SPENCER HERBERT

THE PRINCIPLES OF BIOLOGY, VOLUME 1 (OF 2)

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Содержание

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PREFACE TO THE REVISED AND ENLARGED EDITION

Rapid in all directions, scientific progress has during the last generation been more rapid in the direction of Biology than in any other; and had this work been one dealing with Biology at large, the hope of bringing it up to date could not have been rationally entertained. But it is a work on the *Principles* of Biology; and to bring an exposition of these up to date, seemed not impossible with such small remnant of energy as is left me. Slowly, and often interrupted by ill-health, I have in the course of the last two years, completed this first volume of the final edition.

Numerous additions have proved needful. What was originally said about vital changes of matter has been supplemented by a chapter on "Metabolism." Under the title "The Dynamic Element in Life," I have added a chapter which renders less inadequate the conception of Life previously expressed. A gap in preceding editions, which should have been occupied by some pages on "Structure," is now filled up. Those astonishing actions in cell-nuclei which the microscope has of late revealed, will be found briefly set forth under the head of "Cell-Life and Cell-Multiplication." Further evidence and further thought have resulted in a supplementary chapter on "Genesis, Heredity, and Variation"; in which certain views enunciated in the first edition are qualified and developed. Various modern ideas are considered under the title "Recent Criticisms and Hypotheses." And the chapter on "The Arguments from Embryology" has been mainly rewritten. Smaller increments have taken the shape of new sections incorporated in pre-existing chapters. They are distinguished by the following section-marks: —§ 8*a*, § 46*a*, § 87*a*, § 100*a*, § 113*a*, § 127*a*, §§ 130*a*-130*d*. There should also be mentioned a number of foot-notes of some significance not present in preceding editions. Of the three additional appendices the two longer ones have already seen the light in other shapes.

After these chief changes have now to be named the changes necessitated by revision. In making them assistance has been needful. Though many of the amendments have resulted from further thought and inquiry, a much larger number have been consequent on criticisms received from gentlemen whose aid I have been fortunate enough to obtain: each of them having taken a division falling within the range of his special studies. The part concerned with Organic Chemistry and its derived subjects, has been looked through by Mr. W. H. Perkin, Ph.D., F.R.S., Professor of Organic Chemistry, Owens College, Manchester. Plant Morphology and Physiology have been overseen by Mr. A. G. Tansley, M.A., F.L.S., Assistant Professor of Botany, University College, London. Criticisms upon parts dealing with Animal Morphology, I owe to Mr. E. W. MacBride, M.A., Fellow of St. John's College, Cambridge, Professor of Zoology in the McGill University, Montreal, and Mr. J. T. Cunningham, M.A., late Fellow of University College, Oxford. And the statements included under Animal Physiology have been checked by Mr. W. B. Hardy, M.A., Fellow of Gonville and Caius College, Cambridge, Demonstrator of Physiology in the University. Where the discoveries made since 1864 have rendered it needful to change the text, either by omissions or qualifications or in some cases by additions, these gentlemen have furnished me with the requisite information.

Save in the case of the preliminary portion, bristling with the technicalities of Organic Chemistry (including the pages on "Metabolism"), I have not submitted the proofs, either of the new chapters or of the revised chapters, to the gentlemen above named. The abstention has resulted partly from reluctance to trespass on their time to a greater extent than was originally arranged, and partly from the desire to avoid complicating my own work. During the interval occupied in the preparation of this volume the printers have kept pace with me, and I have feared adding to the entailed attention the further attention which correspondence and discussion would have absorbed: feeling that it was better to risk minor inaccuracies than to leave the volume unfinished: an event which at one time appeared probable. I make this statement because, in its absence, one or other of these gentlemen might be held responsible for some error which is not his but mine.

Yet another explanation is called for. Beyond the exposition of those general truths constituting the Principles of Biology as commonly accepted, the original edition of this work contained sundry views for which biological opinion did not furnish any authority. Some of these have since obtained a certain currency; either in their original forms or in modified forms. Misinterpretations are likely to result. Readers who have met with them in other works may, in the absence of warning, suppose, to my disadvantage, that I have adopted them without acknowledgment. Hence it must be understood that where no indication to the contrary is given the substance is unchanged. Beyond the corrections which have been made in the original text, there are, in some cases, additions to the evidence or amplifications of the argument; but in all sections not marked as new, the essential ideas set forth are the same as they were in the original edition of 1864.

Brighton,
August, 1898.

PREFACE

The aim of this work is to set forth the general truths of Biology, as illustrative of, and as interpreted by, the laws of Evolution: the special truths being introduced only so far as is needful for elucidation of the general truths.

For aid in executing it, I owe many thanks to Prof. Huxley and Dr. Hooker. They have supplied me with information where my own was deficient;[1] and, in looking through the proof-sheets, have pointed out errors of detail into which I had fallen. By having kindly rendered me this valuable assistance, they must not, however, be held committed to any of the enunciated doctrines that are not among the recognized truths of Biology.

The successive instalments which compose this volume, were issued to the subscribers at the following dates: – No. 7 (pp. 1-80) in January, 1863; No. 8 (pp. 81-160) in April, 1863; No. 9 (pp. 161-240) in July, 1863; No. 10 (pp. 241-320) in January, 1864; No. 11 (pp. 321-400) in May, 1864; and No. 12 (pp. 401-476) in October, 1864.

London, September 29th, 1864.

[1] Gross misrepresentations of this statement, which have been from time to time made, oblige me, much against my will, to add here an explanation of it. The last of these perversions, uttered in a lecture delivered at Belfast by the Rev. Professor Watts, D.D., is reported in the *Belfast Witness* of December 18, 1874; just while a third impression of this work is being printed from the plates. The report commences as follows: – "Dr. Watts, after showing that on his own confession Spencer was indebted for his facts to Huxley and Hooker, who," &c., &c.Wishing in this, as in other cases, to acknowledge indebtedness when conscious of it, I introduced the words referred to, in recognition of the fact that I had repeatedly questioned the distinguished specialists named, on matters beyond my knowledge, which were not dealt with in the books at my command. Forgetting the habits of antagonists, and especially theological antagonists, it never occurred to me that my expression of thanks to my friends for "information where my own was deficient," would be turned into the sweeping statement that I was indebted to them for my facts.Had Professor Watts looked at the preface to the second volume (the two having been published separately, as the prefaces imply), he would have seen a second expression of my indebtedness "for their valuable criticisms, and for the trouble they have taken in *checking* the numerous statements of fact on which the arguments proceed" – no further indebtedness being named. A moment's comparison of the two volumes in respect of their accumulations of facts, would have shown him what kind of warrant there was for his interpretation.Doubtless the Rev. Professor was prompted to make this assertion by the desire to discredit the work he was attacking; and having so good an end in view, thought it needless to be particular about the means. In the art of dealing with the language of opponents, Dr. Watts might give lessons to Monsignor Capel and Archbishop Manning.December 28th, 1874.

PART I. THE DATA OF BIOLOGY

CHAPTER I. ORGANIC MATTER

§ 1. Of the four chief elements which, in various combinations, make up living bodies, three are gaseous under all ordinary conditions and the fourth is a solid. Oxygen, hydrogen, and nitrogen are gases which for many years defied all attempts to liquefy them, and carbon is a solid except perhaps at the extremely high temperature of the electric arc. Only by intense pressures joined with extreme refrigerations have the three gases been reduced to the liquid form.[2] There is much significance in this. When we remember how those redistributions of Matter and Motion which constitute Evolution, structural and functional, imply motions in the units that are redistributed; we shall see a probable meaning in the fact that organic bodies, which exhibit the phenomena of Evolution in so high a degree, are mainly composed of ultimate units having extreme mobility. The properties of substances, though destroyed to sense by combination, are not destroyed in reality. It follows from the persistence of force, that the properties of a compound are *resultants* of the properties of its components —*resultants* in which the properties of the components are severally in full action, though mutually obscured. One of the leading properties of each substance is its degree of molecular mobility; and its degree of molecular mobility more or less sensibly affects the molecular mobilities of the various compounds into which it enters. Hence we may infer some relation between the gaseous form of three out of the four chief organic elements, and that comparative readiness displayed by organic matters to undergo those changes in the arrangement of parts which we call development, and those transformations of motion which we call function.

Considering them chemically instead of physically, it is to be remarked that three out of these four main components of organic matter, have affinities which are narrow in their range and low in their intensity. Hydrogen, it is true, may be made to combine with a considerable number of other elements; but the chemical energy which it shows is scarcely at all shown within the limits of the organic temperatures. Of carbon it may similarly be said that it is totally inert at ordinary heats; that the number of substances with which it unites is not great; and that in most cases its tendency to unite with them is but feeble. Lastly, this chemical indifference is shown in the highest degree by nitrogen – an element which, as we shall hereafter see, plays the leading part in organic changes.

Among the organic elements (including under the title not only the four chief ones, but also the less conspicuous remainder), that capability of assuming different states called allotropism, is frequent. Carbon presents itself in the three unlike conditions of diamond, graphite, and charcoal. Under certain circumstances, oxygen takes on the form in which it is called ozone. Sulphur and phosphorus (both, in small proportions, essential constituents of organic matter) have allotropic modifications. Silicon, too, is allotropic; while its oxide, silica, which is an indispensable constituent of many lower organisms, exhibits the analogue of allotropism – isomerism. No other interpretation being possible we are obliged to regard allotropic change as some change of molecular arrangement. Hence this frequency of its occurrence among the components of organic matter is significant as implying a further kind of molecular mobility.

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[2] In this passage as originally written (in 1862) they were described as incondensible; since, though reduced to the density of liquids, they had not been liquefied.

One more fact, that is here of great interest for us, must be set down. These four elements of which organisms are almost wholly composed, exhibit certain extreme unlikenesses. While between two of them we have an unsurpassed contrast in chemical activity; between one of them and the other three, we have an unsurpassed contrast in molecular mobility. While carbon, until lately supposed to be infusible and now volatilized only in the electric arc, shows us a degree of atomic cohesion greater than that of any other known element, hydrogen, oxygen, and nitrogen show the least atomic cohesion of all elements. And while oxygen displays, alike in the range and intensity of its affinities, a chemical energy exceeding that of any other substance (unless fluorine be considered an exception), nitrogen displays the greatest chemical inactivity. Now on calling to mind one of the general truths arrived at when analyzing the process of Evolution, the probable significance of this double difference will be seen. It was shown (*First Principles*, § 163) that, other things equal, unlike units are more easily separated by incident forces than like units are – that an incident force falling on units that are but little dissimilar does not readily segregate them; but that it readily segregates them if they are widely dissimilar. Thus, the substances presenting these two extreme contrasts, the one between physical mobilities, and the other between chemical activities, fulfil, in the highest degree, a certain further condition to facility of differentiation and integration.

§ 2. Among the diatomic combinations of the three elements, hydrogen, nitrogen and oxygen, we find a molecular mobility much less than that of these elements themselves; at the same time that it is much greater than that of diatomic compounds in general. Of the two products formed by the union of oxygen with carbon, the first, called carbonic oxide, which contains one atom[3] of carbon to one of oxygen (expressed by the symbol CO) is a gas condensible only with great difficulty; and the second, carbonic acid, containing an additional atom of oxygen (CO_2) assumes a liquid form also only under a pressure of about forty atmospheres. The several compounds of oxygen with nitrogen, present us with an instructive gradation. Nitrous oxide (N_2O), is a gas condensible only under a pressure of some fifty atmospheres; nitric oxide (NO) is a gas which although it has been liquefied does not condense under a pressure of 270 atmospheres at 46.4° F. (8 °C.): the molecular mobility remaining undiminished in consequence of the volume of the united gases remaining unchanged. Nitrogen trioxide (N_2O_3) is gaseous at ordinary temperatures, but condenses into a very volatile liquid at the zero of Fahrenheit; nitrogen tetroxide (N_2O_4) is liquid at ordinary temperatures and becomes solid at the zero of Fahrenheit; while nitrogen pentoxide (N_2O_5) may be obtained in crystals which melt at 85° and boil at 113°. In this series we see, though not with complete uniformity, a decrease of molecular mobility as the weights of the compound molecules are increased. The hydro-carbons illustrate the same general truth still better. One series of them will suffice. Marsh gas (CH_4) is gaseous except under great pressure and at very low temperatures. Olefiant gas (C_2H_4) and ethane (C_2H_6) may be readily liquefied by pressure. Propane (C_3H_8) becomes liquid without pressure at the zero of Fahrenheit. Hexane (C_5H_{12}) is a liquid which boils at 160°. And the successively higher multiples, heptane (C_7H_{16}), octane (C_8H_{18}), and nonane (C_9H_{20}) are liquids which boil respectively at 210°, 257°, and 302°. Pentadecan ($C_{15}H_{32}$) is a liquid which boils at 270°, while paraffin-wax, which contains the still higher multiples, is solid. There are three compounds of hydrogen and nitrogen that have been obtained in a free state – ammonia (NH_3) is gaseous, but liquefiable by pressure, or by reducing its temperature to -40° F., and it solidifies at -112° F.; hydrazine (NH_2– NH_2) is liquid at ordinary temperatures, but hydrozoic acid (N_3H) has so far only been obtained in the form of a highly explosive gas. In cyanogen, which is composed of carbon and nitrogen, $(CN)_2$, we have a gas that becomes liquid at a pressure of four atmospheres and solid at -30° F. And in paracyanogen, formed of the same proportions of these elements in higher multiples, we have a solid which does not fuse

[3] Here and hereafter the word "atom" signifies a unit of something classed as an element, because thus far undecomposed by us. The word must not be supposed to mean that which its derivation implies. In all probability it is not a simple unit but a compound one.

or volatilize at ordinary temperatures. Lastly, in the most important member of this group, water (H_2O), we have a compound of two difficultly-condensible gases which assumes both the fluid state and the solid state within ordinary ranges of temperature; while its molecular mobility is still such that its fluid or solid masses are continually passing into the form of vapour, though not with great rapidity until the temperature is raised to 212°.

Considering them chemically, it is to be remarked of these diatomic compounds of the four chief organic elements, that they are, on the average, less stable than diatomic compounds in general. Water, carbonic oxide, and carbonic acid, are, it is true, difficult to decompose. But omitting these, the usual strength of union among the elements of the above-named substances is low considering the simplicity of the substances. With the exception of acetylene and possibly marsh gas, the various hydro-carbons are not producible by directly combining their elements; and the elements of most of them are readily separable by heat without the aid of any antagonistic affinity. Nitrogen and hydrogen do not unite with each other immediately save under very exceptional circumstances; and the ammonia which results from their union, though it resists heat, yields to the electric spark. Cyanogen is stable: not being resolved into its components below a bright red heat. Much less stable, however, are several of the oxides of nitrogen. Nitrous oxide, it is true, does not yield up its elements below a red heat; but nitrogen tetroxide cannot exist if water be added to it; nitrous acid is decomposed by water; and nitric acid not only readily parts with its oxygen to many metals, but when anhydrous, spontaneously decomposes. Here it will be well to note, as having a bearing on what is to follow, how characteristic of most nitrogenous compounds is this special instability. In all the familiar cases of sudden and violent decomposition, the change is due to the presence of nitrogen. The explosion of gunpowder results from the readiness with which the nitrogen contained in the nitrate of potash, yields up the oxygen combined with it. The explosion of gun-cotton, which also contains nitrogen, is a substantially parallel phenomenon. The various fulminating salts are all formed by the union with metals of a certain nitrogenous acid called fulminic acid; which is so unstable that it cannot be obtained in a separate state. Explosiveness is a property of nitro-mannite, and also of nitro-glycerin. Iodide of nitrogen detonates on the slightest touch, and often without any assignable cause. And the bodies which explode with the most tremendous violence of any known, are the chloride of nitrogen (NCl_3) and hydrazoic acid (N_3H). Thus these easy and rapid decompositions, due to the chemical indifference of nitrogen, are characteristic. When we come hereafter to observe the part which nitrogen plays in organic actions, we shall see the significance of this extreme readiness shown by its compounds to undergo changes. Returning from these facts parenthetically introduced, we have next to note that though among the diatomic compounds of the four chief organic elements, there are a few active ones, yet the majority of them display a smaller degree of chemical energy than the average of diatomic compounds. Water is the most neutral of bodies: usually producing little chemical alteration in the substances with which it combines; and being expelled from most of its combinations by a moderate heat. Carbonic acid is a relatively feeble acid: the carbonates being decomposed by the majority of other acids and by ignition. The various hydro-carbons are but narrow in the range of their comparatively weak affinities. The compounds formed by ammonia have not much stability: they are readily destroyed by heat, and by the other alkalies. The affinities of cyanogen are tolerably strong, though they yield to those of the chief acids. Of the several oxides of nitrogen, it is to be remarked that, while those containing the smaller proportions of oxygen are chemically inert, the one containing the greatest proportion of oxygen (nitric acid) though chemically active, in consequence of the readiness with which one part of it gives up its oxygen to oxidize a base with which the rest combines, is nevertheless driven from all its combinations by a red heat.

These diatomic compounds, like their elements, are to a considerable degree characterized by the prevalence among them of allotropism; or, as it is more usually called when displayed by compound bodies – isomerism. Professor Graham finds reason for thinking that a change in atomic arrangements of this nature, takes place in water, at or near the melting point of ice. In the various series of hydro-carbons, differing from each other only in the ratios in which the elements are united, we find not simply isomerism but polymerism occurring to an almost infinite extent. In some series of hydro-carbons, as, for example, the terpenes, we find isomerism and at the same time a great tendency to undergo polymerisation. And the relation between cyanogen and paracyanogen is, as we saw, a polymeric one.

