all cases, again, whatever be the chemical nature of the mixed gases, if any event happens which alters the state of the surface of the platinum, as, for instance, by its combination with some other element, in such a manner as to prevent the actual platinum surface from coming into contact with the mixed gases, the power of inducing chemical action is lost. These considerations appear to show conclusively that the action is due to forces exerted by the surface of the platinum, and justify the name of "surface action" usually given by chemists to these phenomena.

Various other metals, such as palladium, gold, etc., possess similar properties when finely divided, but in a less intense degree; even finely pounded glass or rock crystal, and other bodies in a fine state of division, possess some power of the same kind, though but of very slight intensity.

The study of these surface actions (for further details as to which we must refer the reader to works on chemistry) leads us to the following experimental conclusions:—

(1.) Whatever be the chemical nature of the body giving rise to the surface action, its power of doing so depends on the surface remaining chemically unchanged.

(2.) Whatever be the chemical nature of the body giving rise to the surface action, the intensity of the action for the same body depends on the extent of surface exposed in a given space.

(3.) Substances whose surface action is of sufficient intensity to cause chemical action to take place between any two bodies which react with difficulty on each other, also cause chemical action to take place between bodies which react more readily on each other. (It is of course assumed that these latter, and the results of their reaction, do not chemically affect the surface which gives rise to the action.)

If any two bodies react on each other in the presence of a substance having but a feeble power of surface action, these two bodies will also react on each other in the presence of substances having greater powers of surface action.

(4.) If the same two gases be employed, the nature of the reaction between them (if any takes place) is independent of the chemical nature of the body whose surface action gives rise to the chemical change; for instance, all bodies having the power of exerting surface action on a mixture of oxygen and hydrogen cause the formation of water, the difference in effect being one of intensity only.

Exceptional cases, however, may possibly occur, where the concurrent chemical attraction of some of the atoms composing the surface of the solid may aid the chemical forces exerted by the atoms of the gases in decomposing the molecules of the mixed gases, and may have an influence on the result, though the solid itself remains chemically unaltered, and allowance must be made for such cases in applying (3) and (4).

(5.) Where the power of surface action, as in the case of finely divided platinum, is considerable, the action of an element—as, for instance, oxygen—on a vapour of complicated atomic structure—as, for instance, alcohol—is gradual; a series of products containing larger and larger quantities of oxygen being produced, till ultimately a body is produced on which the remaining oxygen is without influence in the presence of the platinum.

(6.) All the products which can be obtained by surface action are such as might be formed by the mutual attractions of the atoms forming them, if these atoms were free to combine, and relieved from the ties which held them together in the molecules of the gases submitted to surface action. All such products obey the law of molecular equilibrium, and all, as far as the writer knows, are known to be formed by the union of atoms of the same elements under other circumstances.

(7.) The formation of the new products obtained as the result of surface action can be explained, on the hypothesis that the surface action of any body operates by bringing the molecules of the gases, which adhere to its surface, within the sphere of action of the mutual chemical affinities exerted by the atoms composing the molecules, though possibly it is in some cases assisted by the chemical forces exerted by the atoms composing the surface of the solid on all or some of the atoms of the adhering molecules, which are thus rendered more easily decomposable.

Very similar results have been obtained by the action of the surfaces of solids on compounds in solution, and there can be little doubt that this action is strictly analogous to the action of surface on gases, though, by reason of our want of knowledge of the laws of solution, it is not so manageable an example of the laws which govern surface action, and we have therefore taken the effect on gases as our example of these actions. It will thus be seen that the phenomena of surface action may be explained as being in the main due to the attractive force which gives rise to such phenomena as adhesion and capillary attraction, and that so far as they are not due to this force they are mere examples of the mutual chemical attraction exerted between atoms of different kinds when two molecules containing such atoms are brought into sufficiently close proximity.

# PART II.

# CHEMICAL ACTION WHERE LIFE IS PRESENT.

## CHAPTER I.

### THE CHEMICAL ACTION OF LIVING BEINGS—GROWTH.

We have now, to the best of our ability, cleared the way for dealing with that host of complications which we shall find beset us in examining the problems presented by the chemical action of living beings; and have supplied ourselves with some means of judging how far the observed changes are to be attributed to the surrounding conditions under which the action takes place, rather than to the influence of the living being itself; and we proceed to examine what the real nature of the action of a living body is, when its presence gives rise to some chemical change. Let us, in the first instance, consider a case in which the living body, as one result of the action, grows, or increases in size.

Here it must be remembered that biologists now consider that the essentially "living" part of all living beings, as distinguished from the skeleton or other framework which serves as a support, or an inclosure, or a protection to the "living" part of the being, consists of a substance which is substantially identical in all known forms of life, whether these are ordinarily referred to the animal or to the vegetable kingdom. To this substance they give the name of protoplasm, or, when they wish to distinguish between the kinds of protoplasm derived from different forms of life, the substances are included under the general name of protein compounds. These protein compounds, however, are all extremely similar, and probably even absolutely identical.

Chemical analysis applied to the protein compounds shows them to be of extraordinary complexity.* All of them contain nitrogen, all also contain a small proportion of sulphur and a small proportion of phosphorus; the other constituent elements, which are all present in considerable quantity, are carbon, oxygen, and hydrogen.

Further, all these compounds are colloids, and are so complex that no formula which can be relied upon can be written down as accurately expressing even

* Compare, for instance, these three formulæ for albumen, each of which, it will be observed, does not even attempt to give an estimate of the phosphorus present, $C^{216}$ $H^{338}$ $N^{51}$ $S^{3}$ $O^{68}$ (Liebig), $C^{90}$ $H^{139}$ $N^{22}$ S $O^{30}$ (Mulder), $C^{72}$ $H^{112}$ $N^{18}$ S $O^{22}$ (Lieberkuhn). We may well be surprised to find that even the most advanced Evolutionist, when inquiring into the history of creation, can consider such compounds too simple to require further study or investigation.

the number and nature, and far less the chemical relations, of the atoms composing their molecules. This complexity of structure is indeed so great, that chemical analyses sufficiently precise to distinguish between the different kinds of protoplasm (if different kinds there be) cannot be obtained. Such analyses require complicated apparatus, and much manual dexterity; and even in the most carefully conducted experiments the probable errors of observation are more than sufficient to account for the discrepancy of the results obtained.

Lastly, it should be noted that the sulphur, and possibly the phosphorus also, are intimately combined with the other atoms forming the protein compound, and are not merely present in the form of sulphuric and phosphoric acids, in whose molecules one or more atoms of hydrogen have been replaced by some composite structure capable of playing the same part in molecular architecture as the atom of hydrogen.

Let us now take a simple example of the growth of a living being, or organism, as it is often called. A very good instance is the one referred to by Professor Huxley, in an article "On the Border Territory between the Animal and Vegetable Kingdoms," published in *Macmillan's Magazine* for February, 1876, and which we are the more willing to take as our example, as the Professor is a distinguished supporter of the theory of Evolution, as well as a very accurate observer. The Professor there says (p. 337):—

"If a single spore of the commonest and most troublesome of moulds, penicillium, be sown in a saucerful of water, in which tartrate of ammonia with a small percentage of phosphates and sulphates is contained, and kept warm, whether in the dark or exposed to light, it will in a short time give rise to a thick crust of mould, which contains many million times the weight of the original spore in protein compounds and cellulose."

(Cellulose is the substance of which the walls of vegetable cells are composed; white cotton consists of it in a tolerably pure condition. Chemically speaking, it is entirely composed of carbon, oxygen, and hydrogen, and though a very complex body, is of great simplicity, as compared with the protein compounds).

Now let us examine this remarkable result of the introduction of the spore of mould a little more closely from a chemical point of view. Let us take the experiment by stages, and let us in the first place form our solution of "tartrate of ammonia with the small percentage of phosphates and sulphates." Our previous study of the action of compounds in mixed solutions leads us to the conclusion that, on making the mixed solution, some chemical action will probably take place; but the same study has also shown us that when this is over, no further chemical change will take place in the absence of some other exciting cause, and also that all the products formed (which in this case will still be tartrates, phosphates, and sulphates, and will remain in solution,) follow the law of molecular equilibrium. Here it is material to observe that no new product is formed which in the slightest degree resembles protoplasm; we do not even meet with a colloid, as may easily be ascertained by testing the power of the various compounds present to diffuse through a colloid partition.

Let us now add the spore of mould: the remarkable chemical action referred to by the Professor is soon set up;* the molecules of the tartrate of ammonia, and of the phosphates and the sulphates, are, as may be ascertained at any stage by actual experiment on the quantities of these bodies present in the liquid after removing the living mould, broken up one after another, and cease to exist as molecules of these substances. On the other hand, a large quantity of protoplasm is produced out of the atoms which previously built up these molecules, the total quantity of protoplasm existing in the liquid is greatly increased, and the mould is said, in common language, to have "grown."

The question is, how was this breaking up of the molecules of the tartrate of ammonia, the phosphates and sulphates, effected? and here it is of importance to notice that the destruction of these molecules has been complete; the sulphur, and possibly the phosphorus † also, having actually been torn from their connection with the oxygen which is wholly united with them in

* As might be expected in such a complex case of chemical action, some time is needed to produce a perceptible result, see *ante*, p. 68.

† Many chemists, however, consider that the phosphorus met with in protoplasm is in combination as phosphoric acid.

sulphuric acid ($SO_2(OH)_2$) and phosphoric acid ($PO(OH)_3$), a disturbance which was not effected when the sulphuric and phosphoric acid gave rise to the sulphates and phosphates, and which, when we consider the enormous intensity of the attractions of oxygen for sulphur and phosphorus, strikes us as very remarkable. How then was this affected by the spore of penicillium? As the molecular equilibrium of the tartrate, the sulphates, and the phosphates has been disturbed, it is certain that force has been brought to bear upon them. How was this force obtained? and whence did it come?

The effect produced cannot be due to the force of chemical attraction exerted between the atoms or some of the atoms composing a portion of the protoplasm existing in the spore of mould and the atoms composing some of the molecules of the tartrate, the sulphates, and the phosphates; for, as the result, or part of the. result, consisted in the production of a portion of protoplasm, the well-known principle of the conservation of energy proves that if the force required to produce this compound chemically were derived from the destruction of other protoplasm, the amount of new protoplasm produced could not exceed the amount of already existing protoplasm destroyed, and growth or increase in the total amount of protoplasm present would be impossible. We may put aside the chemical action, if any, of the cellulose on precisely the same grounds, as this also is increased in quantity.

Further, on looking into the composition of the substances existing in the solution, we find that all the atoms possessing a variable quantivalence, which are present in the tartrates, the sulphates, and the phosphates, the carbon, the nitrogen, the sulphur, and the phosphorus, are acting in these bodies at their maximum of quantivalence; and thus no complication arises through our having to take into account a possible increase of quantivalence in some of the multivalent atoms present in the molecules broken up, which might be supposed to be the means by which a more complicated chemical compound, such as protoplasm, was built up and held together.

Lastly, we should note that while protoplasm and cellulose are both colloids, our mixed solution, at the time when the spore was added to it, did not, as we ascertained by experiment, contain any colloid substance. It is clear therefore that the production of new protoplasm cannot be attributed to any separating action between colloids and crystalloids exerted by the colloid substance of the spore upon the various compounds present in the solution, or to any complex chemical change attendant on such separation.

The chemical forces exerted between the atoms forming the compounds present in the solution and in the spore thus seem altogether insufficient to account for the effect observed, and we are driven to look for some other cause. Can we, for instance, attribute the formation of additional protoplasm to some form of surface action exerted by the spore of mould?

There are very strong reasons for concluding that this is not the case. In the first place, the spore of mould, although it is well known it will grow in other solutions, as well as in the mixture mentioned by the Professor, invariably produces the extremely complex compound called protoplasm, if it produces anything of the kind at all, and never, so far as is known, produces any intermediate body forming a link between the complex protoplasm and the simple tartrate, sulphates, and phosphates.

In the second place, although the spore of mould possesses the power, as we have seen, of breaking up the exceedingly stable union of the oxygen with the sulphur and the phosphorus in the molecules of sulphuric and phosphoric acid, and though it also possesses the power of causing the formation of the exceedingly complex protoplasm from the simple molecules of the tartrate, the sulphates, and the phosphates, and must therefore, if it acts by surface action, be credited with a power of surface action of a very intense kind, it is found on experiment utterly powerless to cause chemical action in mixtures in which other bodies having but the feeblest power of surface action can give rise to chemical change. For instance, the spore of mould, with all its wonderful power, is unable to effect the chemical combination of pure oxygen and hydrogen, although even the extremely feeble surface power of pounded glass is, under favourable circumstances, able to effect this.

In the third place, unless the spore is able to cause some protoplasm to be formed, it has no action at all, whatever be the nature of the solution to which it is added.

We have only to compare these facts with those results of experiment on surface action to which we have previously referred, to see how very different even in kind the action of the spore is, when compared with the surface action of finely divided platinum and other similar bodies.

The spore has to be kept warm to effect the wonderful changes we are considering. Can it be that these are merely due to the action of heat reflected or conducted into the mixture by the spore? Far better means of affecting the mixture by heat in any such way are at our service; but none such, if employed, produce the effect, or anything like the effect, produced by the spore. Precisely similar remarks will apply to any supposition that the effects we observe are simply the result of the action in the ordinary way of electric or magnetic or any other physical force, such as we are familiar with in experimenting on non-living matter.

Experiment, in fact, makes it clear that physical attraction, light, heat, electricity, and other forms of such physical force on the one hand, and the chemical forces of the atoms present in the solution on the other, are all alike incapable, either separately or in combination, of effecting the change accomplished by the spore; that these forces cannot cause the destruction of the molecules of the tartrate, the sulphate, and the phosphates, and then cause the atoms composing these bodies to rearrange themselves in the complex shape of protoplasm; and do not therefore account for the chemical change observed, unless it is assumed that the spore in some unknown way brings these molecules and atoms under the control of the forces, which are thus enabled to act upon them in a manner in which they are either separately or in combination utterly unable to act when unaided. But, as we have seen, chemical change is due to force, and to force alone; and to make such an assumption is to imply, or rather to take for granted, that the spore exerts force in some form or other apart from any physical and chemical forces which it may call to its assistance in producing the ultimate result; and it seems to the writer, that, whatever hypothesis we may adopt to explain the actual formation of protoplasm, we are, in considering the chemical problem of its production, forced to the conclusion that the spore does itself exert force, and that the force so exerted cannot be distinctly referred to any of the known forms of force with which we are familiar in experiments on non-living matter.

It is usual to call this peculiar force exerted by the spore "vital force," or "the force of vitality;" and though these names have frequently been objected to by evolutionists, who maintain that the phenomena we have been considering are due to the action of the ordinary forms of physical force, as observed in non-living matter, or even that they are mere properties of certain compounds—phenomena due to molecular structure, like the phenomenon of fluidity exhibited by the combination of oxygen and hydrogen known as water—it must be admitted that the chemistry of what is called "growth" gives great weight to the assertion that such a force as vitality exists and is exerted by living beings. In fact, the evidence for its existence, though not so full or so extensive, is the *same in kind* as that on which it is universally admitted that electricity is a force, and that an electric current exerts this force when it breaks up the molecules of water, and causes the atoms of hydrogen and oxygen formerly employed in building up molecules of water to rearrange themselves and build up molecules of hydrogen and oxygen, each of which, it will be remembered, is a composite body, containing two atoms of the element.

Many philosophers who have adopted the theory of evolution, have lately put forward elaborate arguments in support of the position that the growth of living beings is to be attributed to the operation of chemical and other ordinary physical force acting in the same manner as that in which we find it in action in the case of non-living matter, which they found upon a supposed analogy between the processes of increase in a crystal deposited from a saturated solution of any substance, and the growth of a living body like the penicillium in a solution which itself contains no protoplasm; but we cannot help thinking that these arguments have been put forward without sufficient consideration of the chemical phenomena attending the growth of a living body under such circumstances.

We will here shortly compare the events which take place in three well-known cases of change; namely, the formation of crystals, or rather, the increase of a crystal introduced into a saturated solution of the substance of which the crystal is composed; the decomposition of water by an electric current; and the growth of our mould spore in the mixed solution; and the comparison will, we think, sufficiently show that the supposed analogy is apparent rather than real.

(1) The increase of a crystal in a solution of the substance from which crystals are being deposited.

The crystal does indeed appear to "grow;" it increases in size, and does so by adding on particles identical in kind with itself. These particles, too, are added to the structure in a particular way; the "growth" follows certain fixed laws, and we can predict the form which the crystal will take. All this is analogous, in appearance at least, and possibly also in fact, to that which takes place in the growth of a living being; but here, when we look into the matter, the analogy ends. The change effected by crystalization is molecular only, for no new substance of any kind is produced; the observed increase is the result of the attraction of molecules of the particular substance of which the crystal is composed, which already exist as portions of such substance in the solution, and which are acted upon by the mass, large in comparison with a molecule, which has already been built up into the form of the crystal by the union of other molecules of the same kind. We should naturally expect to find this attraction governed, under similar conditions, by the shape of the crystal introduced, and the shape and properties of the molecule of the particular substance of which the crystal consists, and we might thus predict from theory that the result would, in the case of each substance, be governed by fixed laws; and it is therefore plain that theory and experiment both point to the conclusion that the ultimate shape which the introduced crystal will assume will be due to the ordinary laws of molecular attraction acting on molecules of particular form. We have here no disturbance of the molecular equilibrium of a single molecule of any substance whatever, no rearrangement of atoms, no chemical change or chemical action of any kind. In short, the whole change is strictly "molecular," as distinguished from "chemical;" it depends on the motion of "molecules," not on that of "atoms."

(2) The decomposition of water by an electric current.

(3) The growth of our mould spore in the mixed solution.

We have placed these cases together, for we have only to look back to our previous investigations to see at once that in both these processes the action is as pointedly "chemical" as distinguished from "molecular" as in the case of the growth of the crystal it was "molecular" as distinguished from "chemical." The very foundation of *both* processes is the disturbance of molecular equilibrium, the destruction of existing molecules by force, and the construction of new molecules entirely differing in kind by a rearrangement of the atoms themselves. It is true that after this has been effected molecular action between the new molecules may and no doubt does occur in the third process, but this does not affect the fact that the production of these new molecules was due to causes entirely unconnected with any molecular attraction which may subsequently be exerted between the newly produced molecule and any others of the same kind present in its vicinity.

The principal differences between (2) and (3) are evidently to be found in the much greater complexity of the ultimate product formed in the latter case, and in the extraordinary manner in which this new product is built up into complicated forms; but if we look to the chemical change produced, it is at all events evident that the growth of a living being, studied from the chemical side, is more analogous to the decomposition of water by the electric current than to the increase of a crystal deposited from a solution, unlike as the phenomena of the decomposition of water and the growth of a living being at first sight appear to be.

In both these processes the change deals with the actual atoms themselves as distinguished from the molecules, whilst in the growth of a crystal the change deals only with the molecules as distinguished from the atoms.

Unless, therefore, we make the enormous and wholly unwarrantable assumption that the forces guiding the molecules to their places in the crystal are similar in kind, mode of action, and distribution, to the forces which lead to the separation of atom from atom in one molecule, and the re-combination of atom with atom in a new molecule, we cannot argue upon the phenomena of the growth of living matter by production of protoplasm by drawing analogies from the phenomena exhibited in the growth of crystals. The validity of any such arguments must, as it seems to the writer, depend wholly on the validity of the enormous assumption we have referred to, and in the present state of our knowledge all such arguments must be pronounced absolutely worthless from a scientific point of view.