There is one further fact respecting these diatomic compounds of the chief organic elements, which must not be overlooked. Those of them which form parts of the living tissues of plants and animals (excluding water which has a mechanical function, and carbonic acid which is a product of decomposition) belong for the most part to one group – the carbo-hydrates.[4] And of this group, which is on the average characterized by comparative instability and inertness, these carbo-hydrates found in living tissues are among the most unstable and inert.

§ 3. Passing now to the substances which contain three of these chief organic elements, we have first to note that along with the greater atomic weight which mostly accompanies their increased complexity, there is, on the average, a further marked decrease of molecular mobility. Scarcely any of them maintain a gaseous state at ordinary temperatures. One class of them only, the alcohols and their derivatives, evaporate under the usual atmospheric pressure; but not rapidly unless heated. The fixed oils, though they show that molecular mobility implied by an habitually liquid state, show this in a lower degree than the alcoholic compounds; and they cannot be reduced to the gaseous state without decomposition. In their allies, the fats, which are solid unless heated, the loss of molecular mobility is still more marked. And throughout the whole series of the fatty acids, in which to a fixed proportion of oxygen there are successively added higher equimultiples of carbon and hydrogen, we see how the molecular mobility decreases with the increasing sizes of the molecules. In the amylaceous and sugar-group of compounds, solidity is the habitual state: such of them as can assume the liquid form, doing so only when heated to 300° or 400° F.; and decomposing when further heated, rather than become gaseous. Resins and gums exhibit general physical properties of like character and meaning.

In chemical stability these triatomic compounds, considered as a group, are in a marked degree below the diatomic ones. The various sugars and kindred bodies, decompose at no very high temperatures. The oils and fats also are readily carbonized by heat. Resinous and gummy substances are easily made to render up some of their constituents. And the alcohols, with their allies, have no great power of resisting decomposition. These bodies, formed by the union of oxygen, hydrogen, and carbon, are also, as a class, chemically inactive. Formic and acetic are doubtless energetic acids; but the higher members of the fatty-acid series are easily separated from the bases with which they combine. Saccharic acid, too, is an acid of considerable power; and sundry of the vegetable acids possess a certain activity, though an activity far less than that of the mineral acids. But throughout the rest of the group, there is shown but a small tendency to combine with other bodies; and such combinations as are formed have usually little permanence.

The phenomena of isomerism and polymerism are of frequent occurrence in these triatomic compounds. Starch and dextrine are probably polymeric. Fruit-sugar and grape-sugar, mannite and sorbite, cane-sugar and milk-sugar, are isomeric. Sundry of the vegetal acids exhibit similar modifications. And among the resins and gums, with their derivatives, molecular re-arrangements of this kind are not uncommon.

One further fact respecting these compounds of carbon, oxygen and hydrogen, should be mentioned; namely, that they are divisible into two classes – the one consisting of substances that result from the destructive decomposition of organic matter, and the other consisting of substances that exist as such in organic matter. These two classes of substances exhibit, in different degrees,

[4] The name hydro-carbons was here used when these pages were written, thirty-four years ago. It was the name then current. In this case, as in multitudinous other cases, the substitution of newer words and phrases for older ones, is somewhat misleading. Putting the thoughts of 1862 in the language of 1897 gives an illusive impression of recency.

the properties to which we have been directing our attention. The lower alcohols, their allies and derivatives, which possess greater molecular mobility and chemical stability than the rest of these triatomic compounds, are rarely found in animal or vegetal bodies. While the sugars and amylaceous substances, the fixed oils and fats, the gums and resins, which have all of them much less molecular mobility, and are, chemically considered, more unstable and inert, are components of the living tissues of plants and animals.

§ 4. Among compounds containing all the four chief organic elements, a division analogous to that just named may be made. There are some which result from the decomposition of living tissues; there are others which make parts of living tissues in their state of integrity; and these two groups are contrasted in their properties in the same way as are the parallel groups of triatomic compounds.

Of the first division, certain products found in the animal excretions are the most important, and the only ones that need be noted; such, namely, as urea, kreatine, kreatinine. These animal-bases exhibit much less molecular mobility than the average of the substances treated of in the last section: being solid at ordinary temperatures, fusing, where fusible at all, at temperatures above that of boiling water, and having no power to assume a gaseous state. Chemically considered, their stability is low, and their activity but small, in comparison with the stabilities and activities of the simpler compounds.

It is, however, the nitrogenous constituents of living tissues, that display most markedly those characteristics of which we have been tracing the growth. Albumen, fibrin, casein, and their allies, are bodies in which that molecular mobility exhibited by three of their components in so high a degree is reduced to a minimum. These substances are known only in the solid state. That is to say, when deprived of the water usually mixed with them, they do not admit of fusion, much less of volatilization. To which add, that they have not even that molecular mobility which solution in water implies; since, though they form viscid mixtures with water, they do not dissolve in the same perfect way as do inorganic compounds. The chemical characteristics of these substances are instability and inertness carried to the extreme. How rapidly albumenoid matters decompose under ordinary conditions, is daily seen: the difficulty of every housewife being to prevent them from decomposing. It is true that when desiccated and kept from contact with air, they may be preserved unchanged for long periods; but the fact that they can be only thus preserved, proves their great instability. It is true, also, that these most complex nitrogenous principles are not absolutely inert, since they enter into combinations with some bases; but their unions are very feeble.

It should be noted, too, of these bodies, that though they exhibit in the lowest degree that kind of molecular mobility which implies facile vibration of the molecules as wholes, they exhibit in high degrees that kind of molecular mobility resulting in isomerism, which implies permanent changes in the positions of adjacent atoms with respect to each other. Each of them has a soluble and an insoluble form. In some cases there are indications of more than two such forms. And it appears that their metamorphoses take place under very slight changes of conditions.

In these most unstable and inert organic compounds, we find that the molecular complexity reaches a maximum: not only since the four chief organic elements are here united with small proportions of sulphur and sometimes phosphorus; but also since they are united in high multiples. The peculiarity which we found characterized even diatomic compounds of the organic elements, that their molecules are formed not of single equivalents of each component, but of two, three, four, and more equivalents, is carried to the greatest extreme in these compounds, which take the leading part in organic actions. According to Lieberkühn, the formula of albumen is $C_{72}H_{112}SN_{18}O_{22}$. That is to say, with the sulphur there are united seventy-two atoms of carbon, one hundred and twelve of hydrogen, eighteen of nitrogen, and twenty-two of oxygen: the molecule being thus made up of more than two hundred ultimate atoms.

§ 5. Did space permit, it would be useful here to consider in detail the interpretations that may be given of the peculiarities we have been tracing: bringing to their solution, the general mechanical principles which are now found to hold true of molecules as of masses. But it must suffice briefly to indicate the conclusions which such an inquiry promises to bring out.

Proceeding on these principles, it may be argued that the molecular mobility of a substance must depend partly on the inertia of its molecules; partly on the intensity of their mutual polarities; partly on their mutual pressures, as determined by the density of their aggregation; and (where the molecules are compound) partly on the molecular mobilities of their component molecules. Whence it is to be inferred that any three of these remaining constant, the molecular mobility will vary as the fourth. Other things equal, therefore, the molecular mobility of molecules must decrease as their masses increase; and so there must result that progression we have traced, from the high molecular mobility of the uncombined organic elements, to the low molecular mobility of those large-moleculed substances into which they are ultimately compounded.

Applying to molecules the mechanical law which holds of masses, that since inertia and gravity increase as the cubes of the dimensions while cohesion increases as their squares, the self-sustaining power of a body becomes relatively smaller as its bulk becomes greater; it might be argued that these large, aggregate molecules which constitute organic substances, are mechanically weak – are less able than simpler molecules to bear, without alteration, the forces falling on them. That very massiveness which renders them less mobile, enables the physical forces acting on them more readily to change the relative positions of their component atoms; and so to produce what we know as re-arrangements and decompositions.

Further, it seems a not improbable conclusion, that this formation of large aggregates of elementary atoms and resulting diminution of self-sustaining power, must be accompanied by a decrease of those dimensional contrasts to which polarity is ascribable. A sphere is the figure of equilibrium which any aggregate of units tends to assume, under the influence of simple mutual attraction. Where the number of units is small and their mutual polarities are decided, this proclivity towards spherical grouping will be overcome by the tendency towards some more special form, determined by their mutual polarities. But it is manifest that in proportion as an aggregate molecule becomes larger, the effects of simple mutual attraction must become relatively greater; and so must tend to mask the effects of polar attraction. There will consequently be apt to result in highly compound molecules like these organic ones, containing hundreds of elementary atoms, such approximation to the spherical form as must involve a less distinct polarity than in simpler molecules. If this inference be correct, it supplies us with an explanation both of the chemical inertness of these most complex organic substances, and of their inability to crystallize.

§ 6. Here we are naturally introduced to another aspect of our subject – an aspect of great interest. Professor Graham has published a series of important researches, which promise to throw much light on the constitution and changes of organic matter. He shows that solid substances exist under two forms of aggregation – the *colloid* or jelly-like, and the *crystalloid* or crystal-like. Examples of the last are too familiar to need specifying. Of the first may be named such instances as "hydrated silicic acid, hydrated alumina, and other metallic peroxides of the aluminous class, when they exist in the soluble form; with starch, dextrine and the gums, caramel, tannin, albumen, gelatine, vegetable and animal extractive matters." Describing the properties of colloids, Professor Graham says: – "Although often largely soluble in water, they are held in solution by a most feeble force. They appear singularly inert in the capacity of acids and bases, and in all the ordinary chemical relations." * * * "Although chemically inert in the ordinary sense, colloids possess a compensating activity of their own arising out of their physical properties. While the rigidity of the crystalline structure shuts out external impressions, the softness of the gelatinous colloid partakes of fluidity, and enables the colloid to become a medium of liquid diffusion, like water itself." * * * "Hence a wide sensibility on the part of colloids to external agents. Another and eminently characteristic quality of colloids is their mutability." * * * "The solution of hydrated silicic acid, for instance, is easily obtained in a state of purity, but it cannot be preserved. It may remain fluid for days or weeks in a sealed tube, but is sure to gelatinize and become insoluble at last. Nor does the change of this colloid appear to stop at that point; for the mineral forms of silicic acid, deposited from water, such as flint, are often found to have passed, during the geological ages of their existence, from the vitreous or colloidal into the crystalline condition (H. Rose). The colloid is, in fact, a dynamical state of matter, the crystalloidal being the statical condition. The colloid possesses *energia*. It may be looked upon as the primary source of the force appearing in the phenomena of vitality. To the gradual manner in which colloidal changes take place (for they always demand time as an element) may the characteristic protraction of chemico-organic changes also be referred."

The class of colloids includes not only all those most complex nitrogenous compounds characteristic of organic tissues, and sundry of the carbo-hydrates found along with them; but, significantly enough, it includes several of those substances classed as inorganic, which enter into organized structures. Thus silica, which is a component of many plants, and constitutes the spicules of sponges as well as the shells of many foraminifera and infusoria, has a colloid, as well as a crystalloid, condition. A solution of hydrated silicic acid passes in the course of a few days into a solid jelly that is no longer soluble in water; and it may be suddenly thus coagulated by a minute portion of an alkaline carbonate, as well as by gelatine, alumina, and peroxide of iron. This last-named substance, too – peroxide of iron – which is an ingredient in the blood of mammals and composes the shells of certain *Protozoa*, has a colloid condition. "Water containing about one per cent. of hydrated peroxide of iron in solution, has the dark red colour of venous blood." * * * "The red solution is coagulated in the cold by traces of sulphuric acid, alkalies, alkaline carbonates, sulphates, and neutral salts in general." * * * "The coagulum is a deep red-coloured jelly, resembling the clot of blood, but more transparent. Indeed, the coagulum of this colloid is highly suggestive of that of blood, from the feeble agencies which suffice to effect the change in question, as well as from the appearance of the product." The jelly thus formed soon becomes, like the last, insoluble in water. Lime also, which is so important a mineral element in living bodies, animal and vegetal, enters into a compound belonging to this class. "The well-known solution of lime in sugar forms a solid coagulum when heated. It is probably, at a high temperature, entirely colloidal."

Generalizing some of the facts which he gives, Professor Graham says: – "The equivalent of a colloid appears to be always high, although the ratio between the elements of the substance may be simple. Gummic acid, for instance, may be represented by $C^{12}H^{22}O^{11}$; but, judging from the small proportions of lime and potash which suffice to neutralize this acid, the true numbers of its formula must be several times greater. It is difficult to avoid associating the inertness of colloids with their high equivalents, particularly where the high number appears to be attained by the repetition of a small number. The inquiry suggests itself whether the colloid molecule may not be constituted by the grouping together of a number of smaller crystalloid molecules, and whether the basis of colloidality may not really be this composite character of the molecule."

§ 7. A further contrast between colloids and crystalloids is equally significant in its relations to vital phenomena. Professor Graham points out that the marked differences in volatility displayed by different bodies, are paralleled by differences in the rates of diffusion of different bodies through liquids. As alcohol and ether at ordinary temperatures, and various other substances at higher temperatures, diffuse themselves in a gaseous form through the air; so, a substance in aqueous solution, when placed in contact with a mass of water (in such way as to avoid mixture by circulating currents) diffuses itself through this mass of water. And just as there are various degrees of rapidity in evaporation, so there are various degrees of rapidity in diffusion: "the range also in the degree of diffusive mobility exhibited by different substances appears to be as wide as the scale of vapour-tensions." This parallelism is what might have been looked for; since the tendency to assume a gaseous state, and the tendency to spread in solution through a liquid, are both consequences of molecular mobility. It also turns out, as was to be expected, that diffusibility, like volatility, has, other things equal, a relation to molecular weight – other things equal, we must say, because molecular mobility must, as pointed out in § 5, be affected by other properties of atoms, besides their inertia. Thus the substance most rapidly diffused of any on which Professor Graham experimented, was hydrochloric acid – a compound which is of low molecular weight, is gaseous save under a pressure of forty atmospheres, and ordinarily exists as a liquid, only in combination with water. Again, "hydrate of potash may be said to possess double the velocity of diffusion of sulphate of potash, and sulphate of potash again double the velocity of sugar, alcohol, and sulphate of magnesia," – differences which have a general correspondence with differences in the massiveness of their molecules.

But the fact of chief interest to us here, is that the relatively small-moleculed crystalloids have immensely greater diffusive power than the relatively large-moleculed colloids. Among the crystalloids themselves there are marked differences of diffusibility; and among the colloids themselves there are parallel differences, though less marked ones. But these differences are small compared with that between the diffusibility of the crystalloids as a class, and the diffusibility of the colloids as a class. Hydrochloric acid is seven times as diffusible as sulphate of magnesia; but it is fifty times as diffusible as albumen, and a hundred times as diffusible as caramel.

These differences of diffusibility manifest themselves with nearly equal distinctness, when a permeable septum is placed between the solution and the water. The result is that when a solution contains substances of different diffusibilities, the process of dialysis, as Professor Graham calls it, becomes a means of separating the mixed substances: especially when such mixed substances are partly crystalloids and partly colloids. The bearing of this fact on the interpretation of organic processes will be obvious. Still more obvious will its bearing be, on joining with it the remarkable fact that while crystalloids can diffuse themselves through colloids nearly as rapidly as through water, colloids can scarcely diffuse themselves at all through other colloids. From a mass of jelly containing salt, into an adjoining mass of jelly containing no salt, the salt spread more in eight days than it spread through water in seven days; while the spread of "caramel through the jelly appeared scarcely to have begun after eight days had elapsed." So that we must regard the colloidal compounds of which organisms are built, as having, by their physical nature, the ability to separate colloids from crystalloids, and to let the crystalloids pass through them with scarcely any resistance.

One other result of these researches on the relative diffusibilities of different substances has a meaning for us. Professor Graham finds that not only does there take place, by dialysis, a separation of *mixed* substances which are unlike in their molecular mobilities; but also that *combined* substances between which the affinities are feeble, will separate on the dialyzer, if their molecular mobilities are strongly contrasted. Speaking of the hydrochloride of peroxide of iron, he says, "such a compound possesses an element of instability in the extremely unequal diffusibility of its constituents;" and he points out that when dialyzed, the hydrochloric acid gradually diffuses away, leaving the colloidal peroxide of iron behind. Similarly, he remarks of the peracetate of iron, that it "may be made a source of soluble peroxide, as the salt referred to is itself decomposed to a great extent by diffusion on the dialyzer." Now this tendency to separate displayed by substances which differ widely in their molecular mobilities, though usually so far antagonized by their affinities as not to produce spontaneous decomposition, must, in all cases, induce a certain readiness to change which would not else exist. The unequal mobilities of the combined atoms must give disturbing forces a greater power to work transformations than they would otherwise have. Hence the probable significance of a fact named at the outset, that while three of the chief organic elements have the greatest atomic mobilities of any elements known, the fourth, carbon, has the least atomic mobility of known elements. Though, in its simple compounds, the affinities of carbon for the rest are strong enough to prevent the effects of this great difference from clearly showing themselves; yet there seems reason to think that in those complex compounds composing organic bodies – compounds in which there are various cross affinities leading to a state of chemical tension – this extreme difference in the molecular mobilities must be an important aid to molecular re-arrangements. In short, we are here led by concrete evidence to the conclusion which we before drew from first principles, that this great unlikeness among the combined units must facilitate differentiations.

§ 8. A portion of organic matter in a state to exhibit those phenomena which the biologist deals with, is, however, something far more complex than the separate organic matters we have been studying; since a portion of organic matter in its integrity, contains several of these.