This comparison of the growth of a crystal with that of a living being shows us distinctly how important the part is which the force of vitality plays in the economy of life, and the questions will naturally be asked, How did the "vital force" which you attribute to the spore arise? From whence did it come? All we know is, that the spore derived its power of manifesting this force from the mould which produced the spore, and that this mould was produced by the action of similar force manifested by another spore of the same kind which itself originally obtained its vital force from other pre-existing mould, and so on; but how far back this could be traced if we could follow the mould, or how the first mould which produced a spore capable of causing the wonderful effects we have considered, was formed, we cannot, from actual experience say. There is certainly up to this time no evidence of the present production of any living being, except from spores or cells, possessed of "vital force" derived from some pre-existing living body, and these questions must therefore remain unanswered, so far as direct knowledge is concerned; but this is no reason for disbelieving in the existence of vital force, for we are equally at a loss to explain the existence of force at all. Who can say from experience how, or in what manner, force first arose, or whence it came?

Another objection which it seems to the writer might be made is, that the spore may lose this force—in ordinary language, it may be "killed," it may "die." Now, it is universally admitted that ordinary physical force of every kind is indestructible, and that it is never "lost," but merely changed in form, and we can readily conceive the objection being made that on the death of the spore its vital force had disappeared, leaving no trace of its existence, and that this could not be the case if "vital force" were really a force at all. But is it necessarily true that because we do not know what becomes of the vital force, or rather because we cannot in our experiments see what becomes of it, when the living body "dies," it ceases to exist as force? An illustration taken from a simple chemical experiment upon a body which manifests force in a form which is far better known to us than the force of vitality, will, we think, show how dangerous such an assumption would be. Let us take a small steel magnet: it is capable of attracting particles of iron with sufficient force to overcome the power of gravitation, and is universally admitted to possess and exert a distinct force which is known as magnetism. Chemically this magnet is a combination of iron and carbon. Let us now dissolve the iron by the aid of some powerful chemical agent. On trial, the solution will be found to possess no magnetic power whatever, and the same will be found to be true of the undissolved carbon. By proper means we can again withdraw the iron from the solution, and this, when withdrawn, will still be found to be devoid of magnetic power; next, we may cause this iron to re-combine with the carbon, and may then bring the steel to its original shape. Suppose this done, we might now reasonably expect to find our piece of steel, again as it was before our experiment, capable of attracting iron and the unquestioned possessor of magnetic force; but what do we actually find? The new piece of steel when tried proves as entirely incapable of exercising magnetic power of itself, as was the solution of the iron, or the iron which we obtained from it, or the carbon which was left when the magnet was dissolved. The force possessed by the original steel magnet has been completely "lost," and, as is well known, can only be restored to the steel by an application of magnetic force from some external source; and yet, who can say with absolute certainty what has become of it in the course of the experiment? Nobody, however, disputes the existence of magnetic force in the original steel magnet, or doubts the occurrence of this form of force, on the evidence of the experiment we have performed. Why, then, should we disbelieve in the existence of vital force because we cannot see or do not know what becomes of it when a living being dies?

This objection is in truth a purely negative one. It may well be that force capable of interfering with the chemical equilibrium of molecules, may exist in some form which is not capable of transformation into other forms of force, and which may only be perceptible to us under certain circumstances; and even if this should ultimately be disproved, we may surely for the present admit that we have not hitherto been able to connect and compare the force of vitality with the ordinary forms of physical force in the same manner as that in which we have succeeded in correlating each of these forms with the others, without jumping to the conclusion that vital force does not exist. Our failure to effect the correlation of this particular form of force cannot affect the strong positive evidence which we have of its existence, and ought to be looked upon rather as a reason for classing vital force at present as very distinct form of force, than as a ground for doubting its occurrence.

## CHAPTER II.

### HIGHER FORMS—VEGETABLE LIFE—ANIMAL LIFE.

So far we have only considered the chemical action of one of the simplest forms of living matter. On experimenting with our mould spore, we should find it incapable of decomposing carbonic anhydride or carbonates, and extracting the carbon from these bodies for its own use in building up protoplasm and other complicated compounds, although it is well known that a great number of living plants do actually possess this power, and are able to supply themselves with carbon from the small quantity of carbonic anhydride distributed through the atmosphere.

This is effected by the aid of a substance present in the growing leaves and stems of green plants, to which the name of chlorophyll has been given. This substance contains nitrogen, carbon, oxygen, and hydrogen; but as we find is usual with those bodies which are more intimately connected with the processes of life, it is, considered chemically, of extreme complexity, and, like protoplasm, defies accurate analysis. It is, however, certain that it does contain nitrogen as well as carbon, hydrogen, and oxygen, and thus differs materially from cellulose and other similar products. Let us now consider the growth of some vegetable which possesses the power of developing this green substance, and of decomposing carbonic anhydride * by its aid. A plant of wheat will make a good example.

This plant is produced by the growing, under suitable surrounding conditions, of a grain which contains protoplasm, but not chlorophyll, and which has not itself any power of extracting carbon from carbonic anhydride. Under the action of the vital force possessed by the grain when assisted by a certain amount of moisture and warmth, the protoplasm contained in the grain is destroyed, or rather converted into other forms, and a sprout is produced, which is also at first devoid of chlorophyll. Soon, however, this sprout divides into two portions, one becoming the root, which still continues devoid of chlorophyll, and serves to supply the plant with water, phosphates, sulphates, and other salts, and also with ammonia, which it absorbs from the soil, while the other portion becomes the stem and leaves, in which chlorophyll is developed, and which constitute the machinery by which the plant procures its supply of carbon. These once produced, the plant becomes independent of the supply of ready-made protoplasm contained in the

* Carbonic anhydride (= carbon dioxide, $CO_2$) is the familiar substance, popularly called carbonic acid, which we meet with so constantly in our every-day life. True carbonic acid ($H_2CO_3$) is unknown, but carbonates and bicarbonates ($M_2CO_3$ and $HMCO_3$) are both abundant; "carbonate of soda" and "carbonate of lime" (chalk) are examples with which every one is acquainted.

grain, and commences providing the materials for growth, and constructing the necessary compounds for itself. The leaves and green stem are in fact the laboratories in which the plant, amongst other products, manufactures protoplasm; water, phosphates, sulphates, and salts of ammonia are brought up to this laboratory from the soil by the sap. Carbonic anhydride is provided by the air, and the living plant then seizes upon these simple bodies, and by means of its chlorophyll, and with the assistance of the light and warmth of the sun, tears the various molecules to pieces, and builds up some of the atoms thus obtained into new molecules of the extremely complex substance to which the name of protoplasm has been given.

This process is so continually repeated before our eyes that we are apt to forget how very wonderful it is, if studied chemically. On the one hand, some of the molecules which are broken up, and that not partially, but utterly and completely, such as the molecules of sulphuric and phosphoric acid, and, above all, those of carbonic anhydride, are amongst the most stable known to chemists. For example, if in our laboratories we wish to effect the complete separation of the carbon from the oxygen with which it is united in carbonic anhydride, we are compelled to make use of the most powerful and energetic chemical reagents, and even with their aid we can only effect this separation with difficulty and under circumstances which would instantly destroy, not only the protoplasm, but the very chlorophyll itself, which appears to be the agent of separation in the plant. In fact, in a chemical laboratory, the combination of oxygen with carbon in carbonic anhydride is looked upon as practically indestructible when once formed, and the molecules, both of phosphoric and sulphuric acid, though not so extremely refractory, must also unquestionably be classed amongst instances of very stable chemical equilibrium. On the other hand, the protoplasm which the plant produces, besides being of extreme complexity, is so easily destroyed that we can scarcely find any reagents in our laboratories whose action, even in the most dilute form, is sufficiently gentle to give us any insight into the chemical structure of protoplasm; the immediate effect of the most gentle reagents is to break it up hopelessly into less complex compounds, too different in properties to be classed along with it, and we can do but little more than guess from these, what may have been the chemical composition of the body with which we commenced our experiment.

In truth, one hardly knows which most to wonder at—the enormous power exerted by the plant in breaking up the extremely stable molecules we have referred to, or the astonishing manipulative skill with which it forms compounds like protoplasm in its laboratory, which we not only cannot form in ours by the exercise of our utmost skill, but which are actually such marvels of chemical architecture that the moment we attempt to see how they are put together we find that the slightest touch has so broken and defaced the building as to make it unrecognizable, and that to undo the mischief we have thus done is quite beyond our power.

If now we turn to still more complex forms of life, and examine the chemical action of living animals, we find instances of chemical processes quite as marvellous, or even in some respects more marvellous, than those we have examined in the case of the wheat plant.

As in the plant, we meet with the phenomenon of growth, of increase of the organism by the addition of particles of matter, which are manufactured by the living being in a laboratory of its own. As in the plant, too, the products formed in this laboratory are of extreme complexity, are constructed out of materials of less complexity, and cannot be produced by us in our laboratories by any process yet discovered. In one respect, however, the higher animals at least seem to be a step in advance on the plant: with both a certain amount of heat must be present, or they cannot carry on their manufacturing operations; but the plant, as we have seen, is obliged to rely on the sun for its principal supply of heat, while the animal actually supplies itself with heat by causing certain portions of the compounds already manufactured to combine with the oxygen of the air, and making use of the heat evolved in the course of this chemical combination.

Animal life also agrees with vegetable life in being capable of "dying," or being "killed." In fact, all the peculiar features which led us to believe that vital force existed in the plant, lead us to the belief that it also exists in the animal, though the chemical processes carried on by the latter differ in many respects from the chemical processes carried on by the former.

One great difference between plant life and animal life consists in the fact that the animal cannot, like the plant, set its laboratory to work when supplied with simple compounds such as ammonia, carbonic anhydride, phosphates, and other salts. The animal requires far more costly materials than these to work with before it can perform its wonderful feats of chemical manufacture; it requires to be supplied with complex products already elaborated by plants or by other animals from material supplied by plants, and its power only extends to building these materials up into structures of a somewhat higher degree of complexity.

On the other hand, animal life exhibits in abundance the phenomena of motion, which are only faintly exhibited by plant life, and it also, in the higher animals, and, above all, in man, exhibits those powers of mental exercise, thought, memory, and reasoning, which, so far as we know, are not exhibited by plant life at all.

It is, we believe, now universally admitted by physiologists that every voluntary movement of any part of the body, and every thought, every effort of memory, every exercise of the mental power, is accompanied by waste or decomposition, in other words, by chemical change, in some part or other of the living structure, and as such changes are only exhibited in living bodies, we can hardly help connecting this chemical change in some way with the presence of the vital force.

While the vital force continues unimpaired, this waste or decomposition is made up by the manufacture of new products which take the place of those decomposed, to be in their turn destroyed in the same way; and while the animal possesses sufficient vital force to manufacture more of these products than are required to replace what has been decomposed, it increases in bulk and actually grows. It is, however, a remarkable fact that a growing "animal" appears to gain in the power of motion, and in the higher power of exerting thought and other mental processes, in proportion as it loses in the power of manufacturing new products to a greater extent than is required to repair losses and of thus adding to its bulk.

In fact, when we come to compare the phenomena exhibited by animal life with those exhibited by vegetable life, we can, as it seems to the writer, scarcely help coming to the conclusion that in vegetable life almost the whole of the vital force is occupied with the manufacture of the chemical compounds which the plant requires for its growth, while in animal life, after the animal has attained its full size, a large portion of the vital force is engaged with the processes which give rise to the phenomena of motion and mental exertion (where this last exists), leaving only so much of the vital force as is absolutely essential for the purpose to provide the materials required for repairs by its work in the animal laboratory.

## CHAPTER III.

### NATURE OF THE ACTION OF LIVING BEINGS.

We shall not examine the elaborate chemical processes carried out by animals in their laboratories in further detail. The complicated nature of these processes, and the variety and chemical complexity of the materials employed, render them even more obscure than the chemical processes carried on by plants. It will here be sufficient to observe that all life, both animal and vegetable, possesses the following properties in common:—

(1) All living beings pass through a period of growth, during which the total amount of protoplasm and other manufactured products present in the bulk of the living being is increased.

(2) All living beings, while their life lasts, appear to undergo a more or less constant waste of their substance, which is compensated for by the continual manufacture of new molecules.

(3) All living beings possess the power, in a greater or less degree, of manufacturing complex chemical compounds from less complex materials, and do so in a way which we cannot explain on the hypothesis

that the new compounds produced are formed under the influence of physical forces acting in the same manner as that in which we find them acting in experiments on non-living matter.

(4) All living beings sooner or later lose this power, and this loss takes place when they undergo that change which we call death.

These are in fact the properties which distinguish all living from non-living matter. It is plain that they are primarily due to that power of exerting force which we have seen living beings possess, and it is probable that this force is manifested in a special form which we have called vital force.

It is true some philosophers have supposed that these distinctive properties of life are due to the peculiar semi-fluid state of aggregation in which protoplasm is met with; but this is clearly not the case. Chemists, as we have seen,* are well acquainted with a number of "inorganic" compounds which occur in the same semi-fluid condition, and these exhibit no trace of life.

Some, too, have supposed that these special properties of life are the mere result of the chemical nature of the particular compound protoplasm; but it is equally plain that this is not the case. If it were so, every portion of this compound which had not undergone chemical change would exhibit these special properties. Let us see whether this is so, and let us test the matter by making the experiment of mechanically remov-

* Ante, p. 66.

ing* part of the protoplasm of a living being. There is no change in the chemical composition of this protoplasm; but on trial it will be found in every case that the portion removed has completely lost those special manufacturing powers which the living being possessed.

Moreover, if the properties of life were due merely to the chemical nature of protoplasm, they ought not to disappear when the living being dies, for we know that in many cases death appears to take place without any chemical change in the greater part of the protoplasm, of the being; and yet in such cases these special properties are invariably lost.

In truth, it is as inaccurate to say that life is due to the chemical nature of the compound known as protoplasm as it is to say that the magnetism exhibited by the load-stone is due to the chemical nature of this oxide of iron. No chemical reason can be assigned in either case why the particular combination should exhibit the special properties observed, and although the manifestation of these properties is no doubt in some manner assisted by the nature and arrangement of the atoms of which the compounds are built up, it is as clear in one case as in the other that something more than the mere nature and position of the atoms must be called in, to account for the wonderful phenomena which the two compounds exhibit under certain conditions.

If, therefore, we should ever succeed in forming the

* Not of course a part of the complex structure of some being, made up of cells, cell-walls, inclosed protoplasm, nuclei, etc., which is in many cases able to replace the part from which it has been separated.

chemical compound protoplasm in our laboratories, it by no means follows that it would exhibit the properties of life. It is highly probable it would not do so.

Yet another hypothesis has been put forward, which we ought here to notice, namely, that life is due to the transforming power of organization, that is, of the particular arrangement of the molecules of which certain portions of matter consist. This view, which has been advocated by Dr. H. C. Bastian in his well-known work, "The Beginnings of Life," admits that living beings exert force, which is manifested in an unusual form, and may for convenience be called "vital force," but regards this force as a mere transformation or transmutation in appearance of the physical forces, such as heat and light, which have been absorbed by the portions of matter which manifest vitality. Doctor Bastian tells us that the incidence of these physical forces* causes the particles of matter to assume different relationships to one another, as the result of which the matter will be changed in its qualities and will display the change to us under the guise of different attributes, or force-manifestations. He also states that forces† "are not separate entities, they are merely modes, affections, properties—call it what you will—of matter, and therefore necessarily vary with the molecular states of matter," and from these premises he ultimately deduces the conclusion that life is the result, not the cause, of organization.‡

* "Beginnings of Life," vol. i. p. 63.

† Ib p. 65. ‡ Ib. p. 68.

Mr. Wallace, in his "Contributions to the Theory of Natural Selection," has well remarked * that the amount of force exerted by a living being in any specified instance has never been so accurately measured, that we are entitled to say that not one thousandth part of a grain more of force has been exerted by any organized body, or in any part of it, than has been derived from the known primary forces of the material world; and striking and plausible as Dr. Bastian's hypothesis at first sight appears, it undoubtedly presents enormous difficulties.

In the first place, we have seen that biologists now consider that the essentially living part, the "protoplasm," is substantially identical in all beings, whether these are generally referred to the vegetable or to the animal kingdom. How, then, does it happen that the same physical forces, falling in the same quantity upon matter in identically the same state, are in the one case transformed to such an extent that the transformed force is able to tear the stubborn molecules of carbonic anhydride to pieces, whilst in the other case the transmutation is so trifling that the new force is but just able to break up some of the most unstable of all known substances?

In the second place, Dr. Bastian's view seems to leave the important fact of death altogether out of account, as we shall now attempt to show.

No more striking instance of the transformation of

* The last essay, p. 367.

one form of physical force into another has perhaps ever been discovered than the beautiful experiment in which Professor Tyndall showed us that, after cutting off the whole of the light emitted by a source producing both heat and light the invisible heat might be transformed into visible light by collecting the heat rays at the focus of a lens, and placing a strip of platinum at that point. In this experiment, so long as the source continues to supply a sufficiency of heat, so long does the platinum continue to transform a part of this heat into light. Moreover, if we remove the source for a time, the platinum ceases to give out light; but if after this has taken place we bring the source back to its original position, we find at once that the platinum has lost none of its power, and that part of the heat emitted is again transformed into light, and on trial it will be found that this experiment may be repeated any number of times with the same result. The one essential to the continuance of the transformation is the continuance of the supply of heat, and the only cessation of the process, the only analogue in the experiment to the phenomenon of death, originates with the source of heat, and not with the transforming material.

Precisely the same observation applies to an instance to which Dr. Bastian himself refers, namely, the transformation of heat into electricity through the agency of the metals forming a thermo-pile. Here, too, the cessation of transformation, the only event which we can in any way compare with death, depends on the source of heat, and not on the metals of which the pile is composed, and on trial we find that this is a general feature of those cases of transformation, where a force, emitted from some external source, is transmuted into force of another kind by the agency of the matter upon which it falls, without causing any change in the chemical, as distinguished from the molecular, state of this matter. If, then, we are to consider vital force as a mere transmutation of heat or light or other physical force effected by the particular molecular state of certain portions of matter, this transmutation of force ought never to cease while a sufficient supply of physical force is kept up, so long as the molecular state of the matter remains unaltered, and if we are to believe that any alteration in the molecular state of the matter of a living being takes place, we have to find some sufficient cause to account for the change. We shall prove in a subsequent page,* that if Dr. Bastian's theory be admitted, the molecules of the matter of which living beings consist must necessarily be in a state of chemical equilibrium, and it follows that no internal force exerted by the atoms of which the molecules are composed can be invoked to account for a change in the molecular state of the matter. On the other hand, it seems difficult to believe that a molecular state, which, so far from being destroyed or disturbed by the incidence of external physical force, is so stable, that it actually has

* See page 123.

the power of transforming such force into a new shape, and utilizing it in bringing additional matter into the same molecular condition, would ever be altered by the incidence of these external forces, provided the amounts of force which reached the living matter did not in quantity or intensity at any time exceed the amounts which habitually fell upon such matter, and underwent a more or less complete transformation without giving rise to any change in the molecular or chemical state of the transforming agent. Yet if this be so, it would seem that death ought not to occur where a living being is exposed only to those conditions under which it at one time flourished and even increased in bulk, although we know that this conclusion is absolutely opposed to all experience.

Moreover, we know that when death does come the supposed power of transformation is completely lost, and yet we have the strongest reasons for believing that death in most, if not in all, cases precedes any change in the molecular state of by far the greater part of the substance of the living being.

We have already seen that a portion of protoplasm removed from a living being loses its power of effecting chemical changes, and it seems tolerably clear that the portion removed does not undergo any change in molecular state in the course of the removal.