In the first place no one of those colloids which make up the mass of a living body, appears capable of carrying on vital changes by itself: it is always associated with other colloids. A portion of animal-tissue, however minute, almost always contains more than one form of protein-substance: different chemical modifications of albumen and gelatine are present together, as well as, probably, a soluble and insoluble modification of each; and there is usually more or less of fatty matter. In a single vegetal cell, the minute quantity of nitrogenous colloid present, is imbedded in colloids of the non-nitrogenous class. And the microscope makes it at once manifest, that even the smallest and simplest organic forms are not absolutely homogeneous.

Further, we have to contemplate organic tissue, formed of mingled colloids in both soluble and insoluble states, as permeated throughout by crystalloids. Some of these crystalloids, as oxygen,[5] water, and perhaps certain salts, are agents of decomposition; some, as the saccharine and fatty matters, are probably materials for decomposition; and some, as carbonic acid, water, urea, kreatine, and kreatinine, are products of decomposition. Into the mass of mingled colloids, mostly insoluble and where soluble of very low molecular mobility or diffusive power, we have constantly passing, crystalloids of high molecular mobility or diffusive power, that are capable of decomposing these complex colloids, or of facilitating decompositions otherwise caused; and from these complex colloids, when decomposed, there result other crystalloids (the two chief ones extremely simple and mobile, and the rest comparatively so) which diffuse away as rapidly as they are formed.

And now we may clearly see the necessity for that peculiar composition which we find in organic matter. On the one hand, were it not for the extreme molecular mobility possessed by three out of the four of its chief elements; and were it not for the consequently high molecular mobility of their simpler compounds; there could not be this quick escape of the waste products of organic action; and there could not be that continuously active change of matter which vitality implies. On the other hand, were it not for the union of these extremely mobile elements into immensely complex compounds, having relatively vast molecules which are made comparatively immobile by their inertia, there could not result that mechanical fixity which prevents the components of living tissue from diffusing away along with the effete matters produced by decomposition.

§ 8*a*. Let us not omit here to note the ways in which the genesis of these traits distinguishing organic matter conforms to the laws of evolution as expressed in its general formula.

In pursuance of the belief now widely entertained by chemists that the so-called elements are not elements, but are composed of simpler matters and probably of one ultimate form of matter (for which the name "protyle" has been suggested by Sir W. Crookes), it is to be concluded that the formation of the elements, in common with the formation of all those compounds of them which Nature presents, took place in the course of Cosmic Evolution. Various reasons for this inference the reader will find set forth in the Addenda to an essay on "The Nebular Hypothesis" (see *Essays*, vol. I, p. 155). On tracing out the process of compounding and re-compounding by which, hypothetically, the elements themselves and afterwards their compounds and re-compounds have arisen, certain cardinal facts become manifest.

1. Considered as masses, the units of the elements are the smallest, though larger than the units of the primordial matter. Later than these, since they are composed of them, and since they cannot exist at temperatures so high as those at which the elements can exist, come the diatomic

[5] It will perhaps seem strange to class oxygen as a crystalloid. But inasmuch as the crystalloids are distinguished from the colloids by their atomic simplicity, and inasmuch as sundry gases are reducible to a crystalline state, we are justified in so classing it.

compounds – oxides, chlorides, and the rest – necessarily larger in their molecules. Above these in massiveness come the molecules of the multitudinous salts and kindred bodies. When associated, as these commonly are, with molecules of water, there again results in each case increase of mass; and unable as they are to bear such high temperatures, these molecules are necessarily later in origin than those of the anhydrous diatomic compounds. Within the general class of triatomic compounds, more composite still, come the carbohydrates, which, being able to unite in multiples, form still larger molecules than other triatomic compounds. Decomposing as they do at relatively low temperatures, these are still more recent in the course of chemical evolution; and with the genesis of them the way is prepared for the genesis of organic matter strictly so called. This includes the various forms of protein-substance, containing four chief elements with two minor ones, and having relatively vast molecules. Unstable as these are in presence of heat and surrounding affinities, they became possible only at a late stage in the genesis of the Earth. Here, then, in that chemical evolution which preceded the evolution of life, we see displayed that process of integration which is the primary trait of evolution at large.

2. Along with increasing integration has gone progress in heterogeneity. The elements, regarding them as compound, are severally more heterogeneous than "protyle." Diatomic molecules are more heterogeneous than these elements; triatomic more heterogeneous than diatomic; and the molecules containing four elements more heterogeneous than those containing three: the most heterogeneous of them being the proteids, which contain two other elements. The hydrated forms of all these compounds are more heterogeneous than are the anhydrous forms. And most heterogeneous of all are the molecules which, besides containing three, four, or more elements, also exhibit the isomerism and polymerism which imply unions in multiples.

3. This formation of molecules more and more heterogeneous during terrestrial evolution, has been accompanied by increasing heterogeneity in the aggregate of compounds of each kind, as well as an increasing number of kinds; and this increasing heterogeneity is exemplified in an extreme degree in the compounds, non-nitrogenous and nitrogenous, out of which organisms are built. So that the classes, orders, genera, and species of chemical substances, gradually increasing as the Earth has assumed its present form, increased in a transcendent degree during that stage which preceded the origin of life.

§ 9. Returning now from these partially-parenthetic observations, and summing up the contents of the preceding pages, we have to remark that in the substances of which organisms are composed, the conditions necessary to that re-distribution of Matter and Motion which constitutes Evolution, are fulfilled in a far higher degree than at first appears.

The mutual affinities of the chief organic elements are not active within the limits of those temperatures at which organic actions take place; and one of these elements is especially characterized by its chemical indifference. The compounds formed by these elements in ascending grades of complexity, become progressively less stable. And those most complex compounds into which all these four elements enter, together with small proportions of two other elements which very readily oxidize, have an instability so great that decomposition ensues under ordinary atmospheric conditions.

Among these elements out of which living bodies are built, there is an unusual tendency to unite in multiples; and so to form groups of products which have the same chemical elements in the same proportions, but, differing in their modes of aggregation, possess different properties. This prevalence among them of isomerism and polymerism, shows, in another way, the special fitness of organic substances for undergoing re-distributions of their components.

In those most complex compounds that are instrumental to vital actions, there exists a kind and degree of molecular mobility which constitutes the plastic quality fitting them for organization. Instead of the extreme molecular mobility possessed by three out of the four organic elements in their separate states – instead of the diminished, but still great, molecular mobility possessed by their simpler combinations, the gaseous and liquid characters of which unfit them for showing to any extent the process of Evolution – instead of the physical properties of their less simple combinations, which, when not made unduly mobile by heat, assume the unduly rigid form of crystals; we have in these colloids, of which organisms are mainly composed, just the required compromise between fluidity and solidity. They cannot be reduced to the unduly mobile conditions of liquid and gas; and yet they do not assume the unduly fixed condition usually characterizing solids. The absence of power to unite together in polar arrangement, leaves their molecules with a certain freedom of relative movement, which makes them sensitive to small forces, and produces plasticity in the aggregates composed of them.

While the relatively great inertia of these large and complex organic molecules renders them comparatively incapable of being set in motion by the ethereal undulations, and so reduced to less coherent forms of aggregation, this same inertia facilitates changes of arrangement among their constituent molecules or atoms; since, in proportion as an incident force impresses but little motion on a mass, it is the better able to impress motion on the parts of the mass in relation to one another. And it is further probable that the extreme contrasts in molecular mobilities among the components of these highly complex molecules, aid in producing modifiability of arrangement among them.

Lastly, the great difference in diffusibility between colloids and crystalloids, makes possible in the tissues of organisms a specially rapid re-distribution of matter and motion; both because colloids, being easily permeable by crystalloids, can be chemically acted on throughout their whole masses, instead of only on their surfaces; and because the products of decomposition, being also crystalloids, can escape as fast as they are produced: leaving room for further transformations. So that while the composite molecules of which organic tissues are built up, possess that low molecular mobility fitting them for plastic purposes, it results from the extreme molecular mobilities of their ultimate constituents, that the waste products of vital activity escape as fast as they are formed.

To all which add that the state of warmth, or increased molecular vibration, in which all the higher organisms are kept, increases these various facilities for re-distribution: not only as aiding chemical changes, but as accelerating the diffusion of crystalloid substances.

CHAPTER II. THE ACTIONS OF FORCES ON ORGANIC MATTER

§ 10. To some extent, the parts of every body are changed in their arrangement by any incident mechanical force. But in organic bodies, and especially in animal bodies, the changes of arrangement produced by mechanical forces are usually conspicuous. It is a distinctive mark of colloids that they readily yield to pressures and tensions, and that they recover, more or less completely, their original shapes, when the pressures or tensions cease. Evidently without this pliability and elasticity, most organic actions would be impossible. Not only temporary but also permanent alterations of form are facilitated by this colloid character of organic matter. Continued pressure on living tissue, by modifying the processes going on in it (perhaps retarding the absorption of new material to replace the old that has decomposed and diffused away), gradually diminishes and finally destroys its power of resuming the outline it had at first. Thus, generally speaking, the substances composing organisms are modifiable by arrested momentum or by continuous strain, in far greater degrees than are inorganic substances.

§ 11. Sensitiveness to certain forces which are quasi-mechanical, if not mechanical in the usual sense, is seen in two closely-related peculiarities displayed by organic matter as well as other matter which assumes the same state of molecular aggregation.

Colloids take up by a power called "capillary affinity," a large quantity of water: undergoing at the same time great increase of bulk with change of form. Conversely, with like readiness, they give up this water by evaporation; resuming, partially or completely, their original states. Whether resulting from capillarity, or from the relatively great diffusibility of water, or from both, these changes are to be here noted as showing another mode in which the arrangements of parts in organic bodies are affected by mechanical actions.

In what is termed osmose, we have a further mode of an allied kind. When on opposite sides of a permeable septum, and especially a septum of colloidal substance, are placed miscible solutions of different densities, a double transfer takes place: a large quantity of the less dense solution finds its way through the septum into the more dense solution; and a small quantity of the more dense finds its way into the less dense – one result being a considerable increase in the bulk of the more dense at the expense of the less dense. This process, which appears to depend on several conditions, is not yet fully understood. But be the explanation what it may, the process is one that tends continually to work alterations in organic bodies. Through the surfaces of plants and animals, transfers of this kind are ever taking place. Many of the conspicuous changes of form undergone by organic germs, are due mainly to the permeation of their limiting membranes by the surrounding liquids.

It should be added that besides the direct alterations which the imbibition and transmission of water and watery solutions by colloids produce in organic matter, they produce indirect alterations. Being instrumental in conveying into the tissues the agents of chemical change, and conveying out of them the products of chemical change, they aid in carrying on other re-distributions.

§ 12. As elsewhere shown (*First Principles*, § 100) heat, or a raised state of molecular vibration, enables incident forces more easily to produce changes of molecular arrangement in organic matter. But besides this, it conduces to certain vital changes in so direct a way as to become their chief cause.

The power of the organic colloids to imbibe water, and to bring along with it into their substance the materials which work transformations, would not be continuously operative if the water imbibed were to remain. It is because it escapes, and is replaced by more water containing more materials, that the succession of changes is maintained. Among the higher animals and higher plants its escape is facilitated by evaporation. And the rate of evaporation is, other things equal, determined by heat. Though the current of sap in a tree is partly dependent on some action, probably osmotic, that goes on in the roots; yet the loss of water from the surfaces of the leaves, and the consequent absorption of more sap into the leaves by capillary attraction, must be a chief cause of the circulation. The drooping of a plant when exposed to the sunshine while the earth round its roots is dry, shows us how evaporation empties the sap-vessels; and the quickness with which a withered slip revives on being placed in water, shows us the part which capillary action plays. In so far, then, as the evaporation from a plant's surface helps to produce currents of sap through the plant, we must regard the heat which produces this evaporation as a part-cause of those re-distributions of matter which these currents effect. In terrestrial animals, heat, by its indirect action as well as by its direct action, similarly aids the changes that are going on. The exhalation of vapour from the lungs and the surface of the skin, forming the chief escape of the water that is swallowed, conduces to the maintenance of those currents through the tissues without which the functions would cease. For though the vascular system distributes nutritive liquids in ramified channels through the body; yet the absorption of these liquids into tissues, partly depends on the escape of liquids which the tissues already contain. Hence, to the extent that such escape is facilitated by evaporation, and this evaporation facilitated by heat, heat becomes an agent of re-distribution in the animal organism.[6]

§ 13. Light, which is now known to modify many inorganic compounds – light, which works those chemical changes utilized in photography, causes the combinations of certain gases, alters the molecular arrangements of many crystals, and leaves traces of its action even on substances that are extremely stable, – may be expected to produce marked effects on substances so complex and unstable as those which make up organic bodies. It does produce such effects; and some of them are among the most important that organic matter undergoes.

The molecular changes wrought by light in animals are of but secondary moment. There is the darkening of the skin that follows exposure to the Sun's rays. There are those alterations in the retina which cause in us sensations of colours. And on certain eyeless creatures that are semi-transparent, the light permeating their substance works some effects evinced by movements. But speaking generally, the opacity of animals limits the action of light to their surfaces; and so renders its direct physiological influence but small.[7] On plants, however, the solar rays that produce in us the impression of yellow, are the immediate agents of those molecular changes through which are hourly accumulated the materials for further growth. Experiments have shown that when the Sun shines on living leaves, they begin to exhale oxygen and to accumulate carbon and hydrogen – results which are traced to the decomposition, by the solar rays, of the carbonic acid and water absorbed. It is now an accepted conclusion that, by the help of certain classes of the ethereal undulations penetrating their leaves, plants are enabled to separate from the associated oxygen those two elements of which their tissues are chiefly built up.

This transformation of ethereal undulations into certain molecular re-arrangements of an unstable kind, on the overthrow of which the stored-up forces are liberated in new forms, is a process that underlies all organic phenomena. It will therefore be well if we pause a moment to consider whether any proximate interpretation of it is possible. Researches in molecular physics give us some clue to its nature.

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[6] The remark made by a critic to the effect that in a mammal higher temperature diminishes the rate of molecular change in the tissues, leads me to add that the exhalation I have alleged is prevented if the heat rises above the range of variation normal to the organism; since, then, unusually rapid pulsations with consequent inefficient propulsion of the blood, cause a diminished rate of circulation. To produce the effect referred to in the text, heat must be associated with dryness; for otherwise evaporation is not aided. General evidence supporting the statement I have made is furnished by the fact that the hot and dry air of the eastern deserts is extremely invigorating; by the fact that all the energetic and conquering races of men have come from the hot and dry regions marked on the maps as rainless; and by the fact that travellers in Africa comment on the contrast between the inhabitants of the hot and dry regions (relatively elevated) and those of the hot and moist regions: active and inert respectively.

[7] The increase of respiration found to result from the presence of light, is probably an *indirect* effect. It is most likely due to the reception of more vivid impressions through the eyes, and to the consequent nervous stimulation. Bright light is associated in our experience with many of our greatest outdoor pleasures, and its presence partially arouses the consciousness of them, with the concomitant raised vital functions.

The elements of the problem are these: – The atoms[8] of several ponderable matters exist in combination: those which are combined having strong affinities, but having also affinities less strong for some of the surrounding atoms that are otherwise combined. The atoms thus united, and thus mixed among others with which they are capable of uniting, are exposed to the undulations of a medium that is so rare as to seem imponderable. These undulations are of numerous kinds: they differ greatly in their lengths, or in the frequency with which they recur at any given point. And under the influence of undulations of a certain frequency, some of these atoms are transferred from atoms for which they have a stronger affinity, to atoms for which they have a weaker affinity. That is to say, particular orders of waves of a relatively imponderable matter, remove particular atoms of ponderable matter from their attachments, and carry them within reach of other attachments. Now the discoveries of Bunsen and Kirchoff respecting the absorption of particular luminiferous undulations by the vapours of particular substances, joined with Prof. Tyndall's discoveries respecting the absorption of heat by gases, show very clearly that the atoms of each substance have a rate of vibration in harmony with ethereal waves of a certain length, or rapidity of recurrence. Every special kind of atom can be made to oscillate by a special order of ethereal waves, which are absorbed in producing its oscillations; and can by its oscillations generate this same order of ethereal waves. Whence it appears that immense as is the difference in density between ether and ponderable matter, the waves of the one can set the atoms of the other in motion, when the successive impacts of the waves are so timed as to correspond with the oscillations of the atoms. The effects of the waves are, in such case, cumulative; and each atom gradually acquires a momentum made up of countless infinitesimal momenta. Note, further, that unless the members of a chemically-compound molecule are so bound up as to be incapable of any relative movements (a supposition at variance with the conceptions of modern science) we must conceive them as severally able to vibrate in unison or harmony with those same classes of ethereal waves that affect them in their uncombined states. While the compound molecule as a whole will have some new rate of oscillation determined by its attributes as a whole; its components will retain their original rates of oscillation, subject only to modifications by mutual influence. Such being the circumstances of the case we may partially understand how the Sun's rays can effect chemical decompositions. If the members of a diatomic molecule stand so related to the undulations falling on them, that one is thrown into a state of increased oscillation and the other not; it is manifest that there must arise a tendency towards the dislocation of the two – a tendency which may or may not take effect, according to the weakness or strength of their union, and according to the presence or absence of collateral affinities. This inference is in harmony with several significant facts. Dr. Draper remarks that "among metallic substances (compounds) those first detected to be changed by light, such as silver, gold, mercury, lead, have all high atomic weights; and such as sodium and potassium, the atomic weights of which are low, appeared to be less changeable." As here interpreted, the fact specified amounts to this; that the compounds most readily decomposed by light, are those in which there is a marked contrast between the atomic weights of the constituents, and probably therefore a marked contrast between the rapidities of their vibrations. The circumstance, too, that different chemical compounds are decomposed or modified in different parts of the spectrum, implies that there is a relation between special orders of undulations and special orders of molecules – doubtless a correspondence between the rates of these undulations and the rates of oscillation which some of the components of such molecules will assume. Strong confirmation of this view may be drawn from the decomposing actions of those longer ethereal waves which we perceive as heat. On contemplating the whole series of diatomic compounds, we see that the elements which are most remote in their atomic weights, as hydrogen and the noble metals generally, will not combine at all, or do so with great difficulty: their vibrations are so unlike that they cannot keep together under any conditions of

[8] To exclude confusion it may be well here to say that the word "atom" is, as before explained, used as the name for a unit of a substance at present undecomposed; while the word "molecule" is used as the name for a unit of a substance known to be compound.

temperature. If, again, we look at a smaller group, as the metallic oxides, we see that whereas those metals which have atoms nearest in weight to the atoms of oxygen, cannot be separated from oxygen by heat, even when it is joined by a powerful collateral affinity; those metals which differ more widely from oxygen in their atomic weights, can be de-oxidized by carbon at high temperatures; and those which differ from it most widely combine with it very reluctantly, and yield it up if exposed to thermal undulations of moderate intensity. Here indeed, remembering the relations among the atomic weights in the two cases, may we not suspect a close analogy between the de-oxidation of a metallic oxide by carbon under the influence of the longer ethereal waves, and the de-carbonization of carbonic acid by hydrogen under the influence of the shorter ethereal waves?