If, too, we compare the vital powers of an individual at two different periods during its life, which are so chosen that at each period it possesses the same, or substantially the same, quantity of living matter, which is to all appearance in the same molecular state, it is well known that, although the individual at both periods seems under ordinary conditions to enjoy perfect health, and to be equally secure against that change which we call death, yet under exceptional conditions, or when exposed to the action of some destructive agent, it will succumb and die at the later period, under circumstances which would not have been sufficient to destroy its life at the earlier period. How can this be explained if Dr. Bastian's theory is correct? Why should the vital powers of an individual diminish as it grows older in those cases where it has been exposed to no violent changes in surrounding conditions, and continues under these conditions to transform the incident physical forces with its habitual power and facility? The feebleness of old age, and that decay of the system which is sufficient to produce death, ought assuredly to be alike unknown under ordinary conditions in any being whose life was the mere manifestation of absorbed physical forces transformed by the molecular state of the matter upon which they fell.

How, again, can the theory which Dr. Bastian advocates account for such cases as that of poisoning by hydrocyanic acid? The effect of this agent is practically instantaneous, and the matters of which the being is composed are so completely unaltered by its action that it is well known that medical men have been convinced that death had been caused by a dose of this poison, simply because the state of the body was such that there was no reason why death should have taken place. In this particular instance it is almost certain that great loss of vital power does precede any change in the molecular state of the bulk of the matter of which the living being is formed, and other examples somewhat of the same kind might easily be given.

In short, it seems to us that Dr. Bastian's hypothesis distinctly leaves the fact of death out of account, and the objections which we have already stated, even if they stood alone, would in our opinion be fatal to this view; but they are far indeed from being the only difficulties which can be brought forward. For instance, in other cases of transformation, substances are known which resemble the transforming agent in chemical composition or in physical peculiarities, and some at least of these are found on trial to possess a similar power of transformation in a greater or less degree; but we meet with nothing of this kind in the case of life. Dead protoplasm and numerous other compounds which more or less closely resemble living protoplasm in chemical composition or in physical properties are well known to us, and yet living protoplasm stands altogether alone in its power of manifesting vital force.

Again, if we transform one form of physical force into another, as, for instance, heat into electricity, this transformation can by proper means be reversed, and the original form of force once more made manifest. But how stands the matter in the case of vital force? Who has ever succeeded in transmuting this into heat or light or any other form of physical force? We can compare the amount of energy produced by the chemical changes involved in the destruction of a certain amount of animal matter within a given time, with the weight lifted, or other work done, by the animal, in that time; but who has ever succeeded in estimating the force, which initiated and set up these chemical changes, in terms of foot-pounds, or of any other unit by which we measure physical force?

Moreover, Dr. Bastian has brought forward strong arguments in support of the position that if his view be accepted, spontaneous generation is not only conceivable, but ought still to be of frequent occurrence; and his theory is certainly not strengthened by the fact that Professor Tyndall and M. Pasteur have conclusively proved that all the instances of supposed spontaneous generation, which Dr. Bastian and others believed they had discovered, are really cases of the production of living beings from spores or germs which were produced by some form of pre-existing life, and which unquestionably obtained their vital powers from their parents. Many other objections will readily occur to the reader, and upon the whole we may safely conclude that life is not the mere result of organization, or of the molecular state of certain portions of matter.

We have, therefore, strong reasons for believing that the phenomena of life are due to the presence in living beings of a form of force, which has not hitherto been correlated with the ordinary forms of physical force, which cannot be treated as a mere transformation or manifestation of any of these well known kinds of force, and whose nature and mode of operation still remain a mystery to which we have as yet found no key; and here we should note that the special properties of life which are due to the presence of this unknown force, give us a satisfactory test when we desire to ascertain whether any given body possesses life or not. To determine this question, we should not look to the mechanical condition, or to the chemical composition, of the body, but to the properties which it exhibits. If the body possesses the properties we have referred to, if it effects chemical decompositions by virtue of its own inherent qualities in the singular manner which we have pointed out, it is alive and not dead, for it exhibits that which forms the grand distinction between living and non-living matter, and which is the real wonder and the real mystery of the strange thing which we call life.

It still remains to consider the class under which we ought to place the chemical actions of living beings; and, from what has already been said, the reader will see that we refer the cases where a living being manufactures new chemical products to the third of those heads into which we divided the instances in which chemical change takes place. For example, it seems almost incredible that the mere chemical attractions exerted between the atoms of carbon, oxygen, hydrogen, and nitrogen, existing in molecules of carbonic anhydride, water, and ammonia should be sufficient, when these are brought together, to break up these highly stable compounds, and leave the atoms composing them free to take part in building up an extremely complex and very unstable substance like protoplasm. Something more than the simple bringing together of these molecules into such proximity that the atoms composing them are within the sphere of their mutual chemical actions must be called in to account with any reasonable probability for the effects produced, and we think that all chemists will agree with us in considering that it is at least highly probable that the force (whatever its true nature may be) which we have called vital force takes a direct part in the chemical actions observed, and that without its aid the reactions would not be accomplished at all; and if this is so, they are plainly instances of chemical change taking place under the influence of those causes which we included under our third class.

In one sense, therefore, it may with truth be said that the reactions caused by living beings are primarily due to the operation of the special form of force which they manifest, and secondarily only to the ordinary forces of chemical affinity exerted between the atoms which take part in the reaction, and this naturally leads us to ask the important question whether the new products manufactured by living beings are true chemical compounds obeying the law of molecular equilibrium.

We might perhaps reasonably infer that this question should be answered in the affirmative, from a consideration of the remarkable uniformity of composition which these products exhibit. So far as our analysis enables us to judge, the protoplasm or the chlorophyll taken from one individual has precisely the same chemical composition as that obtained from another; other organic products, whose analysis presents less difficulty, are undoubtedly always identical in composition, from whatever source they may have been obtained; while in the case of a third and more simple class, including such substances as oxalic acid, the products are unquestionably true chemical compounds obeying the law of molecular equilibrium. Yet all these substances, whether simple or complex, appear to be made up in the same workshop, and it is at least probable that where all the articles manufactured exhibit that same absolute definiteness of atomic structure which is so striking a characteristic of ordinary chemical compounds, they are also all constructed in accordance with the law upon which in other cases this fixity of structure unquestionably depends.

We are not, however, compelled to rely entirely on such considerations; it is well known that death is succeeded by decomposition, in other words, by chemical change, in cases where no alteration is made in the surroundings of the dead body; on the other hand, this chemical change is gradual, and no instance is known where the whole of the body is instantaneously decomposed at the moment of death. If, however, the molecules of the substances of which the living body is composed did not obey the law of molecular equilibrium, but were held together, in contradiction to that law, by the vital force of the living being, it would seem that upon the disappearance of this force, that is, the death of the living being, the whole of the molecules so held together by vital force ought immediately to be decomposed; and though we cannot positively state that every part of a living body dies simultaneously, we, on the whole, think that the phenomena of decomposition after death, and even of death itself, in such cases as that of poisoning by hydrocyanic acid, do distinctly point to the conclusion that the vital force aids in building up the atoms, of which the molecules of protoplasm and other similar compounds are formed, into molecular structures, into which they would not be built up without its intervention, but that these structures, when once formed, are in a state of equilibrium, though this is so unstable, under the conditions to which it is exposed in nature,* that it is unable for any great length of time to resist the chemical attractions exerted by the atoms contained in some of the molecules of adjacent substances; and this view is, we think, further strengthened by the fact that all life, even when the living being is actually increasing in size, or growing, appears to be accompanied by some waste of existing structure, which is compensated for by the new products manufactured in the living laboratory.

* Professor Tyndall's beautiful experiments on the effect of the particles held in suspension by the atmosphere in giving rise to decomposition in solutions containing organic matter, strongly corroborate this view.

On the whole, then, it is at least highly probable that the chemical products of living beings are true chemical compounds whose molecules obey the law of molecular equilibrium; and we shall see how important this conclusion is, when we come to examine the theories which have been put forward to account for the existence of these compounds. It is plain, moreover, that if we deny the existence of that force (whatever its true nature may be) which we have called vital force, or if we consider it as a mere transformation of ordinary physical force, there is no reason whatever for assuming that a particular chemical compound does not comply with the law of molecular equilibrium, merely because it is of unusual complexity, and any arguments attempting to explain the properties of life on the footing that living beings manifest no special form of force, must unquestionably be tested on the hypothesis that all the products formed by living beings are chemical compounds obeying the law of molecular equilibrium.

It will thus be seen that the laws of chemistry as deduced from experiment on non-living matter, when applied to the chemical actions caused by living beings, lead us to the following conclusions:—

(1.) That these chemical actions are primarily due to force exerted by the living being.

(2.) That such force is probably a special manifestation of force.

(3.) That the ultimate results of the action are due in part to this form of force, and in part to other forms of force, such as we find acting on non-living matter.

(4.) That the ultimate products are probably true chemical compounds, which when once produced conform to the general laws governing the structure and continuance of chemical compounds, resulting from actions in which vital force takes no part.

It will, however, be observed that these laws of chemistry give us no answer to the question how the particular form of force which we have called vital force was called into existence, or even to the question how this form of force acts in producing the results observed. Let us now proceed to examine how far the laws of chemistry can throw any light on the relative value of the theories which have been advanced to account for the existence of the wonderfully varied forms and properties which living beings present to us in nature.

# PART III.

# THE HISTORY OF LIFE.

## CHAPTER I.

### THE THEORIES PUT FORWARD TO ACCOUNT FOR THE EXISTENCE AND VARIETY OF THE FORMS OF LIFE.

WE have already seen that we have no direct experimental knowledge of the way in which living beings came to possess the properties which distinguish living matter from dead matter, or of the time at which any bodies possessing these peculiar properties first appeared on the earth.

It is probable on astronomical grounds that the earth was originally in a highly heated state, and that the substances, or at least the greater part of the substances of which its solid mass is made up, were once liquid, or possibly even in a gaseous condition. If this were so, it is plain that no creature of which protoplasm formed an essential constituent could have existed on the earth until extensive cooling by radiation or otherwise had taken place, and we have therefore some experimental reason for considering that life had a beginning on the earth, and has not existed on our globe during the whole period in which the matter of which it is composed has been collected together into one single mass, affected as a whole by the attraction exerted upon it by the sun and the other members of the solar system.

Here we may remark that the most extreme Evolutionists entirely accept the theory that the earth has cooled down, has developed, as they would perhaps express it, from a mass of intensely heated vapour or fluid.

Geology teaches us that there has been a succession of forms of life on the earth, and as to some of these forms, our present knowledge is almost, if not quite, sufficient to prove that they had not appeared on our globe before one fixed date, and had already disappeared as living forms before another fixed date. Geology also proves, or almost proves, that by far the greater part of the living forms which we see around us only came into existence as such forms within an ascertained period, and that a comparatively modern one.

Lastly, we have direct knowledge that the individuals of every so-called species of living being which we meet with in nature are the offspring of parents of the same kind, whose form, qualities, and properties were substantially identical with those of the particular individuals we are considering. It is also universally admitted that, if we exclude hybrids, no case is actually known where a living being can be directly traced back to ancestors substantially differing in form, qualities, and properties from the being which has descended from them. Here our direct experimental knowledge ends; but it must not be supposed that no attempt has been made to explain the origin of life, the succession of living forms due to the disappearance of old forms, and the appearance of new ones as shown to us by geological discovery, and the wonderful variety of distinct forms both existing and extinct.

Two views, dealing with the whole subject, have been put forward, and we have besides Mr. Darwin's view, which does not attempt to account for the origin of life, but merely to explain the succession of forms of life, and the variety observed amongst existing and extinct types. We shall here endeavour to state these three views very shortly.

The first, which we may call the Creationists' view, supposes—

(1.) That life was originally called into existence by a mighty power whose commands matter and force are obliged to obey;

(2.) That the same mighty power, after having originally called the first living beings into existence, has continued to take a direct part in calling into existence the various new forms which have from time to time appeared on the earth.

The nature and mode of operation of this mighty power are left unexplained, and, as is argued, and we think logically argued, are incapable of explanation, or even of being understood, by beings like ourselves, whose powers of thought and reasoning are derived from the very power which we attempt to examine by their aid.

The second view, which is the view of the Evolutionist properly so called, supposes—

(1.) That the first combination of atoms which possessed the distinctive properties of life—the first form of living being—was called into existence by the action of the physical forces, which still surround us, on a portion of the matter of which our earth consists, in the same manner as that in which such physical forces still continue to act on such matter, but under different surrounding conditions; and

(2.) That living beings have always been built up of molecules of a very unstable character; that the first form of living being, when once called into existence, and afterwards its more or less modified descendants have been made to vary gradually, by changes in the external forces incident on this unstable matter; that the actual variations produced were due in part to gradual changes in the external incident forces, and in part to internal variations, the more or less remote consequences of previous changes in the external forces surrounding living beings; that any variation arising in this way, which gave the living being in which it occurred an advantage in the struggle for life under the conditions which then prevailed, was picked out by the survival of the fittest to compete in this struggle, or, as it is generally called, by Natural Selection; that this favourable variation was inherited by the descendants of the being in which it occurred; that living beings thus gradually became adapted to slow changes in the conditions surrounding them; and that all the known forms of life both existing and extinct have in this manner been developed from the first simple form of living being, under the influence of repeated slow changes in the conditions by which living beings were from time to time surrounded.

The philosophers who adopt this view also suppose that the process of development must have been by change from a simple to a more highly specialized form, and that there has thus been continual increase in complexity in the new forms developed, and for this, and for other reasons to which we shall presently refer, they conclude that the first living being must have been of the simplest type, scarcely organized at all, and in fact nothing more than a shapeless mass of protoplasm.

The Evolutionist also supposes (and this we think will be generally admitted) that the external forces changed very gradually. He further supposes that living matter could not have undergone great and sudden changes without being altogether destroyed; and he thus comes to the conclusion that all development, all change of form among living beings, has been very gradual, and that the observed results are the accumulated effect of innumerable variations, in themselves so small as to be almost imperceptible.

We may here remark that this view has the great advantage of being complete; it leaves nothing unexplained, nothing to be supplied by hypotheses which cannot be examined, or which are confessedly beyond the scope of our powers of reasoning, and this we believe is the reason why it has found so many supporters among philosophers.

The third view, which we conceive to be essentially the view taken by Mr. Darwin and his immediate followers, as distinguished from the Evolutionists properly so called, derives all known forms of life, both existing and extinct, from a very few original types. Mr. Darwin supposes that these original forms varied slightly from time to time under changes in surrounding conditions, in much the same manner as we now find animals and plants varying under the changes to which they are subjected by domestication; that any favourable variation that arose in this way was picked out by the survival of the fittest to succeed in the struggle for life; that these favourable variations were inherited; that living beings were thus gradually adapted to changes in the conditions surrounding them; that these surrounding conditions were continually slowly changing; and that all the known forms of life, both existing and extinct, have been developed in the manner above referred to, under the influence of these changes, from the few original living forms.*

This view leaves the origin of the few first types of life entirely unexplained, and does not attempt to give any account of the manner in which life first arose. It will also be observed that it does not attempt to give any precise explanation of the manner in which change in surrounding conditions causes living beings to vary.

Mr. Darwin, however, like the Evolutionists, suppose all development or change of form among living beings to have been very gradual and to have proceeded by almost imperceptible degrees. In the last edition of the "Origin of Species" he expressly states that Natural Selection acts with extreme slowness, that it can act only when there are places in the natural polity of a district which can be better filled by some modification of the existing inhabitants, and that the creation of these places will take place very slowly; and he also devotes several pages to proving that species have been evolved by very small steps.†

It may here be noticed that this view of the cause of the succession and variety of forms is consistent either with the Creationist or the Evolutionist view of the origin of the first living being.

The Evolutionists and Mr. Darwin both agree in insisting on the facts that (1) the struggle for life, even in the case of those forms which are very widely

* "Origin of Species," sixth edition, pp. 84-5.
† Ibid., p. 202, *seq.*

spread and very abundant, is extremely severe, as is evidenced by the enormous number of individuals produced in proportion to the number which survive long enough to perpetuate their kind; (2) that the production of every portion of the structure of any particular living being involves the expenditure of some part of the energy of such being; (3) that the production of a new organ, however incomplete or rudimentary, or of a new structure, however small or insignificant, would likewise involve the expenditure of a portion of the energy of the living being in which such new organ or new structure occurred; and (4) that no living being possesses an unlimited supply of energy, and consequently that any energy which may be applied in adding to any existing organ or structure, or in producing any new organ or structure, must be so applied by withdrawing energy from the other parts or some of the other parts of the living being in which the change in the application of its energy takes place.*

It follows from these facts that no new organ and

* Mr. Darwin's views will be found at pp. 117, 118 of the "Origin of Species," and seem to justify what we have said here, as he expressly states that Natural Selection is continually trying to economise every part of the organization, and that it will be an advantage to the individual not to have its nutriment wasted in building up a useless structure. It is true, at p. 118 he states his belief that Natural Selection may largely develop an organ without requiring as a compensation the reduction of some adjoining part; but we must remember that if the newly developed organ is of advantage to the species, the individuals which possess it in a well developed condition will be the most vigorous, and may readily possess energy sufficient to keep up adjoining and useful structures to their original size.

no new structure can be produced and perpetuated among a race of living beings, unless such new organ or new structure was at its first appearance beneficial, to some extent at least, to the being in which it occurred in the struggle for life under the conditions to which such being was for the time exposed. Any variation, any new organ, or new structure, which did not fall under this rule, could only be produced by the withdrawal of a part of the energy of the being from the production of the other parts of its structure ; but this withdrawal must necessarily be a disadvantage to the being in which it occurred in the struggle for life, and any such variation, new organ, or new structure would therefore be eliminated by the action of Natural Selection.

If, therefore, all living beings have been produced in the manner supposed by the Evolutionist, every specialized organ and every specialized structure found in some living beings, and not in others, must be such that every approach to such special organ or structure, however incomplete or imperfect when it first appeared, must have been of immediate advantage to the living being in which it was produced, in the struggle for life under the conditions to which such being was at the time exposed.

The same remark will apply to all specialized organs and specialized structures met with in some living beings, and not in others, if we suppose the different forms to have been developed according to Mr. Darwin's view, except so far as these specialized organs and specialized structures existed in, and formed points of distinction between, the few original forms which Mr. Darwin takes as his starting-point.

We have used the words "organ," "structure," because these are the words which the Evolutionists and Mr. Darwin use in explaining their theories; but if we look back to our investigations into the nature of a "molecule," we cannot help seeing that this is as much a "structure" as any visible part of a living being. We know that the living being exerted force in tearing apart other molecules to obtain the atoms out of which it built up the molecules of each specialized chemical compound formed in its laboratories, and we cannot doubt that part of its energy was expended in the construction of every single molecule of these compounds. It follows, therefore, that if we accept the Evolutionists' view, every specialized chemical compound met with in some living beings only must fulfil the condition, that every approximation to the complete compound must have been of advantage to the being in which it was produced in the struggle for life; and the same rule must apply to such specialized chemical compounds, if we accept Mr. Darwin's view, unless these very substances existed in, and formed points of difference between, Mr. Darwin's few original forms.

## CHAPTER II.

### THE BEARING OF THESE VIEWS ON THE SPECIAL CHEMICAL PRODUCTS MANUFACTURED BY LIVING BEINGS—THE ORIGIN OF LIFE.

We now propose to examine how far the wonderful chemical phenomena which we meet with among living beings can be accounted for by any of the hypotheses we have just stated.

We need say little or nothing of the Creationists' view. It is admitted, on the one hand, that the mode of operation of the creative power cannot be comprehended by us, and, on the other hand, the theory assumes that the power exerted was sufficient for the purpose, and will therefore, if accepted, completely account for all the observed phenomena of life. It is true we have no experimental knowledge of any such act of creative power having ever been exercised; but we have also no direct knowledge that such an act of power has never been exercised.

The great scientific objection to this view, in the shape in which it is generally put forward, is that it assumes that all the observed phenomena of life are due to the action of a power beyond our means of comprehension, and thus requires us to treat the whole mass of these particular natural phenomena in a manner entirely different from that in which we treat other natural phenomena, and does so without assigning any sufficient cause for the distinction. There is no reason *à priori* why some at least of the phenomena of life should be more beyond our comprehension than the phenomena, for instance, exhibited by the solar system.

It must be admitted that this is a very weighty objection; and (apart from revelation) the only real claim of the Creationists' view, in this extended form, to be accepted as the true explanation of the phenomena observed, must be founded on the insufficiency of all the other theories which can be brought forward to account for the facts which the varied forms of life present to us.

Let us now turn our attention to the Evolutionists' view. This supposes life to have been called into existence, and then developed into various forms, by the action of the ordinary physical forces, and is essentially a scientific theory, capable of being examined in the ordinary way, and, like other scientific theories, it must stand or fall by its sufficiency to account for the phenomena observed.

As we have seen, the philosophers who support this view consider that the higher forms of life were produced by development from the lower forms, and admit that the first living being must have been of the very simplest type, as the necessary and logical consequence of this hypothesis.

Apart from this, however, we shall see that they have good reason for supposing that the first living being was of a very simple type, scarcely distinguishable in appearance from matter not possessing life. Even Professor Hæckel and the most advanced Evolutionists admit that the physical forces under the present conditions of the world cannot, with all the help in special surroundings which we can give them in our laboratories, bring into existence a single being of even the simplest type, when they have matter to act upon which has not previously been elaborated by living beings. How enormous, then, must have been the differences between the conditions which formerly existed, and those which now prevail, if the physical forces were in former ages able to bring into existence a complicated organism, such as a flowering plant or a vertebrate animal, at once, by a single operation upon matter, which up to that time had been formed only into compounds subject to the laws which we meet with in the province of mineral chemistry. It is almost incredible that the surrounding conditions can have changed to such an extent during the period in which life has existed on the earth; and when we consider how easily life is destroyed, we cannot believe that the conditions under which it first appeared can have been very different from those under which it is still able to continue on the face of our globe.

Moreover, if the conditions at the time at which life first appeared were somewhat like those which now obtain, and we are notwithstanding to believe that the physical forces which still surround us were then able to perform such wonders as those we have referred to, it is almost inconceivable that they should not now be able, at all events with the aid which we can give them in our laboratories, to produce some simple form of life, and yet it is universally admitted that this is entirely beyond their power when we use matter not previously elaborated by some living being.

The properties and mode of action of every kind of physical force are so unchangeable, while it retains its special form, that it is incredible that the physical forces should not now be able to produce some simple form of living being, if in former ages they were able to call even complicated forms into existence; and it can hardly be doubted that any living being which the Evolutionist can be permitted to treat as the starting-point of his theory, must have been of the very simplest possible kind, and cannot have exceeded any type which still exists in complexity of structure.

Having got so far, we naturally ask, what was the nature of the surrounding conditions under which it is supposed that the physical forces, which we still find in action, were able to give rise to a body possessing life? In what did these conditions differ from those which now obtain, or from those which we can artificially produce in our laboratories? Here the

Evolutionist philosophers altogether fail us, and the writer has been unable to find a single attempt to answer these questions. It is assumed that when the world was "young" the conditions under which the physical forces acted on matter were different from those which now exist, and were sufficiently different to enable these physical forces to produce a being possessed of life; but this is all that is said, and it must be admitted that it is very vague, and very unsatisfactory to the chemist. We shall see presently how far chemical experiments render it probable that in distant ages, when the world was "young," the surrounding conditions were more favourable to the production of life than they are now.

We have already seen that there is considerable reason for believing that our globe was originally in a molten state, and that its present solid condition is due to the cooling which has gradually taken place, and we have also seen that the Evolutionists entirely adopt this hypothesis: let us, in the first place, inquire how far this supposed cooling can have provided any surrounding conditions which can reasonably be considered sufficient to account for the production of life by the unassisted action of the ordinary physical forces.

We have seen that life is unknown except in beings which contain protoplasm, and it is matter of everyday experience that no living being can bear to have the actual protoplasm of which it is composed heated to a temperature considerably below that of boiling water without losing its vitality. Many forms of life have special means of avoiding this heating, as by cooling apparatus, where evaporation is brought into play, or by strong armour or non-conducting defences, which suffice to exclude a considerable amount of surrounding heat for a short period; but these are all the attributes of elaborately organized beings, and none such can be allowed to the first organism which the Evolutionist believes to have possessed life. If, therefore, the earth has cooled down from a molten state, it is obvious that the first living being, which must on Evolutionist principles have been of the simplest type, and composed of protoplasm only, cannot have maintained its existence on our globe until such a cooling had been effected, that some parts at least had fallen to a temperature considerably below that of boiling water. Moreover, a long period, we do not know how long, but it must have been long, must have elapsed between the time at which water was first able to exist as a fluid on any part of the earth and the time when the temperature at any point had fallen sufficiently low to enable any living being of this type, if formed, to escape instant destruction. Yet experiment has clearly proved that by far the greater number of known chemical compounds might have existed under conditions of temperature which would just permit water to take the form of a fluid; and there can be no doubt that all, or almost all, the chemical compounds, not due to the manufacturing operations of living beings, which we meet with in nature, must have been already formed, and have occurred in larger or smaller quantities, during the whole of the period which elapsed between the time at which water first appeared as a fluid and the time when a being formed of protoplasm only would have been able to live. Experiment has also shown that a large number of these very same compounds could not have been formed, and would not have occurred, under the conditions of a temperature sufficiently high to keep the earth in a molten state. We may therefore fairly consider that we have absolute proof, so far as chemical surroundings are concerned, that when we compare the state of the earth which obtained at the time when the first living being is supposed to have been called into existence with the conditions which prevailed immediately before that wonderful event took place, or with those which now prevail, or which we can at will reproduce in our laboratories, we find that the change, to which the Evolutionist attributes the production of life, must have been altogether insignificant in comparison with the enormous changes which surrounding conditions had undergone during the period in which the earth passed from a molten state to a condition in which water was able to exist as a fluid. It is consequently in the highest degree improbable that so slight a variation in external conditions can have been sufficient to cause the physical forces to operate in any manner distinctly different from that in which they acted before life appeared or even from that in which they now act.

The Evolutionist must, therefore, admit—

(1.) That the earth was for ages upon ages, and through vast changes of condition, under the action of the physical forces which still surround us, but that during all this time no being possessing life was called into existence.

(2.) That as the earth cooled down, a long period occurred during which the conditions of our globe, as compared with those which had previously obtained, were not very different from those which now exist, but that during this period also no being possessing life was called into existence.

(3.) That the change to which he attributes the production of life was a comparatively trifling change, and that it was a change from conditions not very unlike those which now prevail, to conditions which, from the very nature of life, must have been almost identical with those which at present surround us. Nevertheless, he requires us to believe that the physical forces, with no aid but that which they derived from this trifling change in external conditions, suddenly succeeded in calling into existence a combination of elements (now known as protoplasm), which at once exhibited all the properties of life; and he further calls upon us to suppose that, as the earth subsequently grew cooler, the physical forces lost the power of giving rise to this combination, with its special properties, but that some of the forms of life which had then been called into existence succeeded in holding their ground.

Now we have seen that the peculiar power of exerting force, without undergoing any corresponding change, which living beings possess, is the grand distinction which separates living from non-living matter, and that this power cannot be attributed to the mechanical condition or to the chemical composition of protoplasm. We have also seen that the mere chemical compound protoplasm does not invariably or necessarily possess this peculiar power, and that the force which living beings exert cannot be considered a mere transformation of portions of the physical forces effected by the peculiar molecular state of the protoplasm on which the forces fall; and, lastly, we have seen that the powers of living beings are altogether unlike the powers which any other portions of matter exhibit.

The difficulty, therefore, is to explain how the physical forces, after having acted for ages upon ages, and under conditions which had undergone enormous changes, on the chemical elements of which the substance of our earth is composed, without ever endowing any of the innumerable chemical combinations thus formed with the powers of life, came suddenly, without the occurrence of any marked variation in the conditions under which they acted, and without any apparent reason, to change their mode of operation in the case of one single compound only, and to endow this particular compound with wonderful powers, which we actually find are not the invariable or necessary attribute of this special combination of atoms, which are demonstrably not the mere result of complex chemical composition, or of peculiar molecular condition, and which are never exhibited by any other of the very numerous compounds formed by the elements present in protoplasm.

The theory of evolution forbids us to suppose that the physical forces suddenly changed in kind; is it, then, probable that these forces, after forming a chemical compound in the ordinary way, differing in no respect from other compounds such as they had previously formed, except that it was unusually complex and unusually unstable, suddenly proceeded, under the conditions to which we have referred, to endow it with extraordinary powers, altogether unlike anything which other compounds had ever possessed? Can we reasonably believe that they did so, merely because the earth at the time lost some trifling portion of the force which had previously been present in the form of heat?

No doubt we constantly find cases where compounds are not formed under conditions of temperature, under which they would instantly be again decomposed, but where these very compounds are immediately formed, when the conditions are so far changed that their molecules are able to resist decomposition, and the loss of heat might therefore be the reason why the new compound was then formed for the first time, but would not, according to our experience, be in itself any reason why this compound, *when formed,* should be endowed with powers independent of its chemical composition or its molecular condition, which no other compound had or has ever possessed. Indeed, when we consider how trifling, from a chemical point of view, that change in external conditions was, to which the Evolutionist attributes the formation of the first living being, we cannot but feel that to assume that the physical forces did so endow this particular compound, at the time and under the circumstances at and under which the Evolutionist believes life to have been called into existence, is to suppose that a phenomenon occurred which was as much a miracle, as much a breach of the laws which had up to that time governed nature, as any recorded departure from, or breach of, the laws which now govern nature which is called a miracle. Yet scientific men in a scientific inquiry reject this last: why, then, should they not reject the first supposed departure from those laws which had up to that time governed nature?

If, again, we suppose that in the former state of the world the physical forces did not give rise to compounds endowed with the properties of life merely because the amount of heat present was too great to permit such compounds to exist, why should the forces cease to give rise to compounds so endowed when the amount of heat present was actually less than that existing at the time when they were able to do so? And if we suppose that a certain amount of heat must be present to enable the physical forces to produce such compounds, why do they not still continue to produce them when the requisite amount of heat is supplied artificially? Moreover, any variation whatever in external conditions which can have taken place since life first appeared must have been altogether trifling; why, then, should the physical forces, after having once acquired the power of endowing compounds with the properties of life, not continue to preserve such power in spite of any such slight changes? Was there not, at the moment the power was lost, again a breach of the laws which then governed nature—another miracle in fact?

We look in vain for any satisfactory answers to these questions from the Evolutionists; and when we remember what an enormous lapse of time, and what vast changes in external conditions, must have taken place before the period at which the physical forces are supposed to have made a change in their mode of operation, and called a being possessed of life into existence, in comparison with any time which can since have elapsed, and with any changes which can have occurred, either at the epoch when life first appeared or at any more recent date, it must, we think, be admitted that the external change to which the Evolutionist attributes the production of life cannot reasonably be considered sufficient in itself to have effected so wonderful an alteration in the mode in which the physical forces acted, and that the very first test which we have thus applied to the theory reveals a most serious objection to the Evolutionists' view of the origin of life.

In truth, if we compare the views of the Creationist and the Evolutionist on this point, we cannot help feeling that both are equally driven to a miracle—that is, to a departure from the laws which had up to that time governed nature—to account for the first production of a being endowed with the properties of life. The Creationist, however, presupposes the existence of a cause competent to produce the miracle, while the Evolutionist, less logically, assumes a miracle to have taken place, without assigning any sufficient cause for the event.

If in this matter the Evolutionist can give no satisfactory answer to the questions we have asked, if he cannot any more than the Creationist dispense with the supposition of the happening of an event which was a departure from the laws which had up to that time governed nature, his theory stands on no higher scientific ground than the theory of the Creationist; and if we must then choose between the two, the Creationist's view of the origin of life must logically be the one accepted. Passing now from this preliminary difficulty, let us see how far chemical experiment would lead us to expect that the condition of the earth, on the supposition that it has cooled down from a molten state, was more favourable in former ages, than it is at present, to the production of a complex and unstable compound containing carbon, such as protoplasm, by the unaided action of the ordinary physical and chemical forces in their familiar forms.

(1.) Considering the quantity of uncombined oxygen still existing in our atmosphere, if there is one chemical fact which can be asserted with regard to the past condition of the earth with more confidence than another, it is, that at the time when the elements are supposed to have been first combined into a compound body possessing the properties of life, the whole of the available carbon existing on the earth must have been locked up in combination with oxygen in the shape of molecules of carbonates and carbonic anhydride, and it must be remembered that carbon is, so far as we know, an essential constituent of every living thing.

(2.) We must now ask the reader for a moment to recur to our former account of the chemical actions which take place in mixed solutions and in mixtures of compounds in a state of fusion, and to the explanation of these phenomena which we have there attempted to give. The results of actual experiment, where any action takes place at all, may be summed up in the following statements (generally known as the laws of Berthollet) :—

(*a*) In a mixture of solutions of different compounds, if chemical interchange of elements between the compounds in solution will give rise to an insoluble compound, that compound is formed.

(*b*) In a mixture of compounds in a state of fusion, if chemical interchange of elements between the fused compounds will give rise to a volatile compound, that compound is formed.

What, then, should we expect to find had taken place on a globe whose surface had first for ages been in a state of fusion, and had subsequently for a long period been submitted to the solvent action of enormous quantities of heated water, possibly holding in solution energetic chemical reagents, such, for instance, as hydrochloric and sulphuric acid ?

Every chemist will, we think, at once admit that if he were asked to specify the conditions under which, to judge from chemical experiment, the most stable chemical compounds would be formed, and under which those compounds only would in the end be found, whose stability was such that the greatest and most energetic application of force would be required to break up their molecules, these are the very conditions which he would have chosen.

If, again, a chemist were asked in what combination he would lock up carbon in order to make it as unavailable as possible for the purpose of constructing complex compounds, in whose structure carbon played an essential part, he would unquestionably choose the combinations with oxygen known as carbonates and carbonic anhydride.

It is true that with a few rare exceptions we can scarcely venture to state with confidence that the whole available amount of any element existing on the earth was, at the time when life is supposed first to have been called into existence, included in the molecules of one or two specified compounds, but we can undoubtedly state with confidence that all the principal elements, with the exception of oxygen and nitrogen, but including carbon, were then locked up in compound molecules of a stable character, whose molecular equilibrium it would require great force to disturb, and that the relative position of these compounds with respect to one another must have been distinctly unfavourable to chemical reaction betwen them.

The results of chemical experiment are thus most clearly in favour of the proposition that at the time when the first living being is supposed to have been called into existence, the surrounding conditions, so far as chemical change is concerned, were distinctly more unfavourable to the production of protoplasm, capable of manifesting life, by the simple unaided action of the physical forces, than they are at present, when the earth abounds in compounds derived from the chemical action of living bodies, compounds highly complex in character, and of but very moderate stability, and, above all, compounds in which the carbon has already been withdrawn from its combination with oxygen in the refractory molecules of carbonates and carbonic anhydride, and is thus far more readily available for the purposes of building up the complex carbon compounds which are met with in living beings.

Indeed, we cannot help seeing how strongly even the Evolutionists themselves have felt this, if we examine the experiments which have been made with the view of ascertaining whether life is ever generated spontaneously at the present time. All such inquiries have been made under conditions which it is admitted cannot have obtained at the time when the first living being was called into existence, for they have all been investigations into the products formed during the slow decomposition of solutions containing organic matter derived from pre-existing life; while, if the Evolutionists' view of the origin of life is to be adopted, the search should have been prosecuted among the ashes of a volcano or the cinders of a blast furnace; for these have passed through the nearest approach which can be found at the present day to the conditions under which the Evolutionist believes the first living being to have been called into existence, and it is among these, therefore, that the Evolutionist ought to expect to meet with instances of spontaneous generation.

It may perhaps be urged that in those ancient times, when life is supposed to have first appeared, there was a greater supply of physical force than there is at present, and it is highly probable this was the case; but unless we suppose such force to have acted in those times in a different manner from that in which force under the same forms now acts, we can hardly accept this as a sufficient solution of the problem.

As all chemists know, the difficulty in forming complicated "organic" compounds in the laboratory is not that we cannot employ a sufficiency of force, but that the force we employ acts too energetically, and instead of building up the complex structures we wish to produce, leads to such violent chemical action between the atoms, that only comparatively simple molecules, with a comparatively high degree of stability, are produced. We have used too much rather than too little force. In fact, when we try to build up complicated pieces of chemical architecture like protoplasm, we find ourselves much in the position of a man who attempts to execute a fine and delicate piece of woodwork with no tool but an axe. He fails, not because his tool will not cut, but because it cuts too much. From the chemical point of view, there can be no doubt that the greater the quantity and the greater the intensity of the physical forces formerly acting as compared with those which now act, the less probability there would be of such a substance as protoplasm being formed.

Upon the whole, then, we come to the conclusion that the chemical difficulties presented by the Evolutionists' explanation of the manner in which life was first called into existence are so great that in the present state of our knowledge this theory must be altogether rejected as a scientific explanation of the *origin* of life.

## CHAPTER III.

### THE EVOLUTIONISTS' VIEW CONTINUED—THE DEVELOPMENT OF SPECIAL CHEMICAL COMPOUNDS.

LET us now proceed to examine the second part of the Evolutionists' theory, that, namely, which deals with the progress and development of life after it had once been called into existence.

Professor Hæckel * has described to us the form in which he considers that life first appeared on the earth, and on this point we believe he is in agreement with the other Evolutionists as distinguished from Mr. Darwin and his followers.

According to the Professor, this original form, to which he gives the somewhat formidable name of "Archigonic Moneron," was a small homogeneous lump of protoplasm altogether devoid of any special organs, but capable of spontaneous motion to a certain degree, and also capable of selecting and extracting nourishment from particles coming within its reach and suited for that purpose. In fact, it is represented as being very like certain microscopic animalcules, which

* See "The History of Creation."

are still met with both in sea and fresh water. This is a wonderful description, and we must certainly admit that the Professor has taken a sufficiently simple organism as his first living being. It does not very clearly appear how the "moneron" effected its movements, as it is stated to have been homogeneous in structure; but there can be no doubt that if it did make any spontaneous movements, it must have consumed some part of its substance to obtain the requisite force, and must therefore have required nourishment to supply materials to make up this waste, and accordingly we see that the Professor attributes to it the power of taking this nourishment.

Here, however, we seem to meet with a difficulty. Protoplasm is itself incapable of decomposing carbonic anhydride or carbonates, and yet, as we have seen, with the exception of that portion included in the bodies of the monera themselves, the whole of the carbon on the globe at the time when the moneron first appeared was locked up in the compound molecules of these very substances, and there is therefore considerable difficulty in seeing how the monera procured the nourishment by means of which they repaired the waste of life.

In fact, the Professor places the moneron in the world with the wants and necessities of a living being, but entirely forgets to provide it with any means of supplying these wants. He compels the physical forces to labour at the production of the first living being; but when he has once called the creature into existence, he seems to leave it to perish by starvation. We do not of course put this forward as a fatal objection to the Professor's view, but we do think we are fairly entitled to ask for some information as to the manner in which it is conceived the monera procured their materials.

Let us, however, for the present assume that the first living being was such as the Archigonic Moneron is stated to have been, and let us proceed to examine how far, on this supposition, the existence of special chemical compounds, such as chlorophyll, and special chemical powers, such as that of decomposing carbonic anhydride, which are confined to some forms of life only, can be satisfactorily accounted for by the theory of the Evolutionist.