These conceptions help us to some dim notion of the mode in which changes are wrought in light in the leaves of plants. Among the several elements concerned, there are wide differences in molecular mobility, and probably in the rates of molecular vibration. Each is combined with one of the others, but is capable of forming various combinations with the rest. And they are severally in presence of a complex compound into which they all enter, and which is ready to assimilate with itself the new compound molecules they form. Certain of the ethereal waves falling on them when thus arranged, cause a detachment of some of the combined atoms and a union of the rest. And the conclusion suggested is that the induced vibrations among the various atoms as at first arranged, are so incongruous as to produce instability, and to give collateral affinities the power to work a rearrangement which, though less stable under other conditions, is more stable in the presence of these particular undulations. There seems, indeed, no choice but to conceive the matter thus. An atom united with one for which it has a strong affinity, has to be transferred to another for which it has a weaker affinity. This transfer implies motion. The motion is given by the waves of a medium that is relatively imponderable. No one wave of this imponderable medium can give the requisite motion to this atom of ponderable matter: especially as the atom is held by a positive force besides its inertia. The motion required can hence be given only by successive waves; and that these may not destroy each other's effects, it is needful that each shall strike the atom just when it has completed the recoil produced by the impact of previous ones. That is, the ethereal undulations must coincide in rate with the oscillations of the atom, determined by its inertia and the forces acting on it. It is also requisite that the rate of oscillation of the atom to be detached, shall differ from that of the atom with which it is united; since if the two oscillated in unison the ethereal waves would not tend to separate them. And, finally, the successive impacts of the ethereal waves must be accumulated until the resulting oscillations have become so wide in their sweep as greatly to weaken the cohesion of the united atoms, at the same time that they bring one of them within reach of other atoms with which it will combine. In this way only does it seem possible for such a force to produce such a transfer. Moreover, while we are thus enabled to conceive how light may work these molecular changes, we also gain an insight into the method by which the insensible motions propagated to us from the Sun, are treasured up in such ways as afterwards to generate sensible motions. By the accumulation of infinitesimal impacts, atoms of ponderable matter are made to oscillate. The quantity of motion which each of them eventually acquires, effects its transfer to a position of unstable equilibrium, from which it can afterwards be readily dislodged. And when so dislodged, along with other atoms similarly and simultaneously affected, there is suddenly given out all the motion which had been before impressed on it.

Speculation aside, however, that which it concerns us to notice is the broad fact that light is an all-important agent of molecular changes in organic substances. It is not here necessary for us to ascertain *how* light produces these compositions and decompositions. It is necessary only for us to observe that it *does* produce them. That the characteristic matter called chlorophyll, which gives the green colour to leaves, makes its appearance whenever the blanched shoots of plants are exposed to the Sun; that the petals of flowers, uncoloured while in the bud, acquire their bright tints as they unfold; and that on the outer surfaces of animals, analogous changes are induced; are wide inductions which are enough for our present purpose.

§ 14. We come next to the agency of chief importance among those that work changes in organic matter; namely, chemical affinity. How readily vegetal and animal substances are modified by other substances put in contact with them, we see daily illustrated. Besides the many compounds which cause the death of an organism into which they are put, we have the much greater number of compounds which work those milder effects termed medicinal – effects implying, like the others, molecular re-arrangements. Indeed, most soluble chemical compounds, natural and artificial, produce, when taken into the body, alterations that are more or less manifest in their results.

After what was shown in the last chapter, it will be manifest that this extreme modifiability of organic matter by chemical agencies, is the chief cause of that active molecular re-arrangement which organisms, and especially animal organisms, display. In the two fundamental functions of nutrition and respiration, we have the means by which the supply of materials for this active molecular re-arrangement is maintained.

The process of animal nutrition consists partly in the absorption of those complex substances which are thus highly capable of being chemically altered, and partly in the absorption of simpler substances capable of chemically altering them. The tissues always contain small quantities of alkaline and earthy salts, which enter the system in one form and are excreted in another. Though we do not know specifically the parts which these salts play, yet from their universal presence, and from the transformations which they undergo in the body, it may be safely inferred that their chemical affinities are instrumental in working some of the metamorphoses ever going on.

The inorganic substance, however, on which mainly depend these metamorphoses in organic matter, is not swallowed along with the solid and liquid food, but is absorbed from the surrounding medium – air or water, as the case may be. Whether the oxygen taken in, either, as by the lowest animals, through the general surface, or, as by the higher animals, through respiratory organs, is the immediate cause of those molecular changes which are ever going on throughout the living tissues; or whether the oxygen, playing the part of scavenger, merely aids these changes by carrying away the products of decompositions otherwise caused; it equally remains true that these changes are maintained by its instrumentality. Whether the oxygen absorbed and diffused through the system effects a direct oxidation of the organic colloids which it permeates, or whether it first leads to the formation of simpler and more oxidized compounds, which are afterwards further oxidized and reduced to still simpler forms, matters not, in so far as the general result is concerned. In any case it holds good that the substances of which the animal body is built up, enter it in either an unoxidized or in a but slightly oxidized and highly unstable state; while the great mass of them leave it in a fully oxidized and stable state. It follows, therefore, that, whatever the special changes gone through, the general process is a falling from a state of unstable chemical equilibrium to a state of stable chemical equilibrium. Whether this process be direct or indirect, the total molecular re-arrangement and the total motion given out in effecting it, must be the same.

§ 15. There is another species of re-distribution among the component matters of organisms, which is not immediately effected by the affinities of the matters concerned, but is mediately effected by other affinities; and there is reason to think that the re-distribution thus caused is important in amount, if not indeed the most important. In ordinary cases of chemical action, the two or more substances concerned themselves undergo changes of molecular arrangement; and the changes are confined to the substances themselves. But there are other cases in which the chemical action going on does not end with the substances at first concerned, but sets up chemical actions, or changes of molecular arrangement, among surrounding substances that would else have remained quiescent. And there are yet further cases in which mere contact with a substance that is itself quiescent, will cause other substances to undergo rapid metamorphoses. In what we call fermentation, the first species of this communicated chemical action is exemplified. One part of yeast, while itself undergoing molecular change, will convert 100 parts of sugar into alcohol and carbonic acid; and during its own decomposition, one part of diastase "is able to effect the transformation of more than 1000 times its weight of starch into sugar." As illustrations of the second species, may be mentioned those changes which are suddenly produced in many colloids by minute portions of various substances added to them – substances that are not undergoing manifest transformations, and suffer no appreciable effects from the contact. The nature of the first of these two kinds of communicated molecular change, which here chiefly concerns us, may be rudely represented by certain visible changes communicated from mass to mass, when a series of masses has been arranged in a special way. The simplest example is that furnished by the child's play of setting bricks on end in a row, in such positions that when the first is overthrown it overthrows the second, the second the third, the third the fourth, and so on to the end of the row. Here we have a number of units severally placed in unstable equilibrium, and in such relative positions that each, while falling into a state of stable equilibrium, gives an impulse to the next sufficient to make the next, also, fall from unstable to stable equilibrium. Now since, among mingled compound molecules, no one can undergo change in the arrangement of its parts without a molecular motion that must cause some disturbance all round; and since an adjacent molecule disturbed by this communicated motion, may have the arrangement of its constituent atoms altered, if it is not a stable arrangement; and since we know, both that the molecules which are changed by this so-called catalysis *are* unstable, and that the molecules resulting from their changes are *more* stable; it seems probable that the transformation is really analogous, in principle, to the familiar one named. Whether thus interpretable or not, however, there is good reason for thinking that to this kind of action is due a large amount of vital metamorphosis. Let us contemplate the several groups of facts which point to this conclusion.[9]

In the last chapter (§ 2) we incidentally noted the extreme instability of nitrogenous compounds in general. We saw that sundry of them are liable to explode on the slightest incentive – sometimes without any apparent cause; and that of the rest, the great majority are very easily decomposed by heat, and by various substances. We shall perceive much significance in this general characteristic when we join it with the fact that the substances capable of setting up extensive molecular changes in the way above described are all nitrogenous ones. Yeast consists of vegetal cells containing nitrogen, – cells that grow by assimilating the nitrogenous matter contained in wort. Similarly, the "vinegar-plant," which greatly facilitates the formation of acetic acid from alcohol, is a fungoid growth that is doubtless, like others of its class, rich in nitrogenous compounds. Diastase, by which the transformation of starch into sugar is effected during the process of malting, is also a nitrogenous body. So too is a substance called synaptase – an albumenous principle contained in almonds, which has the power of working several metamorphoses in the matters associated with it. These nitrogenized compounds, like the rest of their family, are remarkable for the rapidity with which they decompose; and the extensive changes produced by them in the accompanying carbo-hydrates, are found to vary in their kinds according as the decompositions of the ferments vary in their stages. We have next to note, as having here a meaning for us, the chemical contrasts between those organisms which carry on their functions by the help of external forces, and those which carry on their functions by forces evolved from within. If we compare animals and plants, we see that whereas plants, characterized as a class by containing but little nitrogen, are dependent on the solar rays for their vital activities; animals, the vital activities of which are not thus dependent, mainly consist of nitrogenous substances. There

[9] On now returning to the subject after many years, I meet with some evidence recently assigned, in a paper read before the Royal Society by Mr. J. W. Pickering, D.Sc. (detailing results harmonizing with those obtained by Prof. Grimaux), showing clearly how important an agent in vital actions is this production of isomeric changes by slight changes of conditions. Certain artificially produced substances, simulating proteids in other of their characters and reactions, were found to simulate them in coagulability by trifling disturbances. "In the presence of a *trace of neutral salt* they coagulate on heating at temperatures very similar to proteid solutions." And it is shown that by one of these factitious organic colloids a like effect is produced in coagulating the blood, to that "produced by the intravenous injection of a nucleoproteid."

is one marked exception to this broad distinction, however; and this exception is specially instructive. Among plants there is a considerable group – the Fungi – many members of which, if not all, can live and grow in the dark; and it is their peculiarity that they are very much more nitrogenous than other plants. Yet a third class of facts of like significance is disclosed when we compare different portions of the same organism. The seed of a plant contains nitrogenous substance in a far higher ratio than the rest of the plant; and the seed differs from the rest of the plant in its ability to initiate, in the absence of light, extensive vital changes – the changes constituting germination. Similarly in the bodies of animals, those parts which carry on active functions are nitrogenous; while parts that are non-nitrogenous – as the deposits of fat – carry on no active functions. And we even find that the appearance of non-nitrogenous matter throughout tissues normally composed almost wholly of nitrogenous matter, is accompanied by loss of activity: what is called fatty degeneration being the concomitant of failing vitality. One more fact, which serves to make still clearer the meaning of the foregoing ones, remains – the fact, namely, that in no part of any organism where vital changes are going on, is nitrogenous matter wholly absent. It is common to speak of plants – or at least all parts of plants but the seeds – as non-nitrogenous. But they are only relatively so; not absolutely. The quantity of albumenoid substance in the tissues of plants, is extremely small compared with the quantity contained in the tissues of animals; but all plant-tissues which are discharging active functions have some albumenoid substance. In every living vegetal cell there is a certain part that includes nitrogen as a component. This part initiates those changes which constitute the development of the cell. And if it cannot be said that it is the worker of all subsequent changes undergone by the cell, it nevertheless continues to be the part in which the independent activity is most marked.

Looking at the evidence thus brought together, do we not get an insight into the actions of nitrogenous matter as a worker of organic changes? We see that nitrogenous compounds in general are extremely prone to decompose: their decomposition often involving a sudden and great evolution of energy. We see that the substances classed as ferments, which, during their own molecular changes, set up molecular changes in the accompanying carbo-hydrates, are all nitrogenous. We see that among classes of organisms, and among the parts of each organism, there is a relation between the amount of nitrogenous matter present and the amount of independent activity. And we see that even in organisms and parts of organisms where the activity is least, such changes as do take place are initiated by a substance containing nitrogen. Does it not seem probable, then, that these extremely unstable compounds have everywhere the effect of communicating to the less unstable compounds associated with them, molecular movements towards a stable state, like those they are themselves undergoing? The changes which we thus suppose nitrogenous matter to produce in the body, are clearly analogous to those which we see it produce out of the body. Out of the body, certain carbo-hydrates in continued contact with nitrogenous matter, are transformed into carbonic acid and alcohol, and unless prevented the alcohol is transformed into acetic acid: the substances formed being thus more highly oxidized and more stable than the substances destroyed. In the body, these same carbo-hydrates, in continued contact with nitrogenous matter, are transformed into carbonic acid and water: substances which are also more highly oxidized and more stable than those from which they result. And since acetic acid is itself resolved by further oxidation into carbonic acid and water; we see that the chief difference between the two cases is, that the process is more completely effected in the body than it is out of the body. Thus, to carry further the simile used above, the molecules of carbo-hydrates contained in the tissues are, like bricks on end, not in the stablest equilibrium; but still in an equilibrium so stable, that they cannot be overthrown by the chemical and thermal forces which the body brings to bear on them. On the other hand, being like similarly-placed bricks that have very narrow ends, the nitrogenous molecules contained in the tissues are in so unstable an equilibrium that they cannot withstand these forces. And when these delicately-poised nitrogenous molecules fall into stable arrangements, they give impulses to the more firmly-poised non-nitrogenous molecules, which cause them also to fall into stable arrangements. It is a curious and significant fact that in the arts, we not only utilize this same principle of initiating extensive changes among comparatively stable compounds, by the help of compounds much less stable, but we employ for the purpose compounds of the same general class. Our modern method of firing a gun is to place in close proximity with the gunpowder which we wish to decompose or explode, a small portion of fulminating powder, which is decomposed or exploded with extreme facility, and which, on decomposing, communicates the consequent molecular disturbance to the less-easily decomposed gunpowder. When we ask what this fulminating powder is composed of, we find that it is a nitrogenous salt.[10]

Thus, besides the molecular re-arrangements produced in organic matter by direct chemical action, there are others of kindred importance produced by indirect chemical action. Indeed, the inference that some of the leading transformations occurring in the animal organism, are due to this so-called catalysis, appears necessitated by the general aspect of the facts, apart from any such detailed interpretations as the foregoing. We know that various amylaceous and saccharine matters taken as food do not appear in the excreta, and must therefore be decomposed in their course through the body. We know that these matters do not become components of the tissues, but only of the contained liquids and solids; and that thus their metamorphosis is not a direct result of tissue-change. We know that their stability is such that the thermal and chemical forces to which they are exposed in the body, cannot alone decompose them. The only explanation open to us, therefore, is that the transformation of these carbo-hydrates into carbonic acid and water, is due to communicated chemical action.

§ 16. This chapter will have served its purpose if it has given a conception of the extreme modifiability of organic matter by surrounding agencies. Even were it possible, it would be needless to describe in detail the immensely varied and complicated changes which the forces from moment to moment acting on them, work in living bodies. Dealing with biology in its general principles, it concerns us only to notice how specially sensitive are the substances of which organisms are built up to the varied influences that act upon organisms. Their special sensitiveness has been made sufficiently manifest in the several foregoing sections.

[10] After this long interval during which other subjects have occupied me, I now find that the current view is similar to the view above set forth, in so far that a small molecular disturbance is supposed suddenly to initiate a great one, producing a change compared to an explosion. But while, of two proposed interpretations, one is that the fuse is nitrogenous and the charge a carbo-hydrate, the other is that both are nitrogenous. The relative probabilities of these alternative views will be considered in a subsequent chapter.

CHAPTER III. THE RE-ACTIONS OF ORGANIC MATTER ON FORCES

§ 17. Re-distributions of Matter imply concomitant re-distributions of Motion. That which under one of its aspects we contemplate as an alteration of arrangement among the parts of a body, is, under a correlative aspect, an alteration of arrangement among certain momenta, whereby these parts are impelled to their new positions. At the same time that a force, acting differently on the different units of an aggregate, changes their relations to one another; these units, reacting differently on the different parts of the force, work equivalent changes in the relations of these to one another. Inseparably connected as they are, these two orders of phenomena are liable to be confounded together. It is very needful, however, to distinguish between them. In the last chapter we took a rapid survey of the re-distributions which forces produce in organic matter; and here we must take a like survey of the simultaneous re-distributions undergone by the forces.