If the first living being was composed of protoplasm, and protoplasm only, it seems to the writer that the production of special chemical compounds can only be explained, in any manner which an Evolutionist can possibly accept, in one or other of the three following ways:—

(1.) That these special compounds were produced by the action of the physical forces which still surround us on non-living matter, in the same or somewhat the same manner as that in which these forces originally produced protoplasm.

(2.) That the manufacturing power of living protoplasm was subject to gradual variation, and that these special products are the result of such variation.

(3.) That the actual substance protoplasm has gradually changed, and has in part been thus transformed into the various special chemical compounds we meet with among living beings.

The first of these three suppositions is obviously open to many of the objections we have already examined in considering the production of protoplasm from non-living matter; and it is further open to the objection, that such an explanation of the facts observed does not account for them by a process of evolution or development, but is in reality a mere form of special creation, in which an unknown process of action by the ordinary physical forces is substituted for the unknown action of the mighty being to whom the Creationist appeals. If anything, our present knowledge is in this case unfavourable to attributing any such effects to the action of the ordinary physical forces rather than to an all-powerful Creator. We have some experimental knowledge of the manner of action of the physical forces, and this knowledge is directly opposed to the supposition of their action in the way suggested.

Let us now proceed to consider our second supposition. Here we may observe that this supposition is not open to those philosophers who deny the existence of vital force and consider the phenomena of life to be the result of a mere molecular property of protoplasm, as is the case with fluidity in the instance of water. How can a mere chemical compound which obeys the law of molecular equilibrium vary in the power of exerting force at all, without undergoing chemical change?* If we are to have any variation in this power, unaccompanied by chemical change, such variation can only be due to change in the mechanical condition of the substance. But in the case of protoplasm, such an alteration in mechanical condition is absolutely unknown, and we have every reason to believe that no such alteration can ever have taken place. We must remember that protoplasm is met with among all the forms of life, and yet is always found in the same semi-fluid state of aggregation, and it is therefore extremely improbable that any living beings have ever existed in which protoplasm occurred in a mechanical state differing from that in which we now invariably find it. Moreover, we can scarcely suppose that any living being ever survived a change in external conditions which made the differences between the old and new conditions surrounding it greater than the differences between the conditions which now surround certain forms of life, and yet in these existing forms protoplasm exhibits absolutely no variation in the mechanical state in which it occurs. Is it not, then, unreasonable to suppose that less important differences in surrounding conditions can have been sufficient to cause it to vary in the mechanical state? We cannot, consistently with the

* These considerations are equally applicable to Dr. Bastian's view; for even if we suppose the supply of physical force to have varied at different times, all the protoplasm existing at any one period ought, under similar conditions, to transform the incident physical forces in precisely the same manner and to precisely the same extent, unless we assume that the protoplasm exists in different molecular states.

doctrines of Evolution, suppose that protoplasm varied in mechanical condition without some cause, and yet it seems difficult to conceive that any cause can have been in operation which would be sufficient to account for such variation. Again, experiment proves that protoplasm is extremely liable to undergo chemical change under the influence of external forces, and we can feel but little doubt that any force capable of effecting a change in the mechanical condition of protoplasm, sufficiently extensive to affect the chemical powers of this body, would give rise to some chemical change in its substance, and would thus more or less completely destroy this very unstable compound, and in all probability put an end at once to any manufacturing powers it might possess. We have, however, seen that there is excellent reason for believing in the existence of vital force, and that it is certain that living beings do possess the power of exerting force in some form or other. Have we, then, any sufficient reason for supposing that the manufacturing powers of living protoplasm would vary, and be capable of gradual development?

We think this question must be answered in the negative, if we attribute the variation in manufacturing power to any causes which the Evolutionist can consistently admit.

The arguments which we have already stated, and which we need not repeat, sufficiently prove that there is good ground for believing that protoplasm, as such, has never varied in mechanical condition; but if this be so, the supposed change in manufacturing power must have been due to change in the force exerted by the living being, and we are led to ask what the nature of this change was. Was it a change in the quantity of force only, or in the intensity or the kind of the force present?

If we look to our experience of chemical action in the case of non-living matter, this assuredly points in no uncertain manner to the conclusion that where we find a new and unexpected chemical action set up between certain bodies, this action is due to change in the intensity or in the kind of the forces present, rather than to mere change in their quantity. The Evolutionist, however, can hardly maintain with any consistency, that variation in the force exerted by a living being, sufficient to give rise to the gain or loss of the power of effecting some special chemical change, would not be subject to the same rule; and if this be so, it follows that the supposed change in manufacturing power must have been the result of change in the intensity, or in the kind, of the force exerted by the living being. Such a change in the force must have been due either to external causes or to causes within the protoplasm itself. Let us, in the first place, suppose that the change was due to external causes, and let us inquire what these causes can have been.

The only power which the Evolutionist has at his disposal is the action of the physical forces, and these forces must therefore have been the agents which effected the change; but here it must be remembered that protoplasm is not itself a force, but merely the substance through which the vital force is manifested; and it is at least as hard to conceive that the physical forces, in the course of their action in the ordinary way, gave rise to change in the intensity or in the kind of force manifested by protoplasm as it is to conceive that these forces at the first gave rise in the same way to the original vital force itself.

In truth, this supposition, that the supposed change in the vital force of the protoplasm was due to external causes, must, we think, stand or fall with the hypothesis that the physical forces acting in their ordinary way, but under surrounding conditions differing from those which now obtain, succeeded in calling into existence the first being which possessed the properties of life, and we have already given our reasons for concluding that this hypothesis must be altogether rejected.

On the other hand, if we suppose the change to have been due to causes within the protoplasm itself, we are met by the difficulty that, although the force of vitality appears to be manifested through protoplasm, we have very strong reasons for believing that this substance is itself a true chemical compound, whose molecules are in chemical equilibrium; and any change in the force manifested by the protoplasm, if due to causes within the substance itself, must therefore have been the result of change in its mechanical condition, a supposition which we have already found to be incredible.

Lastly, if we turn to the actual results of experiment on the powers of living protoplasm, as we meet with it among the various forms of life, we find that these agree altogether with the conclusions to which we have come.

It has been most clearly proved that in the cases where special chemical compounds are formed, or special chemical processes carried on, they are invariably accompanied by complex organization, and by the co-existence of special compounds or special apparatus, which are not met with among beings composed of protoplasm only; and it is by means of these special compounds, or this special machinery, and not by means of its protoplasm, that the vital force of the being appears to effect the production of the peculiar compound, or the peculiar chemical action, in question. For instance, in the case of the decomposition of carbonic anhydride, it is the special compound chlorophyll, and not the protoplasm of the plants, which appears to be the immediate agent in effecting this wonderful chemical change.

On the whole, then, we think it is reasonably clear that the Evolutionist is not at liberty to suppose that the manufacturing powers of living protoplasm have ever been subject to gradual variation, and we are thrown back on our third supposition, namely, change in the actual substance of part of the protoplasm itself.

We may here remark that this is really the supposition to which the Evolutionist would naturally have recourse. The other variations, such as those of shape and structure, with which he is concerned, are variations dealing with the matter of which living beings are composed, and not with the forces exerted through such matter; and analogy would naturally lead us to attempt to explain the differences between the chemical products met with among different forms of life, by the same methods as those by which we had explained the existence of the other points of distinction between these forms, without having recourse to any supposed change in the action of forces, unaccompanied by change in the properties and mechanical condition of the matter itself, of which the first living being is supposed to have been made.

We have, however, examined our first two suppositions in order to clear the way, and to show that this third and last supposition is not only the one to which we should most naturally look for an explanation of the phenomena observed, if these can really be explained by the theory put forward by the Evolutionist, but that it is the only one which can possibly give a satisfactory explanation of the occurrence of those chemical differences which we are considering.

Let us now turn our attention to this important question. We will begin by examining the special compounds which take part in those processes, in the course of which the molecules of definite inorganic chemical compounds are torn to pieces, and the atoms of which they are composed made use of as building materials for the complex products manufactured by living beings. As we have already seen, this power of tearing molecules asunder is the most important of all the points of distinction which separate living from non-living matter, and we will choose as our instance the most important of these compounds, and the most wonderful of all these actions, namely, chlorophyll and its power of decomposing carbonic anhydride.

Let us, in the first place, set down the conditions of the problem we are attempting to solve. We have already seen that the theory of the Evolutionist requires us to believe that the first living being was composed of protoplasm only, that protoplasm has no power of decomposing carbonates or carbonic anhydride, and that the only substance by whose aid living beings can effect this decomposition is the chlorophyll which forms the colouring matter of the leaves and other green parts of plants. We have also seen that chlorophyll is a very complex body, the exact composition of which cannot be determined by chemical analysis, but that it differs markedly from protoplasm in not containing phosphorus or sulphur, and from cellulose and other such products of vegetable life in containing nitrogen, and that it must be considered to be a compound of very special character. In addition we have the fact that chlorophyll appears to be useless to the beings which produce it, except as a provider of carbon; for we find that where a supply of carbon is obtained from other sources than the carbonic anhydride of the air, as in the case of such plants as

Neottia Nidus Avis and Orobanche, no chlorophyll is produced, though the other products manufactured by plants of this kind, such as protoplasm, cellulose, etc., are substantially identical with the products manufactured by ordinary green plants. Moreover, in the case of those plants which do not produce chlorophyll, we find them connected with ordinary plants which do produce this substance, by numerous resemblances in form and structure which are frequently so close and so important, that (as for instance in the case of Neottia Nidus Avis) the plants in question have repeatedly been included in the same genus with plants possessing the ordinary green colour of vegetation, and undoubtedly obtaining their supply of carbon from the carbonic anhydride of the air. In no case, however, has any link or intermediate product connecting chlorophyll itself with any of the other products of vegetable life been detected; a plant either produces the perfect compound chlorophyll, capable under suitable conditions of decomposing carbonic anhydride, or it produces nothing of the kind at all, and procures no part of its supply of carbon from the carbonic anhydride of the air.

Lastly, there can be no doubt that all the living beings which have existed from the time when the first Archigonic Moneron appeared down to the present time, have been surrounded by gases and fluids which contained carbonic anhydride and carbonates. The amounts of these compounds present may have varied; but there can be no doubt that they have always been present in quantities at least as great as those in which they are now present, and that there has therefore been no change, or, at all events, no favouring change, in the chemical nature of the surrounding conditions which can be referred to, as having induced living beings to turn to the carbonic anhydride of the air as a source of carbon for use in their manufacturing processes, at a later rather than an earlier period in the history of the earth, after life had once appeared.

In fact, there can be no doubt that the longer life had existed on the earth the greater would be the supply of compounds of carbon far easier to decompose than the stubborn molecules of carbonic anhydride, and far more available for any being in search of a supply of carbon; and it is at least startling to find that the Evolutionist requires us to believe that carbonic anhydride was resorted to for the first time at a period when, if his theory be true, our knowledge of the products of the decomposition of living matter makes it almost impossible to believe that there was not a considerable supply of other material at hand, far better suited for manufacture into protoplasm, cellulose, and other products of life, than the extraordinarily stable molecules of carbonic anhydride.

These are the conditions of the problem given by the facts observed; the theory of the Evolutionist, however, requires us to admit some further conditions before the whole problem which he has to solve is fairly put before us.

We have seen that chlorophyll is a very complex substance, markedly different both in chemical composition and in properties from protoplasm.

The development of the former substance from the latter must therefore, on Evolutionist principles, have been a long process. Many intermediate steps must have intervened to connect the protoplasm of the Archigonic Moneron with the chlorophyll, perfected and capable of decomposing carbonic anhydride. A long period must have elapsed while these intermediate steps were being completed, and each intermediate step must have been of use to the being which produced it in the struggle for life. Lastly, there must have been at least a considerable change in the surrounding conditions to have given rise to so remarkable a change as that from protoplasm to chlorophyll. Such is the complicated problem which the Evolutionist has to solve. We need not go far to meet with some difficulties.

In the first place, what change in the surrounding conditions can be put forward to account for so wonderful a fact as the production of chlorophyll, a compound whose sole function appears to be the decomposition of a substance which is probably the most stable of all known chemical compounds? We have already seen that there has been no favourable change in the surrounding chemical conditions. Can we point to any other great change which may have occurred? But one such can, as we think, be even suggested, and this is, that at the time when the first

Archigonic Moneron appeared, there was not sufficient light to enable chlorophyll to decompose carbonic anhydride, and that the development of chlorophyll was induced by increase in the amount of the light which reached living beings.

We will return to this point presently, as it will be more conveniently discussed after we have examined some of the other difficulties presented by the problem.

Passing now from the cause of the changes to the changes themselves, how does it happen that among all the vast host of forms of vegetable life, some producing chlorophyll, and others not—some living under almost every unfavourable condition under which life can exist at all, others under the most favourable conditions—no single form is known which continues to produce even one of the numerous compounds, intermediate between protoplasm and chlorophyll, which the Evolutionist is forced to suppose have existed? All these intermediate compounds must, as we have seen, according to the theory of Evolution, have been useful under conditions which were necessarily almost if not absolutely identical with those under which many forms of vegetable life still live, and it is certainly most extraordinary that they should all have completely disappeared without leaving a trace behind.

If for a moment we suppose that some of the products of existing living beings do form, so far as relates to their composition, a connecting link between protoplasm and chlorophyll, how does it happen that not one of these compounds has any, even the slightest, power of decomposing carbonic anhydride. We should reasonably expect to find that those intermediate compounds which possessed some power of decomposing the anhydride, and which would therefore still be of considerable utility, would be the compounds which would even now be met with amongst some of the forms of vegetable life, and yet it is precisely this class of intermediate compounds which is conspicuously absent.

How, again, came energy to be expended in the production of new products which were useless to the being which produced them? For these new products must have been useless, as we can hardly suppose that a step in the direction of chlorophyll, by the elimination, for instance, of sulphur alone, or of phosphorus alone, from the molecule of protoplasm, can have been of any service to the being in which it occurred, as producing a new substance through which the powers of vitality were to be exercised with greater ease or greater advantage than through the matter of protoplasm, and at the same time any such compound would, as we have every reason to believe, have been wholly incapable of decomposing the carbonic anhydride of the air. If the laws of Evolution held good, any such products must immediately have been eliminated by the action of Natural Selection.

Again, are we to suppose that those laboratories in which the living being worked up its materials, before carbonic anhydride was resorted to as a source of carbon, were prepared to work up the carbon extracted from carbonic anhydride by the first chlorophyll which was produced, in the same manner, and with the same apparatus, with which they had previously dealt with the other carbonized compounds which the being had been accustomed to resort to as sources of carbon? This can scarcely have been the case when we consider the vast difference between the bodies operated upon, and yet to suppose that the rest of the chemical machinery of the living being varied slightly, simultaneously with the production of the first chlorophyll, and was thus enabled to take advantage of this event, is certainly to suppose that several distinct variations occurred simultaneously, so nicely adapted to one another that each was enabled to take advantage of the other. The improbability of such a coincidence of variations is so great that it amounts almost to certainty that it did not occur, and yet, unless it occurred, even the first chlorophyll that was formed must inevitably have been eliminated by the action of Natural Selection.

It will thus be seen that there are very serious difficulties in explaining the production of chlorophyll from protoplasm, by the gradual and almost imperceptible changes on which the Evolutionist theory is founded. The vast difference in stability between carbonic anhydride and all those bodies which beings that do not produce chlorophyll decompose for the purpose of obtaining a supply of carbon, and the remarkably isolated position of chlorophyll as not merely the only product of living beings, but actually the only body met with in nature, and almost the only body known to us at all, which is under any circumstances capable of completely freeing the carbon of the carbonic anhydride from the oxygen with which it is combined, make it incredible, we might almost say impossible, that chlorophyll can have been developed from such a substance as protoplasm by the accumulation of numerous almost imperceptible variations successively picked out by Natural Selection.

Can we, however, suppose that chlorophyll was developed suddenly and as the result of one single variation? Its complexity of structure and its remarkably isolated chemical properties make this impossible, if we are to hold that its existence must be accounted for by the laws of Evolution. Moreover, even such an assumption would not dispense with the existence of numerous concurrent variations, enabling the living being to avail itself of the powers of chlorophyll, and, as we have seen, this supposition is so improbable as to be almost incredible. There can be little doubt that if Natural Selection were the only power in operation, even suddenly produced chlorophyll must have been eliminated.

Are we, then, to suppose that the living being which first produced chlorophyll exercised a kind of volition, and made chemical experiments in hopes of finding some compound which would be able to decompose the carbonic anhydride around it? Such a supposition is absolutely inconsistent with the view of the Evolutionist, and cannot be accepted by him for a single instant.

And yet what other explanation of the production of chlorophyll by beings composed of protoplasm only can be given, than one of those we have examined, all of which, as we have seen, fail to explain the existence of this substance consistently with the theory of the Evolutionist ?

Let us now for an instant return to the supposition that increase of light may have been the exciting cause of the production of chlorophyll, and see whether we can thus escape the difficulties we have been considering.

In the first place, light, though it has a powerful effect on many chemical compounds, is of itself absolutely without action on carbonic anhydride, and it seems, to say the least, remarkable that the action of a force, which itself exercised no influence over carbonic anhydride, on a substance like protoplasm, which had, and even with the fullest supply of light continues to have, no action on the anhydride, should have caused this substance to vary in a manner which would ultimately lead to the production by gradual steps of a compound which would be capable of decomposing the stubborn anhydride.

In the second place, we can hardly suppose that at the time when the Archigonic Moneron first appeared on the earth, there was not, at some parts of the globe at least, as much diffused light, as that with the aid of which numerous mosses, seaweeds, and other plants, which produce chlorophyll abundantly, but which live in places reached only by a small quantity of diffused light, can decompose carbonic anhydride in large quantity.

Lastly, we appear here to be in this difficulty. Chlorophyll must have been produced either before the time, or at or after the time, when there was sufficient light to enable perfected chlorophyll to decompose carbonic anhydride. If it was produced before that time, the Evolutionist has to account for the production and perpetuation of a product, which would, as we have seen, have apparently been useless to the being which produced it; and a difficulty precisely the same in kind attaches to the supposition that an imperfect chlorophyll was produced before there was light enough to enable even perfected chlorophyll to decompose carbonic anhydride, and that the increasing light found this imperfect product already prepared.

If, on the other hand, we suppose that no approximation to chlorophyll had been effected before the light had become sufficient to enable perfected chlorophyll to decompose carbonic anhydride, and that the whole process of development took place after the light was sufficient for that purpose, we have simply shifted the time at which the difficulty occurred, and are in no better position than we are when we make no supposition as to increase of light.

On the whole, then, it seems tolerably clear that no such supposition will avoid the difficulties which we have pointed out, and we must, we think, come to the conclusion, that in the present state of our knowledge, the production of chlorophyll, from protoplasm, or in a being consisting of protoplasm alone, cannot be satisfactorily explained by the theory of the Evolutionist; and further, that this remarkable compound would not have been met with in nature, if all living beings had actually been developed from a creature of the type of the Archigonic Moneron, by the unassisted action of those causes which the Evolutionist requires us to treat as the only causes which have been in operation.

It is certainly a very remarkable circumstance that the simplest forms of life known to us are composed of protoplasm and other compounds which have no power of decomposing carbonic anhydride, and that it is not till we advance to forms of comparatively great complexity that we meet with chlorophyll. It would almost seem that, if the differences between living beings have arisen through gradual variation, as supposed by the theory of the Evolutionist, these simple forms must have been derived by a process of simplification—by the reverse, so to speak, of the ordinary process of development—from beings, producing chlorophyll, and extracting carbon from the carbonic anhydride of the air, and must have appeared for the first time at a period when living beings of a more complex type had already existed long enough to have manufactured a supply of those organic compounds of carbon, from which alone the simplest known forms are able to manufacture the protoplasm of which they are principally or wholly composed.

Yet, as we have seen, such a supposition is quite at variance with the first principles of the theory of Evolution, and, in addition to this, leads us into most serious difficulties when we come to consider what the conditions of the earth in past times must have been, to enable the existing physical forces to develop a complex living being containing chlorophyll at one operation on non-living matter.

We have examined the problem of the production of chlorophyll by development from protoplasm in detail, because the chemical reaction which this body is able to effect is perhaps the most striking instance of chemical power exhibited by living beings, and also on account of the extreme importance of chlorophyll in the economy of life. It must, however, be remembered that chlorophyll contains no element which does not occur in protoplasm, and there is, therefore, no absolute impossibility in the supposition that it was derived by gradual change from that substance. There are, however, numerous cases in which peculiar chemical compounds are met with in living beings, which contain in combination elements which do not enter into the composition of protoplasm, and, as an example, we will take the case of some of the compounds met with in the blood of one of the higher animals.* It is well known that this fluid plays an essential part in the elaborate process by which these

* The reader should consult the account of Hoppe-Seyler's recent important discoveries, which he will find under the article "Blood," in the supplemental volumes of Watts' "Dictionary of Chemistry."

animals succeed in keeping up the regular supply of heat which enables them to carry on the chemical and other operations of their life continuously; this is, as we have seen, one of the most striking distinctions between higher animal life and vegetable life, and the blood is therefore one of those products whose formation we should naturally call upon the Evolutionist to explain.

In the animal, the supply of heat is kept up by the gradual burning of fuel, which the being has previously prepared, by the aid of the oxygen of the air which is conveyed to the fuel by the circulation of the blood.

Now blood contains an element, iron, which is not met with in protoplasm, but which in the blood takes part in building up some of the very complex molecules of which this fluid consists. The exact manner in which the blood succeeds in absorbing the oxygen of the air, and conveying it to a distance to be brought into contact with the prepared fuel, is not known; but there can be no doubt that the iron plays an essential part in the process, and that it is by availing itself in some way of the facility with which this element, in the presence of oxygen, passes from a lower to a higher degree of oxidation, and again, in the presence of reducing agents, from a higher to a lower degree, that the blood succeeds in bringing the oxygen into contact with the fuel, and thus provides the required heat, as the result of the chemical action which takes place. The compound which contains iron is met with in every kind of blood, and forms the most essential and most characteristic feature of this complex fluid. Without its aid the blood, which, as we all know, is most intimately connected with the continuance of the life of the animal, would be unable to perform its functions; and we have here, therefore, a case of a chemical compound which contains an element not met with in protoplasm, and which is yet as essential to the continuance of the life of the beings in which it occurs, as protoplasm itself is to the existence of this life.

As with most important organic products, the atomic structure of this compound is extremely complex; in addition to the iron, it contains carbon, oxygen, hydrogen, and nitrogen, and probably also phosphorus and sulphur, all united in one unstable combination, and it at least equals, and probably exceeds, protoplasm itself, in the complexity of its molecule.

Let us now examine how far the theory of the Evolutionist can give a satisfactory explanation of the occurrence of this important compound.

In the first place, if all chemical compounds met with in some living beings only, and not in all, have been derived by gradual variation from the compounds produced by the first living being, we are forced to assume that the part of the blood which contains iron in combination was developed from protoplasm by gradual variation. Here, however, we are at once met by a difficulty. How can any variation, any slow and gradual rearrangement of the atoms composing the molecule of a body like protoplasm, which contains no iron, give rise to a new molecule containing iron? This could only be the case by virtue of such a transmutation of elements as even the alchymists never dreamed of, and which can certainly not be accepted at the present day; and it follows that we cannot attribute the formation of this part of the blood to mere gradual variation from protoplasm. There must have been some breach of continuity—in other words, some apparent departure from the principles of Evolution—when an unfinished molecule composed of carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulphur—itself, we may for the sake of argument suppose, the result of the gradual variation of protoplasm—was for the first time completed by the addition of an atom of iron, and the question really is whether such a change is one which we can reasonably and fairly regard as the result of one single variation, when we compare it with other changes which the Evolutionist admits can only have been effected by the accumulation of a series of small variations spread over a long period of time.

We must here remember that we have reason to believe that these complex organic compounds, when once formed, comply with the law of molecular equilibrium, and that, if they do so, the chemical force exerted by each atom plays an important part in the equilibrium, and therefore in the existence, of their molecules. Now we have good reason to suppose that the chemical force exerted by an atom of iron, is very different in amount and in mode and direction of operation, from the chemical force exerted by an atom of any of the elements carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulphur; and the substitution or incorporation of an atom of iron in a molecule, where previously no portion of this metal had been in chemical action, is thus a very great and important change, and is necessarily accompanied by extensive disturbance and rearrangement of the chemical forces acting on the molecule, and in consequence, as we may reasonably suppose, by extensive change also in the relative position of the atoms composing the molecule.

Now if we examine some of the cases which the Evolutionist puts forward as undoubted instances of those variations which he looks upon as the steps through which distinct forms are ultimately developed, we shall find that these are simply due to a rearrangement of molecules unaccompanied by any disturbance or rearrangement of chemical forces, or any displacement or motion of atoms. This is obviously the case in numerous instances of mere change of shape and form which are clearly instances of "molecular change," and not of "chemical change." But, as our previous investigations have shown us, the forces which are sufficient to produce a molecular change, such for instance as from a fluid to a gaseous state, or from a state of solution to the state of a solid forming a crystal, are as a general rule not sufficiently intense and powerful to cause chemical changes to take place; all our experience with non-living matter in fact points to the conclusion that chemical change, that is, displacement of and motion among the actual atoms themselves, is the result of a more intense action of force, and of a greater and more important change in the bodies in which it takes place, than molecular change in which molecules only are moved. But if this be so in the case of living beings (and we cannot doubt this when we consider how uniformly force acts), it is highly illogical to suppose that a change in the products of life, as the result of which a rearrangement of the actual atoms themselves is effected, can be of less magnitude or less importance than a case of mere change in the position of molecules. So far, therefore, from a change in which an atom of a new element such as iron is introduced into an organic molecule being so trifling and insignificant that we may fairly and reasonably look upon it as the result of a single small variation only, commensurate with those to whose accumulated effects we attribute changes which are mere changes of shape and form, our experiments on non-living matter teach us that we must really look upon this change as one of the most extensive and most important changes which have ever occurred among living beings.

Hence, if we continue to insist that all observed changes among living beings have been caused by a succession of small variations, it is certainly in the highest degree illogical to suppose that perceptible changes of form and shape merely, could only be caused by the accumulated effect of a large number of small variations, and at the same time to suppose that the far more important and far more extensive changes which are involved in the production for the first time of a molecule containing an atom of iron, were effected at once and as the result of one single variation only.

Yet, as we have seen, it follows from the very nature of the change itself, and from the fact that the atom is the starting-point of all chemical combination, that the addition of an atom of a new element such as iron to complete a molecule which was in course of manufacture, must of necessity have been a sudden change, and the conclusion thus seems inevitable that we have here an instance of a special organic compound which cannot possibly have been produced by the causes to which the Evolutionist view requires us to attribute all the points of distinction between living beings.

We can hardly escape from the difficulty by supposing that some force, at present unknown, and capable of transforming the atoms which we find in the form of atoms of one element into atoms of another element, was in operation, and assisted in producing the change we are considering. Such a supposition, however improbable, would not of itself perhaps be absolutely impossible, and certainly could not, in our present state of ignorance as to the ultimate nature of matter, be positively disproved; but it must be remembered that the Evolutionist expressly refers the production of the compounds, which we meet with among living beings, to the action of the forces which we still find in operation on the non-living matter around us, and that he is the last person who can be allowed to assume that unknown forces not now in operation have ever acted on living beings, or that there has been any, even the slightest, change in the mode of action, as distinguished from the quantity, of the physical forces which still surround us.

It will here be seen that somewhat similar difficulties might have been raised with regard to the elimination of sulphur and phosphorus from the molecule of protoplasm to obtain chlorophyll, and no doubt there is considerable difficulty on this head; but it must be remembered that we know that protoplasm is easily attacked and reduced to simpler compounds by the action of external forces, and the difficulty is far more formidable when we have to account for an increase of complexity by the actual taking in of atoms of an element which had previously been entirely absent.

On the whole, then, we come to the conclusion that blood containing iron in combination cannot have been derived from protoplasm by the process of gradual variation on which the Evolutionist theory is founded.

We need hardly observe that its production suddenly, or its production by an act of volition, by a series of tentative chemical experiments, carried out by a living being in search of an element well fitted to act as a carrier of oxygen, cannot for a moment be admitted by the Evolutionist, for the reasons which we have already referred to in our examination of the problem presented by chlorophyll.

It is obvious also that the argument from the necessity of concurrent variations having taken place to enable the being to avail itself of the properties of the new product, applies with at least as much force to the peculiar functions of the complex fluid blood as to those of chlorophyll, and that the action of Natural Selection is thus opposed to the production of a chemical compound of such extreme complexity applied to such a very special purpose.

Here again, therefore, we cannot help feeling, even more strongly than in the case of such bodies as chlorophyll, that substances, such as the blood, in which we find compounds which contain elements in combination which are not met with in protoplasm, could not possibly occur in nature, if all the compounds which living beings present to us had been developed by the simple action of those causes on which the Evolutionist relies.

Let us now turn our attention to the manufacture and utilization of a third class of compounds in those cases where a substance with which we are familiar in mineral chemistry, such for instance as silica, is first extracted from compounds which have been carried in a state of solution into the laboratories of living beings, and is then applied in a solid form or otherwise for purposes for which the solutions from which the silica or other body has been extracted could not possibly be used.

For example, silica is absorbed by many plants in the form of some soluble combination with potash, or in some similar shape, and from this soluble compound the insoluble silica is extracted by the plants, and utilized by them for the purpose of constructing a skeleton, or of giving strength and hardness to the outer coatings which serve as a protection to their more vital and essential parts.

Here we have chemical decomposition, and therefore an expenditure of energy by the plant. How came this energy to be so applied? How came the plant first to decompose these solutions? And when it first did so, how came it to have the necessary machinery ready prepared to carry the silica which had been extracted to those parts where it would be of use, and to deposit and accumulate it there? Again we see that some at least of the very same difficulties, which we have already referred to in the examination of the problem presented by chlorophyll, apply with more or less force to this case also, and that we have here the additional difficulty of having to account for the application of a new substance to a useful purpose, when the living being which so applied the substance was necessarily altogether unacquainted with it prior to its being extracted in its laboratories; and we can scarcely help feeling that the Evolutionist theory has once more failed to give any very satisfactory explanation of the occurrence of the chemical changes, as the result of which the silica is obtained and applied to the use of the plant.

We might here examine other special chemical compounds which, like chlorophyll, are engaged in obtaining a supply of materials out of which the living being can form the compounds it requires, and which, like chlorophyll, are not met with in beings entirely composed of protoplasm. We should have no difficulty in bringing forward numerous other instances of chemical compounds met with among living beings, which contain in combination elements not occurring as components of protoplasm, and we might refer to plenty of instances in which inorganic compounds, not met with in beings entirely composed of protoplasm, are found in living beings which have obtained them by breaking up and tearing to pieces other inorganic molecules distinct in structure from the molecules of the compounds we are considering; but we do not think it necessary to examine any other cases in detail. On trial it will be found that all such compounds exhibit the difficulties, or some at least of the difficulties, which we have pointed out in the examples which we have already discussed, and that (if we except the case of the isolated compound chlorophyll) very many of these substances present the difficulties which apply to the class of products to which they belong with quite as much force as the instances which we have already investigated and considered at length.

## CHAPTER IV.

### THE EVOLUTIONISTS' VIEW CONTINUED—THE EVIDENCE AT PRESENT BROUGHT FORWARD.

So far, then, we have ascertained that certain classes of special compounds which occur among some forms of life only, present very grave difficulties if we accept the theory of the Evolutionist; let us now inquire what degree of importance we ought to attach to these classes, when we extend our survey to the whole body of special chemical compounds which are met with among living beings. On trial, it will be found that this vast host of substances may be classified as follows:—

(A) Products which contain only elements which are met with as components of protoplasm.

These may be subdivided into—

(1) Products, such as chlorophyll, which are used as aids in decomposing various substances met with by the living being, for the purpose of obtaining manufacturing materials for the complex compounds which the living being builds up in its laboratory.

(2) Products, such as horn or hair, which are used

for other purposes, as, for instance, for coverings, means of defence, and so forth.

(B) Products containing elements not met with as components of protoplasm.

These may be subdivided into—

(1) Products containing these elements built up into the structure of molecules which are manufactured in the laboratory of the living being.

(2) Products which are familiar to us in mineral chemistry, but which, when met with among living beings, have been obtained by the decomposition of molecules of a different kind, which have been absorbed from the soil or other surrounding substances in the course of procuring a supply of raw material for the operations of the living laboratory.

(3) Products of the same class as those comprised in No. 2, but which have been absorbed in the same form as that in which they are met with in the frame of the living being.

Of these five sub-classes it will be seen that three, namely, A (1) (of which chlorophyll is the most important example), B (1) (of which blood is a very important example), and B (2) (of which we took silica as our example), cannot be satisfactorily accounted for by the Evolutionist.

There remain the sub-classes A (2) and B (3), but it is obvious that the compounds comprised under the head B (3), when met with in living beings, have undergone no other change than one of locality, and may consequently be left out of account altogether, when we are considering the formation of new chemical compounds from protoplasm.

We have therefore only those products forming the sub-class A (2) left, which can fairly be treated as possible examples of chemical compounds occurring among living beings, which may have been formed by variation from protoplasm. Now we must not forget that, so far as our present knowledge extends, all true chemical compounds obeying the law of molecular equilibrium appear from experiment to be absolutely invariable, and the onus of proof that the chemical compound protoplasm is capable of variation is therefore on the Evolutionist, and we are not to assume *à priori* that any special chemical compound was produced by variation from protoplasm, merely because it is not impossible or inconceivable that it was so produced.

Again, one of the first things which strikes us in examining this particular class of compounds is that they are of comparatively but slight importance in the exercise of those chemical powers which form the grand distinction between living and non-living matter, and that they cannot therefore be treated as of equal significance with the products comprised in the classes A (1) and B (1), in any attempt to account for the production of the special chemical compounds which so many living beings present to us.

Besides, even in this class, the Evolutionist does not altogether escape practical difficulties. We will give a short illustration which we think will make this clear, and which, after the detailed examination we have already made of the subject, is all we have space for.

Consider such a compound as the frightful poison aconitine, which is met with only in the roots and other parts of the genus aconite. This is a distinct and specific chemical compound, and is one of the most powerful and active poisons known, and it will at once be said the possession of such a poison must be of great advantage to the plant as a protection from enemies, which would otherwise devour it. No doubt; but the point is whether anything was gained by the elaboration of so very intense and fatal a poison. Would not the same end have been practically attained by the development of an acrid poison of far less intensity, such as we find widely diffused among other members of the Ranunculaceæ, which are more abundant than the aconites? And if so, how came it that this special compound was wrought up to so unnecessary a point of perfection, when the energy of the plant would apparently have been more usefully directed into other operations which were required for the continuance of its life or the perpetuation of the species? Here again we cannot help thinking that the action of Natural Selection is *prima facie* opposed to the production of compounds of such extraordinary virulence as aconitine, and we may fairly consider it doubtful whether the supposed cause is really sufficient to account for the occurrence of such substances.

Many other instances of the same kind might be brought forward, and when we consider the difficulties which even this sub-class presents, and the large number and great importance of the chemical compounds comprised in the other sub-classes, whose occurrence, as we have seen, cannot be satisfactorily accounted for by the Evolutionist, we may be pardoned for feeling some doubt whether any chemical product met with in living beings which is not common to all, however slight may be the amount of difficulty presented by any individual case, has really been produced by the process which the Evolutionist puts forward as sufficient to account for all the differences between the forms of life.

This consideration naturally leads us to examine what in fact the evidence is by which the Evolutionists support the proposition that all the differences exhibited by living beings are due to the unassisted operation of those physical causes on which they rely. This is an important question, for the theory of the Evolutionist claims to be an experimental theory, founded, not on hypothesis, but on deduction from facts actually observed, and we are therefore entitled to require these facts to be produced for examination.

The only observed instances of change which we have been able to find referred to by any Evolutionist, are changes in external form, changes in mechanical structure, changes due to increase or decrease in the amount of some compound produced by some form of life. We have not met with a single instance where the formation of a new chemical compound which has been, or might have been, beneficial to the living being which produced it, under the change of conditions to which the being has been exposed, is alleged to have been observed. And here we must ask the reader to note that no amount of evidence proving that living beings are really able under changed conditions to produce new combinations of the atoms contained in those bodies, which they are in the habit of decomposing in their laboratories, would bring us one single step nearer to proving by actual observation that living beings could, under the pressure of a change in surrounding conditions, have recourse to new compounds, with which they had previously not intermeddled, as sources of the atoms which they required for their manufactures; far less would such evidence prove that living beings could, under the influence of such a change, actually employ new elements, differing widely in character from any of those previously employed, as part of the material which they worked up in forming most essential and important portions of their frame. And yet the existence of such compounds as chlorophyll, and that part of the blood which contains iron, makes it imperative on the Evolutionist to bring forward instances of the production of new combinations involving the features to which we have here referred, if we are to admit that all the chemical products met with among living beings have been produced in the course of the gradual development of a form composed of protoplasm only.

It is clear, therefore, that before the theory of the Evolutionist can properly be treated as one every part of which is founded on actual experience, on fact as distinguished from hypothesis, some examples, however trifling or however rare in occurrence, must be brought forward, in which a new product containing new elements, and an old product manufactured from some new and distinct combination of the old elements not previously decomposed by the species of living being under consideration, have been observed to be produced under the influence of changed conditions, yet we have entirely failed to find a single instance of either kind referred to by any Evolutionist.

In fact, so far from bringing forward evidence of this kind, the Evolutionists have not produced any well-established instance, which we can discover, of even that simplest case of the formation of new chemical compounds, where some living being under the influence of change in the conditions surrounding it has succeeded in constructing a new compound out of the old familiar materials which has or might have proved useful to it under the change to which it has been exposed; and if we examine the question for ourselves, we shall cease to feel any great surprise that no such instance has been put forward.

No doubt it is well established that the amounts of the different chemical compounds, characteristic of some particular species of living being, produced by different individuals of this species vary considerably; but such variations are mere variations of quantity, and can scarcely be treated as evidence of the existence of differences in kind between the chemical compounds manufactured by the individuals. All such cases must therefore be put on one side.

Again, it is a well-established fact that where the tissues of a living being are injured, and the injury is not sufficient to cause death, or where the tissues are brought into direct contact with energetic chemical reagents, not sufficiently powerful, or not present in sufficient quantity, to destroy life, new compounds, such, for instance, as pus, are constantly formed; but can it be said that such compounds are substances produced by the living being in the natural course of its manufacturing operations, which are beneficial to it under the changed conditions to which it is exposed? There can, we think, be no doubt that this is not the case, and that these compounds are really the result of that decomposition which is set up among the tisuess of the living being, in consequence of the injury, or through the presence of the destroying chemical agent, and all such cases therefore must also be put on one side.

Further, it is known that a vast number of compounds which occur as colouring materials possess a perfectly definite chemical composition, and it might be contended that the differences of colour, which so often appear when two individuals of the same species are compared, do probably furnish us with an instance of the very kind of which we are in search, and yet here again we think that all these cases must be put on one side.