At the outset we are met by a difficulty. The parts of an inorganic mass undergoing re-arrangement by an incident force, are in most cases passive – do not complicate those necessary re-actions that result from their inertia, by other forces which they themselves originate. But in organic matter the re-arranged parts do not re-act in virtue of their inertia only. They are so constituted that an incident force usually sets up in them other actions which are much more important. Indeed, what we may call the indirect reactions thus caused, are so great in their amounts compared with the direct re-actions, that they quite obscure them.

The impossibility of separating these two kinds of reaction compels us to disregard the distinction between them. Under the above general title, we must include both the immediate re-actions and those re-actions mediately produced, which are among the most conspicuous of vital phenomena.

§ 18. From organic matter, as from all other matter, incident forces call forth that re-action which we know as heat. More or less of molecular vibration necessarily results when, to the forces at work among the molecules of any aggregate, other forces are added. Experiment abundantly demonstrates this in the case of inorganic masses; and it must equally hold in the case of organic masses. In both cases the force which, more markedly than any other, produces this thermal re-action, is that which ends in the union of different substances. Though inanimate bodies admit of being greatly heated by pressure and by the electric current, yet the evolutions of heat, thus induced are neither so common, nor in most cases so conspicuous, as those resulting from chemical combination. And though in animate bodies there are certain amounts of heat generated by other actions, yet these are secondary to the heat generated by the action of oxygen on the substances composing the tissues and the substances contained in them. Here, however, we see one of the characteristic distinctions between inanimate and animate bodies. Among the first there are but few which ordinarily exist in a condition to evolve the heat caused by chemical combination; and such as are in this condition soon cease to be so when chemical combination and genesis of heat once begin in them. Whereas, among the second there universally exists the ability, more or less decided, thus to evolve heat; and the evolution of heat, in some cases very slight and in no cases very great, continues as long as they remain animate bodies.

The relation between active change of matter and re-active genesis of molecular vibration, is clearly shown by the contrasts between different organisms, and between different states and parts of the same organism. In plants the genesis of heat is extremely small, in correspondence with their extremely small production of carbonic acid: those portions only, as flowers and germinating seeds, in which considerable oxidation is going on, having decidedly raised temperatures. Among animals we see that the hot-blooded are those which expend much force and respire actively. Though insects are scarcely at all warmer than the surrounding air when they are still, they rise several degrees above it when they exert themselves; and in mammals, which habitually maintain a temperature much higher than that of their medium, exertion is accompanied by an additional production of heat.

This molecular agitation accompanies the falls from unstable to stable molecular combinations; whether they be those from the most complex to the less complex compounds, or whether they be those ultimate falls which end in fully oxidized and relatively simple compounds; and whether they be those of the nitrogenous matters composing the tissues or those of the non-nitrogenous matters diffused through them. In the one case as in the other, the heat must be regarded as a concomitant. Whether the distinction, originally made by Liebig, between nitrogenous substances as tissue-food and non-nitrogenous substances as heat-food, be true or not in a narrower sense, it cannot be accepted in the sense that tissue-food is not also heat-food. Indeed he does not himself assert it in this sense. The ability of carnivorous animals to live and generate heat while consuming matter that is almost exclusively nitrogenous, suffices to prove that the nitrogenous compounds forming the tissues are heat-producers, as well as the non-nitrogenous compounds circulating among and through the tissues: a conclusion which is indeed justified by the fact that nitrogenous substances out of the body yield heat, though not a large amount, during combustion. But most likely this antithesis is not true even in the more restricted sense. The probability is that the hydrocarbons and carbo-hydrates which, in traversing the system, are transformed by communicated chemical action, evolve, during their transformation, not heat alone but also other kinds of force. It may be that as the nitrogenous matter, while falling into more stable molecular arrangements, generates both that molecular agitation called heat and such other molecular movements as are resolved into forces expended by the organism; so, too, does the non-nitrogenous matter. Or perhaps the concomitants of this metamorphosis of non-nitrogenous matter vary with the conditions. Heat alone may result when it is transformed while in the circulating fluids, but partly heat and partly another force when it is transformed in some active tissue that has absorbed it; just as coal, though producing little else but heat as ordinarily burnt, has its heat partially transformed into mechanical motion if burnt in a steam-engine furnace. In such case the antithesis of Liebig would be reduced to this – that whereas nitrogenous substance is tissue-food *both* as material for building-up tissue and as material for its function; non-nitrogenous substance is tissue-food *only* as material for function.

There can be no doubt that this thermal re-action which chemical action from moment to moment produces in the body, is from moment to moment an aid to further chemical action. We before saw (*First Principles*, § 100) that a state of raised molecular vibration is favourable to those re-distributions of matter and motion which constitute Evolution. We saw that in organisms distinguished by the amount and rapidity of such re-distributions, this raised state of molecular vibration is conspicuous. And we here see that this raised state of molecular vibration is itself a continuous consequence of the continuous molecular re-distributions it facilitates. The heat generated by each increment of chemical change makes possible the succeeding increment of chemical change. In the body this connexion of phenomena is the same as we see it to be out of the body. Just as in a burning piece of wood, the heat given out by the portion actually combining with oxygen, raises the adjacent portion to a temperature at which it also can combine with oxygen; so, in a living animal, the heat produced by oxidation of each portion of organized or unorganized substance, maintains the temperature at which the unoxidized portions can be readily oxidized.

§ 19. Among the forces called forth from organisms by re-action against the actions to which they are subject, is Light. Phosphorescence is in some few cases displayed by plants – especially by certain fungi. Among animals it is comparatively common. All know that there are several kinds of luminous insects; and many are familiar with the fact that luminosity is a characteristic of various marine creatures.

Much of the evidence is supposed to imply that this evolution of light, like the evolution of heat, is consequent on oxidation of the tissues or of matters contained in them. Light, like heat, is the expression of a raised state of molecular vibration: the difference between them being a difference in the rates of vibration. Hence it seems inferable that by chemical action on substances contained in the organism, heat or light may be produced, according to the character of the resulting molecular vibrations. Some experimental evidence supports this view. In phosphorescent insects, the continuance of the light is found to depend on the continuance of respiration; and any exertion which renders respiration more active, increases the brilliancy of the light. Moreover, by separating the luminous matter, Prof. Matteucci has shown that its emission of light is accompanied by absorption of oxygen and escape of carbonic acid. The phosphorescence of marine animals has been referred to other causes than oxidation; but it may perhaps be explicable without assuming any more special agency. Considering that in creatures of the genus *Noctiluca*, for example, to which the phosphorescence most commonly seen on our own coasts is due, there is no means of keeping up a constant circulation, we may infer that the movements of aerated fluids through their tissues, must be greatly affected by impulses received from without. Hence it may be that the sparkles visible at night when the waves break gently on the beach, or when an oar is dipped into the water, are called forth from these creatures by the concussion, not because of any unknown influence it excites, but because, being propagated through their delicate tissues, it produces a sudden movement of the fluids and a sudden increase of chemical action.

Nevertheless, in other phosphorescent animals inhabiting the sea, as in the *Pyrosoma* and in certain *Annelida*, light seems to be produced otherwise than by direct re-action on the action of oxygen. Indeed, it needs but to recall the now familiar fact that certain substances become luminous in the dark after exposure to sunlight, to see that there are other causes of light-emission.

§ 20. The re-distributions of inanimate matter are habitually accompanied by electrical disturbances; and there is abundant evidence that electricity is generated during those re-distributions of matter that are ever taking place in organisms. Experiments have shown "that the skin and most of the internal membranes are in opposite electrical states;" and also that between different internal organs, as the liver and the stomach, there are electrical contrasts: such contrasts being greatest where the processes going on in the compared parts are most unlike. It has been proved by du Bois-Reymond that when any point in the longitudinal section of a muscle is connected by a conductor with any point in its transverse section, an electric current is established; and further, that like results occur when nerves are substituted for muscles. The special causes of these phenomena have not yet been determined. Considering that the electric contrasts are most marked where active secretions are going on – considering, too, that they are difficult to detect where there are no appreciable movements of liquids – considering, also, that even when muscles are made to contract after removal from the body, the contraction inevitably causes movements of the liquids still contained in its tissues; it may be that they are due simply to the friction of heterogeneous substances, which is universally a cause of electric disturbance. But whatever be the interpretation, the fact remains the same: – there is throughout the living organism, an unceasing production of differences between the electric states of different parts; and, consequently, an unceasing restoration of electric equilibrium by the establishment of currents among these parts.

Besides these general, and not conspicuous, electrical phenomena common to all organisms, vegetal as well as animal, there are certain special and strongly marked ones. I refer, of course, to those which have made the *Torpedo* and the *Gymnotus* objects of so much interest. In these creatures we have a genesis of electricity which is not incidental on the performance of their different functions by the different organs; but one which is itself a function, having an organ appropriate to it. The character of this organ in both these fishes, and its largely-developed connexions with the nervous centres, have raised in some minds the suspicion that in it there takes place a transformation of what we call nerve-force into the force known as electricity. Perhaps, however, the true interpretation may rather be that by nervous stimulation there is set up in these animal-batteries that particular transformation of molecular motion which it is their function to produce.

But whether general or special, and in whatever manner produced, these evolutions of electricity are among the reactions of organic matter called forth by the actions to which it is subject. Though these re-actions are not direct, but seem to be remote consequences of changes wrought by external agencies on the organism, they are yet incidents in that general re-distribution of motion which these external agencies initiate; and as such must here be noticed.

§ 21. To these known modes of motion, has next to be added an unknown one. Heat, Light, and Electricity are emitted by inorganic matter when undergoing changes, as well as by organic matter. But there is manifested in some classes of living bodies a kind of force which we cannot identify with any of the forces manifested by bodies that are not alive, – a force which is thus unknown, in the sense that it cannot be assimilated to any otherwise-recognized class. I allude to what is called nerve-force.

This is habitually generated in all animals, save the lowest, by incident forces of every kind. The gentle and violent mechanical contacts, which in ourselves produce sensations of touch and pressure – the additions and abstractions of molecular vibration, which in ourselves produce sensations of heat and cold, produce in all creatures that have nervous systems, certain nervous disturbances: disturbances which, as in ourselves, are either communicated to the chief nervous centre, and there arouse consciousness, or else result in mere physical processes set going elsewhere in the organism. In special parts distinguished as organs of sense, other external actions bring about other nervous re-actions, that show themselves either as special sensations or as excitements which, without the intermediation of distinct consciousness, beget actions in muscles or other organs. Besides neural discharges following the direct incidence of external forces, others are ever being caused by the incidence of forces which, though originally external, have become internal by absorption into the organism of the agents exerting them. For thus may be classed those neural discharges which result from modifications of the tissues wrought by substances carried to them in the blood. That the unceasing change of matter which oxygen and other agents produce throughout the system, is accompanied by production of nerve-force, is shown by various facts; – by the fact that nerve-force is no longer generated if oxygen be withheld or the blood prevented from circulating; by the fact that when the chemical transformation is diminished, as during sleep with its slow respiration and circulation, there is a diminution in the quantity of nerve-force; by the fact that an excessive expenditure of nerve-force involves excessive respiration and circulation, and excessive waste of tissue. To these proofs that nerve-force is evolved in greater or less quantity, according as the conditions to rapid molecular change throughout the body are well or ill fulfilled, may be added proofs that certain special molecular actions are the causes of these special re-actions. The effects of the vegeto-alkalies put beyond doubt the inference that the overthrow of molecular equilibrium by chemical affinity, when it occurs in certain parts, causes excitement in the nerves proceeding from those parts. Indeed, looked at from this point of view, the two classes of nervous changes – the one initiated from without and the other from within – are seen to merge into one class. Both of them may be traced to metamorphosis of tissue. The sensations of touch and pressure are doubtless consequent on accelerated changes of matter, produced by mechanical disturbance of the mingled fluids and solids composing the parts affected. There is abundant evidence that the gustatory sensation is due to the chemical actions set up by particles which find their way through the membrane covering the nerves of taste; for, as Prof. Graham points out, sapid substances belong to the class of crystalloids, which are able rapidly to permeate animal tissue, while the colloids which cannot pass through animal tissue are insipid. Similarly with the sense of smell. Substances which excite this sense are necessarily more or less volatile; and their volatility being the result of their molecular mobility, implies that they have, in a high degree, the power of getting at the olfactory nerves by penetrating their mucous investment. Again, the facts which photography has familiarized us with, show that those nervous impressions called colours, are primarily due to certain changes wrought by light in the substance of the retina. And though, in the case of hearing, we cannot so clearly trace the connexion of cause and effect, yet as we see that the auditory apparatus is one fitted to intensify those vibrations constituting sound, and to convey them to a receptacle containing liquid in which nerves are immersed, it can scarcely be doubted that the sensation of sound proximately results from molecular re-arrangements caused in these nerves by the vibrations of the liquid: knowing, as we do, that the re-arrangement of molecules is in all cases aided by agitation. Perhaps, however, the best proof that nerve-force, whether peripheral or central in origin, results from chemical change, lies in the fact that most of the chemical agents which powerfully affect the nervous system, affect it whether applied at the centre or at the periphery. Various mineral acids are tonics – the stronger ones being usually the stronger tonics; and this which we call their acidity implies a power in them of acting on the nerves of taste, while the tingling or pain following their absorption through the skin, implies that the nerves of the skin are acted on by them. Similarly with certain vegeto-alkalies which are peculiarly bitter. By their bitterness these show that they affect the extremities of the nerves, while, by their tonic properties, they show that they affect the nervous centres: the most intensely bitter among them, strychnia, being the most powerful nervous stimulant.[11] However true it may be that this relation is not a regular one, since opium, hashish, and some other drugs, which work marked effects on the brain, are not remarkably sapid – however true it may be that there are relations between particular substances and particular parts of the nervous system; yet such instances do but qualify, without negativing, the general proposition. The truth of this proposition can scarcely be doubted when, to the facts above given, is added the fact that various condiments and aromatic drugs act as nervous stimulants; and the fact that anæsthetics, besides the general effects they produce when inhaled or swallowed, produce local effects of like kind – first stimulant and then sedative – when absorbed through the skin; and the fact that ammonia, which in consequence of its extreme molecular mobility so quickly and so violently excites the nerves beneath the skin, as well as those of the tongue and the nose, is a rapidly-acting stimulant when taken internally.

Whether a nerve is merely a conductor, which delivers at one of its extremities an impulse received at the other, or whether, as some now think, it is itself a generator of force which is initiated at one extremity and accumulates in its course to the other extremity, are questions which cannot yet be answered. All we know is that agencies capable of working molecular changes in nerves are capable of calling forth from them manifestations of activity. And our evidence that nerve-force is thus originated, consists not only of such facts as the above, but also of more conclusive facts established by direct experiments on nerves – experiments which show that nerve-force results when the cut end of a nerve is either mechanically irritated, or acted on by some chemical agent, or subject to the galvanic current – experiments which prove that nerve-force is generated by whatever disturbs the molecular equilibrium of nerve-substance.

§ 22. The most important of the re-actions called forth from organisms by surrounding actions, remains to be noticed. To the various forms of insensible motion thus caused, we have to add sensible motion. On the production of this mode of force more especially depends the possibility of all vital

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[11] When writing this passage I omitted to observe the verification yielded of the conclusion contained in § 15 concerning the part played in the vital processes by the nitrogenous compounds. For these vegeto-alkalies, minute quantities of which produce such great effects in exalting the functions (*e. g.*, a sixteenth of a grain of strychnia is a dose), are all nitrogenous bodies, and, by implication, relatively unstable bodies. The small amounts of molecular change which take place in these small quantities of the vegeto-alkalies when diffused through the system, initiate larger amounts of molecular change in the nitrogenous elements of the tissues.But the evidence furnished a generation ago by these vegeto-alkalies has been greatly reinforced by far more striking evidence furnished by other nitrogenous compounds – the various explosives. These, at the same time that they produce by their sudden decompositions violent effects outside the organism, also produce violent effects inside it: a hundredth of a grain of nitro-glycerine being a sufficient dose. Investigations made by Dr. J. B. Bradbury, and described by him in the Bradshaw Lecture on "Some New Vaso-Dilators" (see *The Lancet*, Nov. 16, 1895), details the effects of kindred bodies – methyl-nitrate, glycol-dinitrate, erythrol-tetranitrate. The first two, in common with nitro-glycerine, are stable only when cool and in the dark – sunlight or warmth decomposes them, and they explode by rapid heating or percussion. The fact which concerns us here is that the least stable – glycol-dinitrate – has the most powerful and rapid physiological effect, which is proportionately transient. In one minute the blood-pressure is reduced by one-fourth and in four minutes by nearly two-thirds: an effect which is dissipated in a quarter of an hour. So that this excessively unstable compound, decomposing in the body in a very short time, produces within that short time a vast amount of molecular change: acting, as it seems, not through the nervous system, but directly on the blood-vessels.

phenomena. It is, indeed, usual to regard the power of generating sensible motion as confined to one out of the two organic sub-kingdoms; or, at any rate, as possessed by but few members of the other. On looking closer into the matter, however, we see that plant-life as well as animal-life, is universally accompanied by certain manifestations of this power; and that plant-life could not otherwise continue.

Through the humblest, as well as through the highest, vegetal organisms, there are ever going on certain re-distributions of matter. In Protophytes the microscope shows us an internal transposition of parts, which, when not immediately visible, is proved to exist by the changes of arrangement that become manifest in the course of hours and days. In the individual cells of many higher plants, an active movement among the contained granules may be witnessed. And well-developed cryptogams, in common with all phanerogams, exhibit this genesis of mechanical motion still more conspicuously in the circulation of sap. It might, indeed, be concluded *a priori*, that through plants displaying much differentiation of parts, an internal movement must be going on; since, without it, the mutual dependence of organs having unlike functions would be impossible. Besides keeping up these motions of liquids internally, plants, especially of the lower orders, move their external parts in relation to each other, and also move about from place to place. There are countless such illustrations as the active locomotion of the zoospores of many *Algæ*, the rhythmical bendings of the *Oscillatoræ*, the rambling progression of the *Diatomaceæ*. In fact many of these smallest vegetals, and many of the larger ones in their early stages, display a mechanical activity not distinguishable from that of the simplest animals. Among well-organized plants, which are never locomotive in their adult states, we still not unfrequently meet with relative motions of parts. To such familiar cases as those of the Sensitive plant and the Venus' fly-trap, many others may be added. When its base is irritated the stamen of the Berberry flower leans over and touches the pistil. If the stamens of the wild *Cistus* be gently brushed with the finger, they spread themselves: bending away from the seed-vessel. And some of the orchid-flowers, as Mr. Darwin has shown, shoot out masses of pollen on to the entering bee, when its trunk is thrust down in search of honey.

Though the power of moving is not, as we see, a characteristic of animals alone, yet in them, considered as a class, it is manifested to an extent so marked as practically to become their most distinctive trait. For it is by their immensely greater ability to generate mechanical motion, that animals are enabled to perform those actions which constitute their visible lives; and it is by their immensely greater ability to generate mechanical motion, that the higher orders of animals are most obviously distinguished from the lower orders. Though, on remembering the seemingly active movements of infusoria, some will perhaps question this last-named contrast, yet, on comparing the quantities of matter propelled through given spaces in given times, they will see that the momentum evolved is far less in the *Protozoa* than in the *Metazoa*. These sensible motions of animals are effected in sundry ways. In the humblest forms, and even in some of the more developed forms which inhabit the water, locomotion results from the oscillations of whip-like appendages, single or double, or from the oscillations of cilia: the contractility resides in these waving hairs that grow from the surface. In many *Cœlenterata* certain elongations or tails of ectodermal or endodermal cells shorten when stimulated, and by these rudimentary contractile organs the movements are effected. In all the higher animals, however, and to a smaller degree in many of the lower, sensible motion is generated by a special tissue, under a special excitement. Though it is not strictly true that such animals show no sensible motions otherwise caused, since all of them have certain ciliated membranes, and since the circulation of liquids in them is partially due to osmotic and capillary actions; yet, generally speaking, we may say that their movements are effected solely by muscles which contract solely through the agency of nerves.

What special transformations of force generate these various mechanical changes, we do not, in most cases, know. Those re-distributions of liquid, with the alterations of form sometimes caused by them, that result from osmose, are not, indeed, incomprehensible. Certain motions of plants which, like those of the "animated oat," follow contact with water, are easily interpreted; as are also such other vegetal motions as those of the Touch-me-not, the Squirting Cucumber, and the *Carpobolus*. But we are ignorant of the mode in which molecular movement is transformed into the movement of masses, in animals. We cannot refer to known causes the rhythmical action of a Medusa's disc, or that slow decrease of bulk which spreads throughout the mass of an *Alcyonium* when one of its component individuals has been irritated. Nor are we any better able to say how the insensible motion transmitted through a nerve, gives rise to sensitive motion in a muscle. It is true that Science has given to Art several methods of changing insensible into sensible motion. By applying heat to water we vaporize it, and the movement of its expanding vapour we transfer to solid matter; but evidently the genesis of muscular movement is in no way analogous to this. The force evolved in a galvanic battery or by a dynamo, we communicate to a soft iron magnet through a wire coiled round it; and it would be possible, by placing near to each other several magnets thus excited, to obtain, through the attraction of each for its neighbours, an accumulated movement made up of their separate movements, and thus mechanically to imitate a muscular contraction. But from what we know of organic matter there is no reason to suppose that anything analogous to this takes place in it. We can, however, through one kind of molecular change, produce sensible changes of aggregation such as possibly might, when occurring in organic substance, cause sensible motion in it. I refer to change that is allotropic or isomeric. Sulphur, for example, assumes different crystalline and non-crystalline forms at different temperatures, and may be made to pass backwards and forwards from one form to another, by slight variations of temperature: undergoing each time an alteration of bulk. We know that this allotropism, or rather its analogue isomerism, prevails among colloids – inorganic and organic. We also know that some of these metamorphoses among colloids are accompanied by visible re-arrangements: instance hydrated silicic acid, which, after passing from its soluble state to the state of an insoluble jelly, begins, in a few days, to contract and to give out part of its contained water. Now considering that such isomeric changes of organic as well as inorganic colloids, are often rapidly produced by very slight causes – a trace of a neutral salt or a degree or two rise of temperature – it seems not impossible that some of the colloids constituting muscle may be thus changed by a nervous discharge: resuming their previous condition when the discharge ceases. And it is conceivable that by structural arrangements, minute sensible motions so caused may be accumulated into large sensible motions.

§ 23. But the truths which it is here our business especially to note, are independent of hypotheses or interpretations. It is sufficient for the ends in view, to observe that organic matter *does* exhibit these several conspicuous reactions when acted on by incident forces. It is not requisite that we should know *how* these re-actions originate.

In the last chapter were set forth the several modes in which incident forces cause re-distributions of organic matter; and in this chapter have been set forth the several modes in which is manifested the motion accompanying this re-distribution. There we contemplated, under its several aspects, the general fact that, in consequence of its extreme instability, organic matter undergoes extensive molecular re-arrangements on very slight changes of conditions. And here we have contemplated, under its several aspects, the correlative general fact that, during these extensive molecular re-arrangements, there are evolved large amounts of energy. In the one case the components of organic matter are regarded as falling from positions of unstable equilibrium to positions of stable equilibrium; and in the other case they are regarded as giving out in their falls certain momenta – momenta that may be manifested as heat, light, electricity, nerve-force, or mechanical motion, according as the conditions determine.

I will add only that these evolutions of energy are rigorously dependent on these changes of matter. It is a corollary from the primordial truth which, as we have seen, underlies all other truths, (*First Principles*, §§ 62, 189,) that whatever amount of power an organism expends in any shape, is the correlate and equivalent of a power which was taken into it from without. On the one hand, it follows from the persistence of force that each portion of mechanical or other energy which an organism exerts, implies the transformation of as much organic matter as contained this energy in a latent state.

And on the other hand, it follows from the persistence of force that no such transformation of organic matter containing this latent energy can take place, without the energy being in one shape or other manifested.

CHAPTER III[A.]
METABOLISM

§ 23*a*. In the early forties the French chemist Dumas pointed out the opposed actions of the vegetal and animal kingdoms: the one having for its chief chemical effect the decomposition of carbon-dioxide, with accompanying assimilation of its carbon and liberation of its oxygen, and the other having for its chief chemical effect the oxidation of carbon and production of carbon-dioxide. Omitting those plants which contain no chlorophyll, all others de-oxidize carbon; while all animals, save the few which contain chlorophyll, re-oxidize carbon. This is not, indeed, a complete account of the general relation; since it represents animals as wholly dependent on plants, either directly or indirectly through other animals, while plants are represented as wholly independent of animals; and this last representation though mainly true, since plants can obtain direct from the inorganic world certain other constituents they need, is in some measure not true, since many with greater facility obtain these materials from the decaying bodies of animals or from their *excreta*. But after noting this qualification the broad antithesis remains as alleged.

How are these transformations brought about? The carbon contained in carbon-dioxide does not at a bound become incorporated in the plant, nor does the substance appropriated by the animal from the plant become at a bound carbon-dioxide. It is through two complex sets of changes that these two ultimate results are brought about. The materials forming the tissues of plants as well as the materials contained in them, are progressively elaborated from the inorganic substances; and the resulting compounds, eaten and some of them assimilated by animals, pass through successive changes which are, on the average, of an opposite character: the two sets being constructive and destructive. To express changes of both these natures the term "metabolism" is used; and such of the metabolic changes as result in building up from simple to compound are distinguished as "anabolic," while those which result in the falling down from compound to simple are distinguished as "katabolic." These antithetical names do not indeed cover all the molecular transformations going on. Many of them, known as isomeric, imply neither building up nor falling down: they imply re-arrangement only. But those which here chiefly concern us are the two opposed kinds described.

A qualification is needful. These antithetic changes must be understood as characterizing plant-life and animal-life in general ways rather than in special ways – as expressing the transformations in their totalities but not in their details. For there are katabolic processes in plants, though they bear but a small ratio to the anabolic ones; and there are anabolic processes in animals, though they bear but a small ratio to the katabolic ones.

From the chemico-physical aspect of these changes we pass to those distinguished as vital; for metabolic changes can be dealt with only as changes effected by that living substance called protoplasm.

§ 23*b*. On the evolution-hypothesis we are obliged to assume that the earliest living things – probably minute units of protoplasm smaller than any the microscope reveals to us – had the ability to appropriate directly from the inorganic world both the nitrogen and the materials for carbo-hydrates without both of which protoplasm cannot be formed; since in the absence of preceding organic matter there was no other source. The general law of evolution as well as the observed actions of *Protozoa* and *Protophyta*, suggest that these primordial types simultaneously displayed animal-life and plant-life. For whereas the developed animal-type cannot form from its inorganic surroundings either nitrogenous compounds or carbo-hydrates; and whereas the developed plant-type, able to form carbo-hydrates from its inorganic surroundings, depends for the formation of its protoplasm mainly, although indirectly, on the nitrogenous compounds derived from preceding organisms, as do also most of the plants devoid of chlorophyll – the fungi; we are obliged to assume that in the beginning, along with the expending activities characterizing the animal-type, there went the accumulating activities characterizing both of the vegetal types – forms of activity by-and-by differentiated.

Though the successive steps in the artificial formation of organic compounds have now gone so far that substances simulating proteids, if not identical with them, have been produced, yet we have no clue to the conditions under which proteids arose; and still less have we a clue to the conditions under which inert proteids became so combined as to form active protoplasm. The essential fact to be recognized is that living matter, originated as we must assume during a long stage of progressive cooling in which the infinitely varied parts of the Earth's surface were slowly passing through appropriate physical conditions, possessed from the outset the power of assimilating to itself the materials from which more living matter was formed; and that since then all living matter has arisen from its self-increasing action. But now, leaving speculation concerning these anabolic changes as they commenced in the remote past, let us contemplate them as they are carried on now – first directing our attention to those presented in the vegetal world.

§ 23*c*. The decomposition of carbon-dioxide (§ 13) – the separation of its carbon from the combined oxygen so that it may enter into one or other form of carbo-hydrate, – is not now ordinarily effected, as we must assume it once was, by the undifferentiated protoplasm; but is effected by a specialized substance, chlorophyll, imbedded in the protoplasm and operating by its instrumentality. The chlorophyll-grain is not simply immersed in protoplasm but is permeated throughout its substance by a protoplasmic network or sponge-work apparently continuous with the protoplasm around; or, according to Sachs, consists of protoplasm holding chlorophyll-particles in suspension: the mechanical arrangement facilitating the chemical function. The resulting abstraction of carbon from carbon-dioxide, by the aid of certain ethereal undulations, appears to be the first step in the building up of organic compounds – the first step in the primary anabolic process. We are not here concerned with details. Two subsequent sets of changes only need here to be noted – the genesis of the passive materials out of which plant-structure is built up, and the genesis of the active materials by which these are produced and the building up effected.

The hydrated carbon which protoplasm, having the chlorophyll-grain as its implement, produces from carbonic acid and water, appears not to be of one kind only. The possible carbo-hydrates are almost infinite in number. Multitudes of them have been artificially made, and numerous kinds are made naturally by plants. Though perhaps the first step in the reduction of the carbon from its dioxide may be always the same, yet it is held probable that in different types of plants different types of carbo-hydrates forthwith arise, and give differential characters to the compounds subsequently formed by such types: sundry of the changes being katabolic rather than anabolic. Of leading members in the group may be named dextrin, starch, and the various sugars characteristic of various plants, as well as the cellulose elaborated by further anabolism. Considered as the kind of carbo-hydrate in which the products of activity are first stored up, to be subsequently modified for divers purposes, starch is the most important of these; and the process of storage is suggested by the structure of the starch-grain. This consists of superposed layers, implying intermittent deposits: the probability being that the variations of light and heat accompanying day and night are associated now with arrest of the deposit and now with recommencement of it. Like in composition as this stored-up starch is with sugar of one or other kind, and capable of being deposited from sugar and again assuming the sugar form, this substance passes, by further metabolism, here into the cellulose which envelopes each of the multitudinous units of protoplasm, there into the spiral fibres, annuli, or fenestrated tubes which, in early stages of tissue-growth, form channels for the sap, and elsewhere into other components of the general structure. The many changes implied are effected in various ways: now by that simple re-arrangement of components known as isomeric change; now by that taking from a compound one of its elements and inserting one of another kind, which is known as substitution; and now by oxidation, as when the oxy-cellulose which constitutes wood-fibre, is produced.

Besides elaborating building materials, the protoplasm elaborates itself – that is, elaborates more of itself. It is chemically distinguished from the building materials by the presence of nitrogen. Derived from atmospheric ammonia, or from decaying or excreted organic matter, or from the products of certain fungi and microbes at its roots, the nitrogen in one or other combination is brought into a plant by the upward current; and by some unknown process (not dependent on light, since it goes on equally well if not better in darkness) the protoplasm dissociates and appropriates this combined nitrogen and unites it with a carbo-hydrate to form one or other proteid – albumen, gluten, or some isomer; appropriating at the same time from certain of the earth-salts the requisite amount of sulphur and in some cases phosphorus. The ultimate step, as we must suppose, is the formation of living protoplasm out of these non-living proteids. A cardinal fact is that proteids admit of multitudinous transformations; and it seems not improbable that in protoplasm various isomeric proteids are mingled. If so, we must conclude that protoplasm admits of almost infinite variations in nature. Of course *pari passu* with this dual process – augmentation of protoplasm and accompanying production of carbo-hydrates – there goes extension of plant-structure and plant-life.

To these essential metabolic processes have to be added certain ancillary and non-essential ones, ending in the formation of colouring matters, odours, essential oils, acrid secretions, bitter compounds and poisons: some serving to attract animals and others to repel them. Sundry of these appear to be excretions – useless matters cast out, and are doubtless katabolic.

The relation of these facts here sketched in rude outline to the doctrine of Evolution at large should be observed. Already we have seen how (§ 8*a*), in the course of terrestrial evolution, there has been an increasingly heterogeneous assemblage of increasing heterogeneous compounds, preparing the way for organic life. And here we may see that during the development of plant-life from its lowest algoid and fungoid forms up to those forms which constitute the chief vegetal world, there has been an increasing number of complex organic compounds formed; displayed at once in the diversity of them contained in the same plant and in the still greater diversity displayed in the vast aggregate of species, genera, orders, and classes of plants.

§ 23*d*. On passing to the metabolism characterizing animal life, which, as already indicated, is in the main a process of decomposition undoing the process of composition characterizing vegetal life, we may fitly note at the outset that it must have wide limits of variation, alike in different classes of animals and even in the same animal.

If we take, on the one hand, a carnivore living on muscular tissue (for wild carnivores preying upon herbivores which can rarely become fat obtain scarcely any carbo-hydrates) and observe that its food is almost exclusively nitrogenous; and if, on the other hand, we take a graminivorous animal the food of which (save when it eats seeds) contains comparatively little nitrogenous matter; we seem obliged to suppose that the parts played in the organic processes by the proteids and the carbo-hydrates can in considerable measures replace one another. It is true that the quantity of food and the required alimentary system in the last case, are very much greater than in the first case. But this difference is mainly due to the circumstance that the food of the graminivorous animal consists chiefly of waste-matter – ligneous fibre, cellulose, chlorophyll – and that could the starch, sugar, and protoplasm be obtained without the waste-matter, the required bulks of the two kinds of food would be by no means so strongly contrasted. This becomes manifest on comparing flesh-eating and grain-eating birds – say a hawk and a pigeon. In powers of flight these do not greatly differ, nor is the size of the alimentary system conspicuously greater in the last than in the first; though probably the amount of food consumed is greater. Still it seems clear that the supply of energy obtained by a pigeon from carbo-hydrates with a moderate proportion of proteids is not widely unlike that obtained by a hawk from proteids alone. Even from the traits of men differently fed a like inference may be drawn. On the one hand we have the Masai who, during their warrior-days, eat flesh exclusively; and on the other hand we have the Hindus, feeding almost wholly on vegetable food. Doubtless the quantities required in these cases differ much; but the difference between the rations of the flesh-eater and the grain-eater is not so immense as it would be were there no substitution in the physiological uses of the materials.