It must be remembered that the brilliant colours which so many living beings exhibit are not due to light emitted by the being itself, but are the result of the more or less exclusive reflection of some of the coloured rays which are sent to us by the sun, and that the absorption of the rays of other colours is effected, not by the atoms, but by the molecules of which the living being is built up. It is known, too, that the relative position and arrangement of these molecules, and the relative number in any particular part, of molecules of a kind possessing special powers of absorption, will powerfully affect the result, and it is an established fact that different individuals of the same species do present slight variations in the relative position of the molecules of which corresponding parts are built up, and do also exhibit variation in the relative amounts of the special chemical compounds characteristic of the species which the individuals produce. It is plain, therefore, that the slight variations in colour which occur among different individuals of the same species are amply accounted for by those molecular differences which are known to occur, and that we need not have recourse to the violent hypothesis that these observed differences of colour are due to differences in the kind of chemical compound manufactured by the individual; and we may add that chemical analysis, so far as it can be appealed to, in such a matter, entirely confirms this conclusion.

Lastly, let us turn to some of those observed facts on which the theory of the Evolutionist has in a considerable degree been founded, and let us examine what support they give to the proposition that living beings do, under the influence of changed surrounding conditions, give rise to new chemical compounds which might prove beneficial to them under the change to which they have been exposed.

Numerous animals and plants have been transported by man into climates very unlike those in which they were native, and have thus been exposed to great changes in the conditions which surrounded them, many others have been exposed to the extensive changes in their manner of life, which are incident to domestication, and in both these cases the change has been sufficient to cause some more or less visible variation in those matters of shape and structure which depend upon the relative position of the molecules which build up corresponding parts in different individuals; but can we bring forward a single well-established instance in which these changes have given rise to the formation of a new and distinct chemical compound? Can we even adduce any single instance in which it can be proved that any form of living being has, under the influence of changed surroundings, completely lost the power of forming some chemical compound which it habitually formed in its native climate or in its natural state? And if we cannot do this, ought we not, at the least, to hesitate before we admit that the very slow and gradual changes in external conditions on which the Evolutionist relies, have been competent to give rise to any of the differences which occur among the chemical compounds produced by the various forms of life, to say nothing of the wonderful differences between these compounds and the protoplasm of the Archigonic Moneron?

Possibly some evidence of the kind which is required may exist; but if any such can be produced, the facts should be far more strongly put forward by the Evolutionist than they have yet been; for it is on these facts that the theory must be founded, if we are to treat it as an experimental theory, and at the same time rely upon it in any degree as explaining the production of the numerous special chemical products which are confined to some particular forms of life.

Our examination of the second part of the Evolutionists' view thus leads us to the conclusion, that (1) this view cannot, as at present put forward, give a satisfactory explanation of the occurrence of the most important chemical phenomena and points of distinction exhibited by living beings, and (2) that the evidence put forward as proof that any chemical compound met with among living beings is due to the action of gradual variation, as observed in slight changes of external form and so forth, is extremely unsatisfactory, and upon the whole it must, we think, be admitted that in its present form the Evolutionists' view fails to account for the chemical phenomena exhibited by living beings, and that an examination of these phenomena does prove, as far as such a matter is at present capable of positive proof, that it is not the fact that all living beings have been developed, or derived by gradual variation, from a single simple form of life composed of homogeneous protoplasm.

We have already seen that the view of the Evolutionist fails entirely to give any satisfactory explanation of the origin of life; as we have just seen, it fails to support the hypothesis of derivation from a simple form composed of protoplasm only; and we have already proved that it can derive no support from any of the arguments deduced from the supposed analogy between the growth of a crystal and the growth of a living being.

On all points, therefore, in which the view of the Evolutionist differs from Mr. Darwin's view, it must, we think, be treated by chemists as erroneous, and must, as at present put forward, be rejected altogether, as having proved quite unable to deal with the problems presented by the chemistry of life.

It is true the theory of the Evolutionist agrees well with numerous geological and zoological facts, and also gives at least an intelligible explanation of the wonderful stages through which the embryos of the higher animals pass; but then Mr. Darwin's theory explains these facts equally well; and in weighing the arguments for and against the theory of the Evolutionist, it must not be forgotten that it was founded upon these very facts, and therefore does naturally explain them, though it no more follows that the explanation is correct, than it followed that the geocentric theory of the solar system was correct because it explained some remarkable phenomena in a reasonable and intelligible manner when these were the only phenomena taken into consideration.

## CHAPTER V.

### MR. DARWIN'S VIEW.

MR. DARWIN'S view still remains to be considered, though here we find but little which can be said to be properly within the field of chemical inquiry. Mr. Darwin does not profess to explain the origin of life, or to attribute all existing and extinct forms to development from one single simple organism, itself a mere shapeless lump of protoplasm. He does not give any very decided answer to the question whether he admits several original forms, or only one; but on the whole we may perhaps infer from the concluding passage of the last edition of the "Origin of Species" that his inclination is to admit several original forms. He also abstains, and apparently purposely abstains, from giving any express description of the original forms or form, and he leaves it an open question whether these forms were very simple, or of considerable, or even of comparatively great, complexity.

We may fairly suppose that so clear a thinker and so acute a reasoner would not have left these points untouched, if he had not himself felt convinced that in the present state of our knowledge no trustworthy inferences on these heads could be drawn from our experience, and, as we have seen, the chemical tests which we have applied to the theory of the Evolutionists lead us to precisely the same conclusion. Nevertheless, Mr. Darwin has repeatedly been charged by the Evolutionists with being untrue to himself, when he stops at the point beyond which he does not profess to carry his explanation of the phenomena of life, although we cannot but think that this charge is altogether unfounded. The difference between Mr. Darwin and the Evolutionists appears to us to be one of principle and not of detail; and if the reader will look back to that part of our subject which we have already discussed, we think that he will agree with us in considering the limitation of the field to which Mr. Darwin's views are applied, a point of the highest importance; for it is this very limitation which removes some of the most formidable chemical difficulties presented by the theory of the Evolutionist, and which for the chemical student places Mr. Darwin's view in a very different position from that in which he feels compelled to place the view of the Evolutionists properly so called.

Moreover, if there were several original forms, as Mr. Darwin seems inclined to believe, we can hardly doubt that these were markedly distinct from one another, and that each must therefore have had some specialization of form, and some distinctive properties. We have only to suppose that among these few original forms, one was distinguished by its power of obtaining a supply of carbon from the carbonic anhydride of the air by the aid of chlorophyll, another by the possession of compounds of iron which it used as a means of procuring heat by effecting the oxidation of some part of its substance, and so on, and we shall at once be relieved from the greater part of the remaining chemical difficulties which the theory of the Evolutionist presented.

It is true that Mr. Darwin does not himself make any such suppositions as to the properties of the original forms; but is it in any degree more unreasonable to suppose that there were chemical as well as structural differences between them, than it is to suppose that the points of distinction were confined to mere differences of form? It certainly does not appear to us to be so, and we imagine Mr. Darwin would himself be quite willing to admit that if there were several distinct original forms, it is probable there were points of chemical as well as of structural difference between them.

Such a supposition as to the original forms would, as we have said, remove the greater part of the remaining chemical difficulties; but some difficulty would unquestionably be left. The number of special chemical compounds which occur among some only of the great host of different living forms is so large, that we apprehend Mr. Darwin would absolutely reject the notion that each of these occurred among some or one of the original forms; if then we are to look to Natural

Selection to explain the occurrence of all the existing differences met with among living beings which did not form points of distinction between the original forms, Mr. Darwin's view must account for the production of some at least of these special compounds; and it is when this is required of it, that we for the first time meet with some difficulty in reconciling the results of chemical experiment with Mr. Darwin's view. It will at once be seen that Mr. Darwin gives us no such simple starting-point as the homogeneous lump of protoplasm with which the Evolutionist begins, and we cannot, therefore, here conveniently deal with the problem by selecting some special compound to exemplify the difficulty in the manner which we adopted when we were discussing the theory of the Evolutionist; for we can never be certain that any product, presenting special difficulties, which we may select, did not exist in one of the original forms, and may therefore not be a case in point at all. Moreover, Mr. Darwin does not profess to explain the origin or the nature of life, and certainly does not treat it as the mere effect of some action of the ordinary physical forces of nature; and although chemistry does, as we have seen, give us good reasons for rejecting the hypothesis that the manufacturing powers of the mere chemical compound protoplasm could ever vary, these reasons in no way affect the position that an unknown power, whose origin and nature are confessedly treated as at present inexplicable, and which manifests itself in part by manufacturing special chemical compounds, may be the subject of gradual variation, and thus ultimately give rise to new chemical products. The Evolutionist, as we have shown, is precluded from arguing that the manufacturing power, as distinguished from the substance, of protoplasm, has ever varied; but it is clearly open to the Darwinian, if he thinks fit to do so, to attempt to solve the problem theoretically on the hypothesis that the manufacturing powers which life confers on living beings are capable of variation.

No doubt if the Darwinian were compelled to resort to the hypothesis of the gradual variation of the actual substance of protoplasm, or of any other definite chemical compound, his view would, from the very nature of chemical combination, be open with more or less force to many of the objections which the view of the Evolutionist presents, and we should at once decide that Mr. Darwin's view had on the whole failed to give a satisfactory explanation of the occurrence of special chemical compounds among different forms of life; but it is plain that the subject cannot be dealt with in this simple manner, and that in considering the application of Mr. Darwin's view, we must examine the question whether the manufacturing powers of living beings do actually vary.

This is in the main a question of evidence; let us see how the case stands.

The very ground-work* of Mr. Darwin's view is that

* The reader will find this very distinctly stated in Mr. Wallace's "Contributions to the Theory of Natural Selection," pp. 265, 266.

the laws which regulate the formation of the shape and structure of any particular species of living being *never* give identical results: no two individuals of the same species are exactly alike; there is a strong general resemblance, but there are also minute variations in every part, which distinguish the two individuals, and which, it is conceivable, inheritance and Natural Selection might under suitable conditions be able to preserve and accumulate.

This is the celebrated "law of variation," and Mr. Darwin and his followers have shown that it applies to every form of life.

On the other hand, the laws which govern chemical combination operate in a manner precisely opposite. Here the result of the action is absolutely invariable. So far as our present knowledge teaches us, two molecules of the same substance, of water, for instance, instead of presenting a mere general resemblance to each other, do not differ at all; the two structures are not merely similar, but actually identical. In the case we have chosen, we know that hydrogen and oxygen are capable of entering into a different combination; but this, if formed, will be found to possess an equally definite structure, and its molecules, like those of water, exhibit, not mere general resemblance, but absolute identity. The only variation with which we meet is that the surrounding conditions determine which of these two compounds shall be formed; but in no case do we find anything like that indefinite variation in every direction which occurs among the forms of the organs of two individuals of the same species. These observations apply to all true chemical compounds, in whatever manner they may have been produced, and, in short, we may fairly say that the "law of variation," which is of universal application in the building up of the organs and general form of a living being, has absolutely no application in the formation of the molecule of a chemical compound. It may of course be contended that we are unable to ascertain the precise composition of many of the products of living beings, as, for instance, in the cases of protoplasm and chlorophyll, and that we cannot be certain that such products are really true chemical compounds; but we have already explained what strong reasons we have for concluding that these complex substances, like other chemical compounds, obey the law of molecular equilibrium, and therefore, like other compounds, possess an absolutely invariable atomic structure. Yet, if this conclusion be correct, we might not unreasonably infer that this perfectly definite structure was due to the action of equally definite forces; and we have certainly no more right *à priori* to suppose that the vital forces exerted by living beings of the same kind habitually cause the atoms which form a molecule of protoplasm, or of chlorophyll, or of any other such complex product, to unite in an ever-varying manner, than we have to suppose that any external forces, by means of which we can succeed in bringing the atoms of hydrogen and oxygen within the sphere of their mutual chemical attractions, will cause the atoms of these elements to unite in all sorts of chance combinations, varying indefinitely from time to time in every direction, instead of forming one or other of those two definite compounds which, so far as our experience goes, are the only combinations of these elements which exist.

These considerations do not of course prove that the manufacturing powers of living beings are not capable of gradual variation; but they do, in our opinion, throw the burden of proof on those who assert that these powers do so vary, and it is here that we think the evidence is at present insufficient.

The facts adduced are the same as those which we have already considered in our examination of the view of the Evolutionists; and, as we have there pointed out, cases of variation in the quantity of some substance produced, instances of the formation of new chemical compounds when the tissues of a living being have suffered some injury, or have been exposed to the direct action of chemical agents, and examples of differences in colour between individuals of the same species, all fail to furnish us with satisfactory evidence that the power of effecting chemical combination is subject to variation.

The Darwinian, too, like the Evolutionist, will have to bring forward instances of the formation of the ordinary chemical products from materials which had never previously been used, and of the formation of new products containing elements which up to that time had never been employed, before the evidence will carry his theory sufficiently far to account for the occurrence of such products as chlorophyll and that part of the blood which contains iron, unless, indeed, he is content to make extensive suppositions as to the chemical compounds which occurred among the few original forms of life; at present, however, we have been unable to find any well-established instance brought forward of that simplest form of the production of a new chemical compound, where the living being is found to have built up new substances out of the old familiar raw materials.

The Darwinian, in fact, as it seems to us, has still to prove that the law of variation applies in any degree to the formation of the kind, as distinguished from the quantity, of the chemical compounds which living beings manufacture; and this is a point of the utmost importance, for until we shall have succeeded in bringing the chemical compounds produced by living beings within the law, Natural Selection and inheritance can have nothing to operate upon in the case of chemical differences, and these must therefore be entirely excluded from the operation of the theory, which must be confined to the explanation of differences in those matters of form and shape to which the law of variation has been proved to apply.

No doubt any such restriction greatly affects the generality of the theory; but the very fact that Mr. Darwin has been able to bring forward such strong arguments, founded on actual observation, in support of the proposition that the differences of form and shape which we meet with among living beings are in the main due to the accumulation of small variations by the action of Natural Selection and inheritance, makes us call for some evidence which is equally in point when it is proposed to extend this valuable theory to the explanation of the differences between the chemical compounds which are met with among the various forms of life.

It must be remembered that an alteration in the position of the molecules which form some special structure, and the formation of a new chemical compound, are matters so thoroughly and intrinsically different, that we cannot safely apply the reasoning or the conclusions drawn from our examination of the first, to explain the difficulties which the second presents: to do so would be to confuse "atoms" with "molecules," and to compare cases of change which have been proved to be subject to the law of variation, with changes which appear to depend upon the action of laws which absolutely exclude all variation. It is plain, therefore, that if such last-mentioned changes are really to be brought within the theory, we must seek for evidence which bears directly upon these puzzling chemical differences, and which may enable us to employ those methods which Mr. Darwin has so skilfully applied to the points of distinction which depend upon variations in the relative position of molecules.

We cannot help thinking that on this head the theory still presents grave deficiencies, and until these are removed, and further evidence adduced, chemical considerations compel us to come unwillingly to the conclusion, that Mr. Darwin's view must for the present be restricted to the explanation of those differences of shape and structure which depend upon the relative position of molecules, while it leaves even the minor chemical differences which are so numerous among the various forms of life altogether unexplained.

The remarkable facts relating to the geographical distribution of the various forms of living beings, which Mr. Darwin and Mr. Wallace have collected, point to the conclusion that some at least of the minor chemical differences which distinguish some special forms have been developed since these forms have occupied their present stations, and we may therefore expect that proof will some day be obtained that new chemical compounds are occasionally manufactured from the materials which the living being is in the habit of decomposing.

At present, however, we see no reason for supposing that any evidence sufficient to account for the production of such compounds as chlorophyll and that part of the blood which contains iron, will ever be obtained, or that Mr. Darwin's view, as a theory founded on observed fact, will ever be carried sufficiently far to account for the existence of the more important chemical differences which living beings exhibit, unless indeed these are assumed to have constituted points of distinction between the original forms.

An example will perhaps make the difficulty we feel more intelligible. Let us take two animals, A and B, of the same species; these present that general resemblance coupled with minute variations of all kinds in shape and structure which prove that in these matters they might conceivably be modified in accordance with Mr. Darwin's view; but how stands the case with regard to the chemical compounds of which they are made up? If we examine the phosphate of lime derived from the bones of A, we shall find that it exhibits not general resemblance to, but actual chemical identity with, the phosphate of lime derived from the bones of B. So if we analyse the protoplasm obtained from A, our analysis will show that, so far as we can ascertain its composition, it is not merely similar to, but absolutely the same as that obtained from B, and so we might go through the whole series of the compounds manufactured or made use of by A and B, and in every case we should find, not mere general resemblance, but absolute identity between the products of the two individuals. What material have inheritance and Natural Selection to operate upon here? How can their action possibly give rise to the production of a new chemical compound? It seems necessary to have recourse to the hypothesis that the manufacturing power of living beings is subject to variation, and this must be proved by independent evidence, and cannot be inferred from cases where form and structure only are proved to have varied.

Indeed, we can hardly read the works of Mr. Darwin or of Mr. Wallace without feeling that they have themselves been pressed by this difficulty. Nothing in these works is more striking than the manner in which time after time some problem presented by the occurrence of some marvellous structure is taken in hand, at a stage when the chemical change upon which the explanation ultimately depends is supposed to have already taken place. The explanation is frequently a wonder of ingenuity, but it is an explanation dealing with molecular change only.

For instance, let us take the case of the enormously prolonged nectary of the Angræcum Sesquipedale.* A most ingenious explanation is given which accounts for the length of this extraordinary organ by attributing it to a prolonged contest between the plant and certain large moths, in the course of which those plants only produced seed, whose form compelled the moths with the longest probosces to use their utmost endeavours to reach the bottom of the nectary, when they desired to obtain the whole of the nectar secreted by the plant, which other moths with shorter probosces were unable to exhaust. It will be seen at once that the change here explained is purely molecular; given the nectar, the contest between the moth and the plant might lead to the production of the structure observed; but we find no attempt to explain how the chemical change was effected, as the result of which the first nectar was produced, and yet it is on the production of this compound that the whole explanation ultimately rests.

* "Fertilization of Orchids," pp. 197, 201—203.

Again, in his work on insectivorous plants, Mr. Darwin attributes the formation of the wonderfully complex machinery exhibited by a leaf of Drosera,* to the operation of Natural Selection working upon a plant which produced an acid secretion capable of acting on nitrogenous substances as a digestive fluid.

Many plants, as Mr. Darwin says, produce acid secretions, and any acid will apparently act as a digestive fluid. Here again the problem is taken up at a stage where the chemical change on which it ultimately depends is supposed to have been already effected, and the changes dealt with are molecular only.

All plants, as Mr. Darwin's own words admit, do not produce acid secretions capable of digesting nitrogenous substances, and yet no attempt is made to explain the first production of one of these acid fluids, though the whole explanation ultimately depends upon the existence of this compound.

We have taken these two cases at random, but numberless other instances are to be met with in Mr. Darwin's works, and indeed they occur so constantly that we almost feel tempted to believe that Mr. Darwin himself would not extend his view so far as to make it include cases of chemical as distinguished from molecular change.

However this may be, chemical considerations do, as we have seen, require us to limit Mr. Darwin's theory in the manner we have already stated, and though it cannot be used when thus restricted to construct the lengthy

* "Insectivorous Plants," pp. 361—363.

and elaborate pedigrees by which the Evolutionist attempts to connect all living things with the Archigonic Moneron, it, on the other hand, gains the great advantage of completely avoiding the chemical difficulties which the theory of the Evolutionist undoubtedly presents.

In truth, Mr. Darwin's theory thus limited does give an explanation of the varieties of shape and structure met with among the different allied forms of life, which none can deny is at least both conceivable and intelligible, which is not open to objection on chemical grounds, and which is supported by a large number of well-established facts which present great difficulties if we attempt to account for them in any other way. Whether the theory is really to be looked upon as the true explanation of these differences of shape and structure must be left to the decision of those who have studied the subject, and are competent to weigh the vast mass of evidence which has been collected both in support of and in opposition to the theory. We are here beyond the bounds of chemical inquiry, and we must leave the reader to consult those who have explored the region, in which the further examination of the question must be carried on, and are capable of acting as his guides over the ground which he has to traverse.