Concerning the special aspects of animal-metabolism, we have first to note those various minor transformations that are auxiliary to the general transformation by which force is obtained from food. For many of the vital activities merely subserve the elaboration of materials for activity at large, and the getting rid of waste products. From blood passing through the salivary glands is prepared in large quantity a secretion containing among other matters a nitrogenous ferment, ptyaline, which, mixed with food during mastication, furthers the change of its starch into sugar. Then in the stomach come the more or less varying secretions known in combination as gastric juice. Besides certain salts and hydrochloric acid, this contains another nitrogenous ferment, pepsin, which is instrumental in dissolving the proteids swallowed. To these two metabolic products aiding solution of the various ingested solids, is presently added that product of metabolism in the pancreas which, added to the chyme, effects certain other molecular changes – notably that of such amylaceous matters as are yet unaltered, into saccharine matters to be presently absorbed. And let us note the significant fact that the preparation of food-materials in the alimentary canal, again shows us that unstable nitrogenous compounds are the agents which, while themselves changing, set up changes in the carbo-hydrates and proteids around: the nitrogen plays the same part here as elsewhere. It does the like in yet another viscus. Blood which passes through the spleen on its way to the liver, is exposed to the action of "a special proteid of the nature of alkali-albumin, holding iron in some way peculiarly associated with it." Lastly we come to that all-important organ the liver, at once a factory and a storehouse. Here several metabolisms are simultaneously carried on. There is that which until recent years was supposed to be the sole hepatic process – the formation of bile. In some liver-cells are masses of oil-globules, which seem to imply a carbo-hydrate metamorphosis. And then, of leading importance, comes the extensive production of that animal-starch known as glycogen – a substance which, in each of the cells generating it, is contained in a plexus of protoplasmic threads: again a nitrogenous body diffused through a mass which is now formed out of sugar and is now dissolved again into sugar. For it appears that this soluble form of carbo-hydrate, taken into the liver from the intestine, is there, when not immediately needed, stored up in the form of glycogen, ready to be re-dissolved and carried into the system either for immediate use or for re-deposit as glycogen at the places where it is presently to be consumed: the great deposit in the liver and the minor deposits in the muscles being, to use the simile of Prof. Michael Foster, analogous in their functions to a central bank and branch banks.

An instructive parallelism may be noted between these processes carried on in the animal organism and those carried on in the vegetal organism. For the carbo-hydrates named, easily made to assume the soluble or the insoluble form by the addition or subtraction of a molecule of water, and thus fitted sometimes for distribution and sometimes for accumulation, are similarly dealt with in the two cases. As the animal-starch, glycogen, is now stored up in the liver or elsewhere and now changed into glucose to be transferred, perhaps for consumption and perhaps for re-deposit; so the vegetal starch, made to alternate between soluble and insoluble states, is now carried to growing parts where by metabolic change it becomes cellulose or other component of tissue and now carried to some place where, changed back into starch, it is laid aside for future use; as it is in the turgid inside leaves of a cabbage, the root of a turnip, or the swollen underground stem we know as a potato: the matter which in the animal is used up in generating movement and heat, being in the plant used up in generating structures. Nor is the parallelism even now exhausted; for, as by a plant starch is stored up in each seed for the subsequent use of the embryo, so in an embryo-animal glycogen is stored up in the developing muscles for subsequent use in the completion of their structures.

§ 23*e*. We come now to the supreme and all-pervading metabolism which has for its effects the conspicuous manifestations of life – the nervous and muscular activities. Here comes up afresh a question discussed in the edition of 1864 – a question to be reconsidered in the light of recent knowledge – the question what particular metabolic changes are they by which in muscle the energy existing under the form of molecular motion is transformed into the energy manifested as molar motion?

There are two views respecting the nature of this transformation. One is that the carbo-hydrate present in muscle must, by further metabolism, be raised into the form of a nitrogenous compound or compounds before it can be made to undergo that sudden decomposition which initiates muscular contraction. The other is the view set forth in § 15, and there reinforced by further illustrations which have occurred to me while preparing this revised edition – the view that the carbo-hydrate in muscle, everywhere in contact with unstable nitrogenous substance, is, by the shock of a small molecular change in this, made to undergo an extensive molecular change, resulting in the oxidation of its carbon and consequent liberation of much molecular motion. Both of these are at present only hypotheses, in support of which respectively the probabilities have to be weighed. Let us compare them and observe on which side the evidence preponderates.

We are obliged to conclude that in carnivorous animals the katabolic process is congruous with the first of these views, in so far that the evolution of energy must in some way result solely from the fall of complex nitrogenous compounds into those simpler matters which make their appearance as waste; for, practically, the carnivorous animal has no carbo-hydrates out of which otherwise to evolve force. To this admission, however, it should be added that possibly out of the exclusively nitrogenous food, glycogen or sugar has to be obtained by partial decomposition before muscular action can take place. But when we pass to animals having food consisting mainly of carbo-hydrates, several difficulties stand in the way of the hypothesis that, by further compounding, proteids must be formed from the carbo-hydrates before muscular energy can be evolved. In the first place the anabolic change through which, by the addition of nitrogen, &c., a proteid is formed from a carbo-hydrate, must absorb an energy equal to a moiety of that which is given out in the subsequent katabolic change. There can be no dynamic profit on such part of the transaction as effects the composition and subsequent decomposition of the proteid, but only on such part of the transaction as effects the decomposition of the carbo-hydrate. In the second place there arises the question – whence comes the nitrogen required for the compounding of the carbo-hydrates into proteids? There is none save that contained in the serum-albumen or other proteid which the blood brings; and there can be no gain in robbing this proteid of nitrogen for the purpose of forming another proteid. Hence the nitrogenizing of the surplus carbo-hydrates is not accounted for. One more difficulty remains. If the energy given out by a muscle results from the katabolic consumption of its proteids, then the quantity of nitrogenous waste matters formed should be proportionate to the quantity of work done. But experiments have proved that this is not the case. Long ago it was shown that the amount of urea excreted does not increase in anything like proportion to the amount of muscular energy expended; and recently this has been again shown.

On this statement a criticism has been made to the following effect: – Considering that muscle will contract when deprived of oxygen and blood and must therefore contain matter from which the energy is derived; and considering that since carbonic acid is given out the required carbon and oxygen must be derived from some component of muscle; it results that the energy must be obtained by decomposition of a nitrogenous body. To this reasoning it may be objected, in the first place, that the conditions specified are abnormal, and that it is dangerous to assume that what takes place under abnormal conditions takes place also under normal ones. In presence of blood and oxygen the process may possibly, or even probably, be unlike that which arises in their absence: the muscular substance may begin consuming itself when it has not the usual materials to consume. Then, in the second place, and chiefly, it may be replied that the difficulty raised in the foregoing argument is not escaped but merely obscured. If, as is alleged, the carbon and oxygen from which carbonic acid is produced, form, under the conditions stated, parts of a complex nitrogenous substance contained in muscle, then the abstraction of the carbon and oxygen must cause decomposition of this nitrogenous substance; and in that case the excretion of nitrogenous waste must be proportionate to the amount of work done, which it is not. This difficulty is evaded by supposing that the "stored complex explosive substance must be, in living muscle, of such nature" that after explosion it leaves a "nitrogenous residue available for re-combination with fresh portions of carbon and oxygen derived from the blood and thereby the re-constitution of the explosive substance." This implies that a molecule of the explosive substance consists of a complex nitrogenous molecule united with a molecule of carbo-hydrate, and that time after time it suddenly decomposes this carbo-hydrate molecule and thereupon takes up another such from the blood. That the carbon is abstracted from the carbo-hydrate molecule can scarcely be said, since the feebler affinities of the nitrogenous molecule can hardly be supposed to overcome the stronger affinities of the carbo-hydrate molecule. The carbo-hydrate molecule must therefore be incorporated bodily. What is the implication? The carbo-hydrate part of the compound is relatively stable, while the nitrogenous part is relatively unstable. Hence the hypothesis implies that, time after time, the unstable nitrogenous part overthrows the stable carbo-hydrate part, without being itself overthrown. This conclusion, to say the least of it, does not appear very probable.

The alternative hypothesis, indirectly supported as we saw by proofs that outside the body small amounts of change in nitrogenous compounds initiate large amounts of change in carbonaceous compounds, may in the first place be here supported by some further indirect evidences of kindred natures. A haystack prematurely put together supplies one. Enough water having been left in the hay to permit chemical action, the decomposing proteids forming the dead protoplasm in each cell, set up decomposition of the carbo-hydrates with accompanying oxidation of the carbon and genesis of heat; even to the extent of producing fire. Again, as shown above, this relation between these two classes of compounds is exemplified in the alimentary canal; where, alike in the saliva and in the pancreatic secretion, minute quantities of unstable nitrogenous bodies transform great quantities of stable carbo-hydrates. Thus we find indirect reinforcements of the belief that the katabolic change generating muscular energy is one in which a large decomposition of a carbo-hydrate is set up by a small decomposition of a proteid.[12]

§ 23*f*. A certain general trait of animal organization may fitly be named because its relevance, though still more indirect, is very significant. Under one of its aspects an animal is an apparatus for the multiplication of energies – a set of appliances by means of which a minute amount of motion initiates a larger amount of motion, and this again a still larger amount. There are structures which do this mechanically and others which do it chemically.

Associated with the peripheral ends of the nerves of touch are certain small bodies —*corpuscula tactus*– each of which, when disturbed by something in contact with the skin, presses on the adjacent fibre more strongly than soft tissue would do, and thus multiplies the force producing sensation. While serving the further purpose of touching at a distance, the *vibrissæ* or whiskers of a feline animal achieve a like end in a more effectual way. The external portion of each bristle acts as the long arm of a lever, and the internal portion as the short arm. The result is that a slight touch at the outer end of the bristle produces a considerable pressure of the inner end on the nerve-terminal: so intensifying the impression. In the hearing organs of various inferior types of animals, the otolites in contact with the auditory nerves, when they are struck by sound-waves, give to the nerves much stronger impressions than these would have were they simply immersed in loose tissue; and in the ears of developed creatures there exist more elaborate appliances for augmenting the effects of aerial vibrations. From this multiplication of molar actions let us pass to the multiplication of molecular actions. The retina is made up of minute rods and cones, so packed together side by side that they can be separately affected by the separate parts of the images of objects. As each of them is but 1⁄10,000th of an inch in diameter, the ethereal undulations falling upon it can produce an amount of change almost infinitesimal – an amount probably incapable of exciting a nerve-centre, or indeed

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[12] This interpretation is said to be disproved by the fact that the carbo-hydrate contained in muscle amounts to only about 1.5 of the total solids. I do not see how this statement is to be reconciled with the statement cited three pages back from Professor Michael Foster, that the deposits of glycogen contained in the liver and in the muscles may be compared to the deposits in a central bank and branch banks.

of overcoming the molecular inertia of the nerve leading to it. But in close proximity are layers of granules into which the rods and cones send fibres, and beyond these, about 1/100th of an inch from the retinal layer, lie ganglion-cells, in each of which a minute disturbance may readily evolve a larger disturbance; so that by multiplication, single or perhaps double, there is produced a force sufficient to excite the fibre connected with the centre of vision. Such, at least, judging from the requirement and the structure, seems to me the probable interpretation of the visual process; though whether it is the accepted one I do not know.

But now, carrying with us the conception made clear by the first cases and suggested by the last, we shall appreciate the extent to which this general physiological method, as we may call it, is employed. The convulsive action caused by tickling shows it conspicuously. An extremely small amount of molecular change in the nerve-endings produces an immense amount of molecular change, and resulting molar motion, in the muscles. Especially is this seen in one whose spinal cord has been so injured that it no longer conveys sensations from the lower limbs to the brain; and in whom, nevertheless, tickling of the feet produces convulsive actions of the legs more violent even than result when sensation exists: clearly proving that since the minute molecular change produced by the tickling in the nerve-terminals cannot be equivalent in quantity to the amount implied by the muscular contraction, there must be a multiplication of it in those parts of the spinal cord whence issue the reflex stimuli to the muscles.

Returning now to the question of metabolism, we may see that the processes of multiplication above supposed to take place in muscle, are analogous in their general nature to various other physiological processes. Carrying somewhat further the simile used in § 15 and going back to the days when detonators, though used for small arms, were not used for artillery, we may compare the metabolic process in muscle to that which would take place if a pistol were fired against the touch-hole of a loaded cannon: the cap exploding the pistol and the pistol the cannon. For in the case of the muscle, the implication is that a nervous discharge works in certain unstable proteids through which the nerve-endings are distributed, a small amount of molecular change; that the shock of this causes a much larger amount of molecular change in the inter-diffused carbo-hydrate, with accompanying oxidation of its carbon; and that the heat liberated sets up a transformation, probably isomeric, in the contractile substance of the muscular fibre: an interpretation supported by cases in which small rises and falls of temperature cause alternating isomeric changes; as instance Mensel's salt.

Ending here this exposition, somewhat too speculative and running into details inappropriate to a work of this kind, it suffices to note the most general facts concerning metabolism. Regarded as a whole it includes, in the first place, those anabolic or building-up processes specially characterizing plants, during which the impacts of ethereal undulations are stored up in compound molecules of unstable kinds; and it includes, in the second place, those katabolic or tumbling-down changes specially characterizing animals, during which this accumulated molecular motion (contained in the food directly or indirectly supplied by plants), is in large measure changed into those molar motions constituting animal activities. There are multitudinous metabolic changes of minor kinds which are ancillary to these – many katabolic changes in plants and many anabolic changes in animals – but these are the essential ones.[13]

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[13] Before leaving the topic let me remark that the doctrine of metabolism is at present in its inchoate stage, and that the prevailing conclusions should be held tentatively. As showing this need an anomalous fact may be named. It was long held that gelatine is of small value as food, and though it is now recognized as valuable because serving the same purposes as fats and carbo-hydrates, it is still held to be valueless for structural purposes (save for some inactive tissue); and this estimate agrees with the fact that it is a relatively stable nitrogenous compound, and therefore unfit for those functions performed by unstable nitrogenous compounds in the muscular and other tissues. But if this is true, it seems a necessary implication that such substances as hair, wool, feathers, and all dermal growths chemically akin to gelatine, and even more stable, ought to be equally innutritive or more innutritive. In that case, however, what are we to say of the larva of the clothes-moth, which subsists exclusively on one or other of these substances, and out of it forms all those unstable nitrogenous compounds needful for carrying on its life and developing its tissues? Or again, how are we to understand the nutrition of the book-worm, which, in the time-stained leaves through which it burrows, finds no proteid save that contained in the

dried-up size, which is a form of gelatine; or, once more, in what form is the requisite amount of nitrogenous substance obtained by the coleopterous larva which eats holes in wood a century old?

CHAPTER IV.[14]
PROXIMATE CONCEPTION OF LIFE

§ 24. To those who accept the general doctrine of Evolution, it need scarcely be pointed out that classifications are subjective conceptions, which have no absolute demarcations in Nature corresponding to them. They are appliances by which we limit and arrange the matters under investigation; and so facilitate our thinking. Consequently, when we attempt to define anything complex, or make a generalization of facts other than the most simple, we can scarcely ever avoid including more than we intended, or leaving out something which should be taken in. Thus it happens that on seeking a definite idea of Life, we have great difficulty in finding one that is neither more nor less than sufficient. Let us look at a few of the most tenable definitions that have been given. While recognizing the respects in which they are defective, we shall see what requirements a more satisfactory one must fulfil.

Schelling said that Life is the tendency to individuation. This formula, until studied, conveys little meaning. But we need only consider it as illustrated by the facts of development, or by the contrast between lower and higher forms of life, to recognize its significance; especially in respect of comprehensiveness. As before shown, however (*First Principles*, § 56), it is objectionable; partly on the ground that it refers not so much to the functional changes constituting Life, as to the structural changes of those aggregates of matter which manifest Life; and partly on the ground that it includes under the idea Life, much that we usually exclude from it: for instance – crystallization.

The definition of Richerand, – "Life is a collection of phenomena which succeed each other during a limited time in an organized body," – is liable to the fatal criticism, that it equally applies to the decay which goes on after death. For this, too, is "a collection of phenomena which succeed each other during a limited time in an organized body."

"Life," according to De Blainville, "is the two-fold internal movement of composition and decomposition, at once general and continuous." This conception is in some respects too narrow, and in other respects too wide. On the one hand, while it expresses what physiologists distinguish as vegetative life, it does not indicate those nervous and muscular functions which form the most conspicuous and distinctive classes of vital phenomena. On the other hand, it describes not only the integrating and disintegrating process going on in a living body, but it equally well describes those going on in a galvanic battery; which also exhibits a "two-fold internal movement of composition and decomposition, at once general and continuous."

Elsewhere, I have myself proposed to define Life as "the co-ordination of actions."[15] This definition has some advantages. It includes all organic changes, alike of the viscera, the limbs, and the brain. It excludes the great mass of inorganic changes; which display little or no co-ordination. By making co-ordination the specific character of vitality, it involves the truths, that an arrest of co-ordination is death, and that imperfect co-ordination is disease. Moreover, it harmonizes with our ordinary ideas of life in its different grades; seeing that the organisms which we rank as low in their degrees of life, are those which display but little co-ordination of actions; and seeing that from these up to man, the recognized increase in degree of life corresponds with an increase in the extent and complexity of co-ordinations. But, like the others, this definition includes too much. It may be said of the Solar System, with its regularly-recurring movements and its self-balancing perturbations,

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[14] This chapter and the following two chapters originally appeared in Part III of the original edition of the *Principles of Psychology* (1855): forming a preliminary which, though indispensable to the argument there developed, was somewhat parenthetical. Having now to deal with the general science of Biology before the more special one of Psychology, it becomes possible to transfer these chapters to their proper place.

[15] See *Westminster Review* for April, 1852. – Art. IV. "A Theory of Population." See Appendix A.

that it, also, exhibits co-ordination of actions. And however plausibly it may be argued that, in the abstract, the motions of the planets and satellites are as properly comprehended in the idea of life as the changes going on in a motionless, unsensitive seed: yet, it must be admitted that they are foreign to that idea as commonly received, and as here to be formulated.