## CHAPTER VI.

### CHEMICAL FACTS WHICH POINT TO THE EXISTENCE OF SOME MORE UNIVERSAL CAUSE THAN THE ACTION OF NATURAL SELECTION AND INHERITANCE—GENERAL CONCLUSIONS FROM THE WHOLE INQUIRY.

WE ought not, however, to leave the subject without referring to one class of chemical facts which do certainly throw some doubt on the question whether Mr. Darwin's theory, if accepted as an explanation of the facts which he and others have observed and recorded, is the only explanation of which those facts are capable, and if it is not, whether it really gives us that complete explanation which it professes to give.

The point to which we refer is one which we believe was first put forward by the author of the well-known article in the "North British Review," * and has, we think, scarcely received the amount of attention it deserves. The Reviewer points out that there is as much difficulty in classifying chemical compounds as there is in determining the groups into which living beings are to be arranged—that, for instance, there are

* "North British Review," No. 92.

just as fine-drawn distinctions as to what is an acid and what is a base as there can possibly be about the line of demarcation between animal or vegetable life—and the Reviewer evidently implies that chemistry presents us with numerous intermediate links, connecting substances which are themselves very distinct, of much the same kind as those links which connect distinct forms of animal or vegetable life, although, in the case of these chemical compounds, inheritance and Natural Selection, and even the law of variation itself, can have had no share in producing the resemblances observed. In one of the latest books on the subject, Mr. Maclaren refers to the points raised by the Reviewer,* and observes that he does not allude to the peculiar manner in which Mr. Darwin supposes species to be assembled in groups, a remark which we shall see is of great importance, as this is in fact the very point in which chemical experiment has revealed the most surprising analogies between inorganic substances and beings which possess life.

Not only are substances—even elementary substances—met with in groups, but in many cases the points of relationship between the members of the group are such that we can hardly doubt that in the case of living beings Mr. Darwin would refer corresponding similarities to descent from a common ancestor, and that ancestor not a very remote one. An illustration will make this clear.

* "Examination of the Arguments for and against Darwinism," p. 146.

No elements are better known to us than those commonly called the halogens, chlorine, bromine, and iodine, and with these we will join the less known element fluorine. We will here shortly compare the points of similarity which they present, and we must premise that fluorine is what is called an aberrant member of the group when we are talking of groups of living beings supposed to be connected by descent, and that it is comparatively but little known. All are monatomic.* The molecular structure of chlorine, bromine, and iodine is well known to us, and the molecules of all three are found to belong to the common double-atom form, as for instance [Cl. Cl.] Fluorine is believed also to have a molecule containing two atoms. The atomic weights are chlorine 35.5., bromine 80, iodine 127, fluorine 19.

Fluorine is a transparent colourless gas possessed of very intense chemical properties. Chlorine is, at ordinary temperatures, a heavy-coloured gas of a dull greenish yellow, possessed of a strong odour, and also of very intense chemical properties, though less active than fluorine. At low temperatures and under pressure, chlorine becomes a dense yellow fluid, somewhat resembling bromine in appearance, but not so deep in colour.

Bromine is, at ordinary temperatures, a dense red

* It would perhaps be more correct to say that all are ordinarily monatomic, but that all occasionally and under special conditions appear to be triatomic. As, however, these bodies are clearly monatomic in the vast majority of instances, we have retained the usual classification which places them among the monatomic elements.

fluid, which gives off an offensive vapour; at a slightly increased temperature it becomes a heavy gas, which possesses an odour somewhat like that of chlorine, and which in colour is orange-red, and much darker in tint than the vapour of chlorine, though proportionately less deep in colour than the vapour of iodine. At low temperatures bromine is a crystalline dark-coloured solid, apparently taking the same lamellated form as iodine after this last element has undergone fusion.

Iodine is at ordinary temperatures a crystalline dark-coloured solid; when heated, it melts, forming a dense dark-coloured fluid, and at a slight increase of temperature it is converted into a heavy gas of a deep violet colour and peculiar odour, bearing some resemblance to the odours of chlorine and bromine.

Chlorine, bromine, and iodine are all very active chemical agents; but chlorine is more energetic than bromine, and bromine than iodine.

Chlorine, bromine, iodine, and fluorine all present a general similarity in their action on other bodies; but chlorine, bromine, and iodine form compounds of most remarkable similarity, which, curiously enough, agree with one another even minutely and in properties of the most unusual occurrence. For instance, chlorides, bromides, and iodides are, as a rule, soluble in water. Chloride, bromide, and iodide of silver are, however, all exceptions to this rule, and all, unlike other chlorides, bromides, and iodides, are under certain circumstances powerfully and in substance similarly affected by exposure to the light of the sun.

It is well known that in many chemical experiments chlorine, bromine, or iodine may be used indifferently; whichever is used, the required reaction is effected, the only difference in the result being that a chloride, a bromide, or an iodide is formed, as the case may be.

We need not go into further detail as to the remarkable similarity between chlorine, bromine, and iodine, as exhibited in their chemical action. It is sufficient to observe that bromine is almost exactly intermediate in this respect between chlorine and iodine.

Fluorine, on the other hand, appears to be more closely allied to chlorine than to the other two.

On referring to the atomic weights it will be at once seen that bromine (80) is almost exactly intermediate between chlorine (35.5) and iodine (127).

Again, on looking to their external properties, we see that in colour, form, smell, and properties generally, bromine is almost exactly intermediate between chlorine and iodine, fluorine being more distinct from all three than any one of the three is from the others.

Lastly, all the three, chlorine, bromine, and iodine, are met with in nature in the same localities and under similar circumstances and conditions, chlorine being abundant, bromine and iodine both comparatively rare. Fluorine is met with in different localities and under different conditions, and, compared with any of the others, may be said to be very rare.

Thus we have marked similarities in chemical action, in structure of molecule, in form, in colour, in smell, in general external appearance and properties, and in locality in nature, connecting the three elements, chlorine, bromine, and iodine, and less marked similarities connecting all three with fluorine.

These facts are all the more remarkable when we consider that with the exception of their close ally, fluorine, the three halogens, chlorine, bromine, and iodine, form a remarkably isolated family of elements. No others approach them even in a remote degree in properties, and they are separated from all other monatomic elements by an interval, certainly as great, and probably greater, than that separating any other two classes of elements whatever.

These close relations between chlorine, bromine, and iodine are so extraordinary that we have stated them here in some detail, as we can hardly help believing that these elements must be connected together in some way, for otherwise they could scarcely be so like each other and so unlike all other elements. It is true we cannot in the present state of science give any explanation of their similarities, and yet in what way can it be said that these relations differ in kind from those relations between living animals or living vegetables, on the strength of which we collect these into groups? Can any important point be selected among these similarities existing between chlorine, bromine, and iodine which has not over and over again been urged by naturalists, either as a reason for classing two living beings together, or as a reason for classing some living being as a vegetable rather than an animal? Have we not here a very well-marked "group" consisting of three members very closely related, and another member, fluorine, more distantly connected with the others?

Yet no one has ever ventured to suppose that chlorine, bromine, and iodine were derived by descent from one substance, that they owe their remarkable similarity in properties to inheritance from a common ancestor which possessed properties somewhat different from those possessed by any one of them. The very notion will be laughed at as too absurd for statement, as only fit for an alchymist; but it we reject such a supposition, can we deny that instances of the very similarities which, when occurring in living beings, Mr. Darwin explains by descent from a common ancestor, and by slight variations from his type selected by the struggle for life and the survival of the fittest, actually exist in nature under circumstances where not one of these causes can possibly have contributed to the result? And if these similarities are thus not necessarily the result of the causes to which Mr. Darwin attributes them, have we not some ground for supposing that all such similarities, as well as those which can be explained by Mr. Darwin's hypotheses as those which cannot, may really be due to one and the same cause, and that not the cause which Mr. Darwin puts forward?

It must not for a moment be supposed that the family of the halogens is the only group known to chemists. On the contrary, we might have brought forward the remarkable group which comprises barium, strontium, and calcium, or the no less remarkable groups of cobalt, nickel, and iron, or of potassium, sodium, and lithium, as examples of cases of distinct elements closely allied and possessed of similarities, such as in the case of living beings would be referred to descent from a common ancestor. And even these examples do not nearly exhaust the list of known groups among the elements alone, although the whole number of known elements is but little more than sixty, a mere trifle in comparison with the number of different forms of life even now in existence.

In fact, even among the elements, groups are the rule, isolated elements, such as boron, the exception; and even boron, perhaps the most isolated of all elements, appears to have some connection and to present some points of resemblance, though but distant, with carbon and silicon.

If now we turn our attention to compounds, we find at once that it is unnecessary to seek for groups; a large part of "organic" chemistry is made up of the mere enumeration and classification of these, and they are also exceedingly numerous among the compounds derived from inorganic bodies. No doubt it may, and may with reason, be said that these remarkable similarities among compounds are due to similarity of chemical composition, or to one element being replaced by another very similar one, and therefore there is nothing surprising in this. This is probably true, but does not the very same argument apply with even greater force to the forms of living beings?

Moreover, we must not suppose that even elements in all cases exhibit absolute invariability of form —the well-known phenomena of allotropy * and dimorphism,† as exhibited, for instance, by the elements phosphorus and sulphur, absolutely forbid us to make any such statement; and though it is true that many of these variations in form are due or probably due to change in atomic structure, to the union of a larger or smaller number of atoms in one molecule, yet when we come to examine the forms presented by compounds, we find some cases of dimorphism, as for example the forms of carbonate of lime, known as calc-spar and arragonite,‡ which appear to be as truly instances of molecular as distinguished from chemical variation, as any of those variations among living beings on which Mr. Darwin founds his theory.

In truth, if we are to look upon the variations of form exhibited by living beings as solely due to the action of any forces or any causes which act in the immutable manner and with the invariable results which the known forces of nature present to us, when the conditions under which they operate are the same, we cannot but admit that the real wonder is that there should be such surprising differences, not that

* "The property by virtue of which the same body is capable of presenting different chemical characters."

† "The property which some bodies possess of manifesting different physical peculiarities according to the conditions in which they are placed, although they continue chemically identical under all these conditions." These definitions will be found in Naquet's "Principes de Chimie," pp. 78, 79.

‡ Both are chemically $CaCO_3$.

there should be so many points of resemblance, between the various forms of living beings; and when all the facts are taken into account, it seems but reasonable to expect that striking cases of similarity and of apparent connection between distinct forms would occur among the vast host of living beings, even if descent had had nothing to do with the production of these closely allied forms.

It does not of course necessarily follow that Mr. Darwin's supposed cause of similarity may not have co-existed or co-operated with other causes which may have contributed to the observed results: the chemical facts to which we have referred above merely tend to show that Mr. Darwin's cause may not be the only cause, and that it is not the only possible cause, of some of the instances of similarity among various forms of life; but if there really is some other cause in existence which could or might have produced some of the phenomena observed, this fact does unquestionably add weight to the objections of those authors who consider Mr. Darwin's view as insufficient to account for all the differences exhibited by living beings. Cases of doubt and difficulty, which, if exceptional, might be left for future discovery to bring within the theory, (if it were granted that Mr. Darwin had given us the only admissible explanation of the facts observed,) stand in a very different position when we have to look upon them as possible examples of the action of another cause, which cause there is considerable reason to believe actually exists.

## SUMMARY.

To sum up. Chemical considerations do, as we have seen, require us to limit Mr. Darwin's theory for the present to the explanation of the molecular differences alone, which the various forms of life present to us, although we have some reason to expect that at a future day we may be able to apply the theory to some at least of those minor chemical differences which appear to be due to the formation of new compounds from the usual raw materials; but thus restricted, the theory is supported by many important and well-established facts, and stands in a very different position from that which the Evolutionist theory occupies. Still, if we take into consideration the chemical differences which the various forms of life present, the theory seems open to the following objections:—

(1.) The number of distinct chemical compounds which are found to be strictly confined to special forms of life is so large, and the properties of these compounds are in many cases so peculiar, that these chemical compounds, taken as a whole, present an array of differences which stands at least on a level with, and perhaps even exceeds in importance, the whole mass of differences of form which we meet with among the various types of living beings, and they cannot therefore be left out of sight in any attempt to trace the history of life. Moreover, it is in many cases impossible to pass from one order or class, or even from one species, of being, to another, by a process of development, without accounting for the formation of some of these chemical compounds, and yet before we can explain the production of one single special compound by Mr. Darwin's theory, we must at the least prove by actual observation or experiment that living beings do possess the power of producing some new and beneficial compounds out of the materials they have always used, under the influence of a change in surrounding conditions; and, as we have seen, the evidence on this head is at present very insufficient to establish the existence of such a power.

(2.) Chemical experiments do make it to a certain degree probable that some more general cause may have aided in producing the similarities on which Mr. Darwin's theory is founded, and that they need not necessarily be attributed solely to the causes to which he attributes them. If this is really the case, the theory loses some of its value, as it will become necessary in each case to explain which phenomena are to be attributed to the causes Mr. Darwin puts forward, and which to the more general cause, and also how far any particular phenomenon should be attributed to the action of Mr. Darwin's supposed cause, and how far to the action of that more general cause which appears to give rise to somewhat similar points of resemblance between bodies which cannot possibly have acquired these similarities by the operation of Natural Selection and inheritance.

Lastly, it may be objected that to assert the existence of any special chemical compounds among the original forms, whose existence Mr. Darwin supposes, such as we have suggested should be attributed to these forms, is to make a most improbable assumption ; and yet, if we do not attempt to explain how the first living form or forms came to exist, can we fairly say that such an assumption is more improbable, *à priori*, than the supposition that an elephant on the one hand, and a magnolia tree or a rhododendron on the other, have been derived by Natural Selection from organisms which were chemically very much alike, or than the supposition that a whale and a wheat plant are descended from ancestors which could scarcely be distinguished ? Moreover, if we do not assume that the few forms referred to by Mr. Darwin were markedly distinct, we can hardly refuse to go with the Evolutionist proper, and contend that if the wonderful existing differences between living forms have all been produced by Natural Selection or Evolution from a few original forms much resembling one another, it is highly unreasonable to suppose that these were not all themselves descended from some one original form of very simple organization, and thus we shall be logically compelled to have recourse to the Evolutionist theory proper, and shall have to meet the tremendous chemical difficulties which that theory presents, when we endeavour to explain the chemical phenomena exhibited by living beings by its aid.

No doubt there is a certain want of logical sequence in supposing that the cause, whatever it was, which called the original forms into existence, entirely ceased to operate after the completion of this process, and took no similar part in producing the changes of type which subsequently took place; but this is a logical difficulty which must always apply with something like equal force to any theory which does not attribute the origin of life to the operation of the same causes to which it attributes the existence of the variety of living forms, and which does not affect the question whether the original forms were markedly distinct or not. No chemist can for a moment refuse to admit that the differences between the most dissimilar living beings are infinitesimal, and may be altogether neglected, in comparison with the differences between any living being and a portion of matter not possessed of life.

It will thus be seen that though on chemical grounds we absolutely reject the theory of the Evolutionist, we do not and cannot on the same grounds so absolutely reject Mr. Darwin's theory. Mr. Darwin has unquestionably given us a very possible and rational explanation of many natural phenomena, and has, we think, established the claim of his theory to be taken into account in any attempt to give a scientific explanation of the succession and variety of the forms of life, though it by no means follows that the theory must be accepted as the complete explanation of all the facts which have been observed, and it is still less to be treated as assigning the only cause which was actually at work in producing the results which nature presents to us. Mr. Darwin himself does not, we think, claim such a position for his theory, and, as we have seen, chemical facts certainly render it possible, and in some degree even probable, that some of those very similarities in form and structure, as distinguished from chemical composition, upon which Mr. Darwin has founded his theory, may have been the result of causes altogether different from those on which Mr. Darwin relies.

## CONCLUSION.

We have now only to consider whether any general conclusions can be drawn from the whole mass of phenomena which we have examined, and it seems to us that the results of our inquiry may be summed up as follows :—

(1.) The origin of life remains as great a mystery as ever. It is entirely unexplained by any theory founded on experiment which has hitherto been put forward; and we must either be content to leave it unexplained, or we must accept the Creationists' view, on the ground that it is the only theory put forward which gives even a possible solution of the problem.

(2.) So far as the more important chemical phenomena exhibited by living beings are concerned, these also must be treated as altogether unexplained by any experimental theory as yet put forward. With regard, however, to variations of form, structure, and so forth, to which we may possibly at a future day be able to add some of the minor chemical differences met with among living beings, Mr. Darwin's theory does give a possible explanation of these; but the question whether it is the complete explanation is still open, and there is some evidence that a more general cause has at least had a share in creating even those resemblances which are most clearly within the province in which Mr. Darwin has worked.

The real difficulty in dealing with the problems offered by living beings arises, as it appears to the writer, from our ignorance of the nature and mode of action of that form of force which we have called vital force. As we have seen, the singular chemical phenomena which form the grand distinction between living matter and dead matter in every shape are due to the action of this force, and till we shall have discovered how it was originally called into action, or at least in what manner it still continues to operate, we shall not be able to rely on any experimental theory as being the complete and proved explanation of any phenomena presented by living beings.

In every such case some degree of probability only, be it greater or less, must take the place of actual knowledge; for we can never say how far any particular phenomenon was due to external causes alone, or how far the action of these causes was checked or interfered with, or even dispensed with altogether, by the action of vital force, an agent as to which we have at present no real knowledge whatever.

It will be seen that the writer does not look to Mr. Darwin's theory, or to any theory founded on resemblances of form, structure, and so on—on molecular change, in fact, as distinguished from chemical change—for more light on these points. The real problem of the nature of life is to be approached, if at all, through those chemical phenomena which we have seen form its most striking feature, and it is to future chemical discovery, and not to the observations of naturalists, that we think we must look for an increase of knowledge in this direction.

All chemists have long looked forward to the time when the powerful methods used by the mathematician will become applicable to the problems presented in the laboratory, and chemistry does now appear to be approaching the point at which this great step will be made. If this can be done, if we can once succeed in predicting by theory a result which on being tried experimentally is found invariably to follow, we may hope to lay down definite laws for the action of chemical affinity, as mathematicians have already succeeded in doing in the case of the laws of gravitation, and we shall then be in a condition to attack the problem of life with a better chance of gaining some insight into this greatest of all mysteries.

At present chemistry supplies us with no key to the problem; and on the points to which we have referred, we must be content, either to confess our utter inability to account for the phenomena presented to us, and to wait till the progress of discovery may have thrown further light upon the causes which gave rise to them, or to accept the Creationists' view, or at all events, some more or less modified form of it,* on the

* Such as that of Mr. Mivart, or the theory of derivation, put forward by Professor Owen, both of which seem to us to be mere methods of special creation.

ground that it is the only explanation yet put forward which is at all capable of accounting for the whole mass of facts observed.

The reader may perhaps wish to learn the conclusion to which we have ourselves come in this matter, and we will therefore close these pages by referring him to the following memorable words :—

" In all phenomena, the more closely they are investigated, the more are we convinced that, humanly speaking, neither matter nor force can be created or annihilated, and that an essential cause is unattainable. Causation is the will, Creation the act, of God."* This is the utterance of one of the greatest thinkers of our day, and it expresses in language as clear as it is forcible that conviction which, it seems to us, is irresistibly pressed upon those who will examine for themselves the real facts which nature lays before us.

* Mr. Justice Grove, "Correlation and Continuity," p. 271.

THE END.

# INDEX.

## H.



## I.



## L.



## M.

Hazell, Watson, and Viney, Printers, London and Aylesbury.