It remains to add the definition since suggested by Mr. G. H. Lewes – "Life is a series of definite and successive changes, both of structure and composition, which take place within an individual without destroying its identity." The last fact which this statement brings into view – the persistence of a living organism as a whole, in spite of the continuous removal and replacement of its parts – is important. But otherwise it may be argued that, since changes of structure and composition, though concomitants of muscular and nervous actions, are not the muscular and nervous actions themselves, the definite excludes the more visible movements with which our idea of life is most associated; and further that, in describing vital changes as *a series*, it scarcely includes the fact that many of them, as Nutrition, Circulation, Respiration, and Secretion, in their many subdivisions, go on simultaneously.

Thus, however well each of these definitions expresses the phenomena of life under some of its aspects, no one of them is more than approximately true. It may turn out that to find a formula which will bear every test is impossible. Meanwhile, it is possible to frame a more adequate formula than any of the foregoing. As we shall presently find, these all omit an essential peculiarity of vital changes in general – a peculiarity which, perhaps more than any other, distinguishes them from non-vital changes. Before specifying this peculiarity, however, it will be well to trace our way, step by step, to as complete an idea of Life as may be reached from our present stand-point; by doing which we shall both see the necessity for each limitation as it is made, and ultimately be led to feel the need for a further limitation.

And here, as the best mode of determining what are the traits which distinguish vitality from non-vitality, we shall do well to compare the two most unlike kinds of vitality, and see in what they agree. Manifestly, that which is essential to Life must be that which is common to Life of all orders. And manifestly, that which is common to all forms of Life, will most readily be seen on contrasting those forms of Life which have the least in common, or are the most unlike.[16]

§ 25. Choosing assimilation, then, for our example of bodily life, and reasoning for our example of that life known as intelligence; it is first to be observed, that they are both processes of change. Without change, food cannot be taken into the blood nor transformed into tissue; without change, there can be no getting from premisses to conclusion. And it is this conspicuous display of changes which forms the substratum of our idea of Life in general. Doubtless we see innumerable changes to which no notion of vitality attaches. Inorganic bodies are ever undergoing changes of temperature, changes of colour, changes of aggregation; and decaying organic bodies also. But it will be admitted that the great majority of the phenomena displayed by inanimate bodies, are statical and not dynamical; that the modifications of inanimate bodies are mostly slow and unobtrusive; that on the one hand, when we see sudden movements in inanimate bodies, we are apt to assume living agency, and on the other hand, when we see no movements in living bodies, we are apt to assume death. Manifestly then, be the requisite qualifications what they may, a true idea of Life must be an idea of some kind of change or changes.

On further comparing assimilation and reasoning, with a view of seeing in what respect the changes displayed in both differs from non-vital changes, we find that they differ in being not simple changes; in each case there are *successive* changes. The transformation of food into tissue involves mastication, deglutition, chymification, chylification, absorption, and those various actions gone through after the lacteal ducts have poured their contents into the blood. Carrying on an

[16] This paragraph replaces a sentence that, in *The Principles of Psychology*, referred to a preceding chapter on "Method;" in which the mode of procedure here indicated was set forth as a mode to be systematically pursued in the choice of hypotheses. This chapter on Method is now included, along with other matter, in a volume entitled *Various Fragments*.

argument necessitates a long chain of states of consciousness; each implying a change of the preceding state. Inorganic changes, however, do not in any considerable degree exhibit this peculiarity. It is true that from meteorologic causes, inanimate objects are daily, sometimes hourly, undergoing modifications of temperature, of bulk, of hygrometric and electric condition. Not only, however, do these modifications lack that conspicuousness and that rapidity of succession which vital ones possess, but vital ones form an *additional* series. Living as well as not-living bodies are affected by atmospheric influences; and beyond the changes which these produce, living bodies exhibit other changes, more numerous and more marked. So that though organic change is not rigorously distinguished from inorganic change by presenting successive phases; yet vital change so greatly exceeds other change in this respect, that we may consider it as a distinctive character. Life, then, as thus roughly differentiated, may be regarded as change presenting successive phases; or otherwise, as a series of changes. And it should be observed, as a fact in harmony with this conception, that the higher the life the more conspicuous the variations. On comparing inferior with superior organisms, these last will be seen to display more rapid changes, or a more lengthened series of them, or both.

On contemplating afresh our two typical phenomena, we may see that vital change is further distinguished from non-vital change, by being made up of many *simultaneous* changes. Nutrition is not simply a series of actions, but includes many actions going on together. During mastication the stomach is busy with food already swallowed, on which it is pouring out solvent fluids and expending muscular efforts. While the stomach is still active, the intestines are performing their secretive, contractile, and absorbent functions; and at the same time that one meal is being digested, the nutriment obtained from a previous meal is undergoing transformation into tissue. So too is it, in a certain sense, with mental changes. Though the states of consciousness which make up an argument occur in series, yet, as each of them is complex, a number of simultaneous changes have taken place in establishing it. Here as before, however, it must be admitted that the distinction between animate and inanimate is not precise. No mass of dead matter can have its temperature altered, without at the same time undergoing an alteration in bulk, and sometimes also in hygrometric state. An inorganic body cannot be compressed, without being at the same time changed in form, atomic arrangement, temperature, and electric condition. And in a vast and mobile aggregate like the sea, the simultaneous as well as the successive changes outnumber those going on in an animal. Nevertheless, speaking generally, a living thing is distinguished from a dead thing by the multiplicity of the changes at any moment taking place in it. Moreover, by this peculiarity, as by the previous one, not only is the vital more or less clearly marked off from the non-vital; but creatures possessing high vitality are marked off from those possessing low vitality. It needs but to contrast the many organs cooperating in a mammal, with the few in a polype, to see that the actions which are progressing together in the body of the first, as much exceed in number the actions progressing together in the body of the last, as these do those in a stone. As at present conceived, then, Life consists of simultaneous and successive changes.

Continuance of the comparison shows that vital changes, both visceral and cerebral, differ from other changes in their *heterogeneity*. Neither the simultaneous acts nor the serial acts, which together constitute the process of digestion, are alike. The states of consciousness comprised in any ratiocination are not repetitions one of another, either in composition or in modes of dependence. Inorganic processes, on the other hand, even when like organic ones in the number of the simultaneous and successive changes they involve, are unlike them in the relative homogeneity of these changes. In the case of the sea, just referred to, it is observable that countless as are the actions at any moment going on, they are mostly mechanical actions that are to a great degree similar; and in this respect differ widely from the actions at any moment taking place in an organism. Even where life is nearly simulated, as by the working of a steam-engine, we see that considerable as is the number of simultaneous changes, and rapid as are the successive ones, the regularity with which they soon recur in the same order and degree, renders them unlike those varied changes exhibited by a living creature. Still, this peculiarity, like the foregoing ones, does not divide the two classes of changes with precision; since there are inanimate things presenting considerable heterogeneity of change: for instance, a cloud. The variations of state which this undergoes, both simultaneous and successive, are many and quick; and they differ widely from one another both in quality and quantity. At the same instant there may occur change of position, change of form, change of size, change of density, change of colour, change of temperature, change of electric state; and these several kinds of change are continuously displayed in different degrees and combinations. Yet when we observe that very few inorganic objects manifest heterogeneity of change comparable to that manifested by organic objects, and further, that in ascending from low to high forms of life, we meet with an increasing variety in the kinds of changes displayed; we see that there is here a further leading distinction between vital and non-vital actions. According to this modified conception, then, Life is made up of heterogeneous changes both simultaneous and successive.

If, now, we look for some trait common to the nutritive and logical processes, by which they are distinguished from those inorganic processes that are most like them in the heterogeneity of the simultaneous and successive changes they comprise, we discover that they are distinguished by the *combination* among their constituent changes. The acts which make up digestion are mutually dependent. Those composing a train of reasoning are in close connection. And, generally, it is to be remarked of vital changes, that each is made possible by all, and all are affected by each. Respiration, circulation, absorption, secretion, in their many sub-divisions, are bound up together. Muscular contraction involves chemical change, change of temperature, and change in the excretions. Active thought influences the operations of the stomach, of the heart, of the kidneys. But we miss this union among non-vital activities. Life-like as may seem the action of a volcano in respect of the heterogeneity of its many simultaneous and successive changes, it is not life-like in respect of their combination. Though the chemical, mechanical, thermal, and electric phenomena exhibited have some inter-dependence, yet the emissions of stones, mud, lava, flame, ashes, smoke, steam, take place irregularly in quantity, order, intervals, and mode of conjunction. Even here, however, it cannot be said that inanimate things present no parallels to animate ones. A glacier may be instanced as showing nearly as much combination in its change as a plant of the lowest organization. It is ever growing and ever decaying; and the rates of its composition and decomposition preserve a tolerably constant ratio. It moves; and its motion is in immediate dependence on its thawing. It emits a torrent of water, which, in common with its motion, undergoes annual variations as plants do. During part of the year the surface melts and freezes alternately; and on these changes depend the variations in movement, and in efflux of water. Thus we have growth, decay, changes of temperature, changes of consistence, changes of velocity, changes of excretion, all going on in connexion; and it may be as truly said of a glacier as of an animal, that by ceaseless integration and disintegration it gradually undergoes an entire change of substance without losing its individuality. This exceptional instance, however, will scarcely be held to obscure that broad distinction from inorganic processes which organic processes derive from the combination among their constituent changes. And the reality of this distinction becomes yet more manifest when we find that, in common with previous ones, it not only marks off the living from the not-living, but also things which live little from things which live much. For while the changes going on in a plant or a zoophyte are so imperfectly combined that they can continue after it has been divided into two or more pieces, the combination among the changes going on in a mammal is so close that no part cut off from the rest can live, and any considerable disturbance of one chief function causes a cessation of the others. Hence, as we now regard it, Life is a combination of heterogeneous changes, both simultaneous and successive.

When we once more look for a character common to these two kinds of vital action, we perceive that the combinations of heterogeneous changes which constitute them, differ from the few combinations which they otherwise resemble, in respect of *definiteness*. The associated changes going on in a glacier, admit of indefinite variation. Under a conceivable alteration of climate, its thawing and its progression may be stopped for a million years, without disabling it from again displaying these phenomena under appropriate conditions. By a geological convulsion, its motion may be arrested without an arrest of its thawing; or by an increase in the inclination of the surface it slides over, its motion may be accelerated without accelerating its rate of dissolution. Other things remaining the same, a more rapid deposit of snow may cause great increase of bulk; or, conversely, the accretion may entirely cease, and yet all the other actions continue until the mass disappears. Here, then, the combination has none of that definiteness which, in a plant, marks the mutual dependence of respiration, assimilation, and circulation; much less has it that definiteness seen in the mutual dependence of the chief animal functions; no one of which can be varied without varying the rest; no one of which can go on unless the rest go on. Moreover, this definiteness of combination distinguishes the changes occurring in a living body from those occurring in a dead one. Decomposition exhibits both simultaneous and successive changes, which are to some extent heterogeneous, and in a sense combined; but they are not combined in a definite manner. They vary according as the surrounding medium is air, water, or earth. They alter in nature with the temperature. If the local conditions are unlike, they progress differently in different parts of the mass, without mutual influence. They may end in producing gases, or adipocire, or the dry substance of which mummies consist. They may occupy a few days or thousands of years. Thus, neither in their simultaneous nor in their successive changes, do dead bodies display that definiteness of combination which characterizes living ones. It is true that in some inferior creatures the cycle of successive changes admits of a certain indefiniteness – that it may be suspended for a long period by desiccation or freezing, and may afterwards go on as though there had been no breach in its continuity. But the circumstance that only a low order of life can have its changes thus modified, serves but to suggest that, like the previous characteristics, this characteristic of definiteness in its combined changes, distinguishes high vitality from low vitality, as it distinguishes low vitality from inorganic processes. Hence, our formula as further amended reads thus: – Life is a definite combination of heterogenous changes, both simultaneous and successive.

Finally, we shall still better express the facts if, instead of saying *a* definite combination of heterogeneous changes, we say *the* definite combination of heterogeneous changes. As it at present stands, the definition is defective both in allowing that there may be *other* definite combinations of heterogeneous changes, and in directing attention to the heterogeneous changes rather than to the definiteness of their combination. Just as it is not so much its chemical elements which constitute an organism, as it is the arrangement of them into special tissues and organs; so it is not so much its heterogeneous changes which constitute Life, as it is the co-ordination of them. Observe what it is that ceases when life ceases. In a dead body there are going on heterogeneous changes, both simultaneous and successive. What then has disappeared? The definite combination has disappeared. Mark, too, that however heterogeneous the simultaneous and successive changes exhibited by such an inorganic object as a volcano, we much less tend to think of it as living than we do a watch or a steam-engine, which, though displaying changes that, serially contemplated, are largely homogeneous, displays them definitely combined. So dominant an element is this in our idea of Life, that even when an object is motionless, yet, if its parts be definitely combined, we conclude either that it has had life, or has been made by something having life. Thus, then, we conclude that Life is —*the* definite combination of heterogeneous changes, both simultaneous and successive.

§ 26. Such is the conception at which we arrive without changing our stand-point. It is, however, an incomplete conception. This ultimate formula (which is to a considerable extent identical with one above given – "the co-ordination of actions;" seeing that "definite combination" is synonymous with "co-ordination," and "changes both simultaneous and successive" are comprehended under the term "actions;" but which differs from it in specifying the fact, that the actions or changes are "heterogeneous") – this ultimate formula, I say, is after all but a rude approximation. It is true that it does not fail by including the growth of a crystal; for the successive changes this implies cannot be called heterogeneous. It is true that the action of a galvanic battery is not comprised in it; since here, too, heterogeneity is not exhibited by the successive changes. It is true that by this same qualification the motions of the Solar System are excluded, as are also those of a watch and a steam-engine. It is true, moreover, that while, in virtue of their heterogeneity, the actions going on in a cloud, in a volcano, in a glacier, fulfil the definition; they fall short of it in lacking definiteness of combination. It is further true that this definiteness of combination distinguishes the changes taking place in an organism during life from those which commence at death. And beyond all this it is true that, as well as serving to mark off, more or less clearly, organic actions from inorganic actions, each member of the definition serves to mark off the actions constituting high vitality from those constituting low vitality; seeing that life is high in proportion to the number of successive changes occurring between birth and death; in proportion to the number of simultaneous changes; in proportion to the heterogeneity of the changes; in proportion to the combination subsisting among the changes; and in proportion to the definiteness of their combination. Nevertheless, answering though it does to so many requirements, this definition is essentially defective. *The definite combination of heterogeneous changes, both simultaneous and successive*, is a formula which fails to call up an adequate conception. And it fails from omitting the most distinctive peculiarity – the peculiarity of which we have the most familiar experience, and with which our notion of Life is, more than with any other, associated. It remains now to supplement the conception by the addition of this peculiarity.

CHAPTER V. THE CORRESPONDENCE BETWEEN LIFE AND ITS CIRCUMSTANCES

§ 27. We habitually distinguish between a live object and a dead one, by observing whether a change which we make in the surrounding conditions, or one which Nature makes in them, is or is not followed by some perceptible change in the object. By discovering that certain things shrink when touched, or fly away when approached, or start when a noise is made, the child first roughly discriminates between the living and the not-living; and the man when in doubt whether an animal he is looking at is dead or not, stirs it with his stick; or if it be at a distance, shouts, or throws a stone at it. Vegetal and animal life are alike primarily recognized by this process. The tree that puts out leaves when the spring brings increase of temperature, the flower which opens and closes with the rising and setting of the sun, the plant that droops when the soil is dry and re-erects itself when watered, are considered alive because of these induced changes; in common with the acorn-shell which contracts when a shadow suddenly falls on it, the worm that comes to the surface when the ground is continuously shaken, and the hedgehog that rolls itself up when attacked.

Not only, however, do we look for some response when an external stimulus is applied to a living organism, but we expect a fitness in the response. Dead as well as living things display changes under certain changes of condition: instance, a lump of carbonate of soda that effervesces when dropped into sulphuric acid; a cord that contracts when wetted; a piece of bread that turns brown when held near the fire. But in these cases, we do not see a connexion between the changes undergone and the preservation of the things that undergo them; or, to avoid any teleological implication – the changes have no apparent relations to future events which are sure or likely to take place. In vital changes, however, such relations are manifest. Light being necessary to vegetal life, we see in the action of a plant which, when much shaded, grows towards the unshaded side, an appropriateness which we should not see did it grow otherwise. Evidently the proceedings of a spider which rushes out when its web is gently shaken and stays within when the shaking is violent, conduce better to the obtainment of food and the avoidance of danger than were they reversed. The fact that we feel surprise when, as in the case of a bird fascinated by a snake, the conduct tends towards self-destruction, at once shows how generally we have observed an adaptation of living changes to changes in surrounding circumstances.

A kindred truth, rendered so familiar by infinite repetition that we forget its significance, must be named. There is invariably, and necessarily, a conformity between the vital functions of any organism and the conditions in which it is placed – between the processes going on inside of it and the processes going on outside of it. We know that a fish cannot live long in air, or a man under water. An oak growing in the ocean and a seaweed on the top of a hill, are incredible combinations of ideas. We find that each kind of animal is limited to a certain range of climate; each kind of plant to certain zones of latitude and elevation. Of the marine flora and fauna, each species is found only between such and such depths. Some blind creatures flourish in dark caves; the limpet where it is alternately covered and uncovered by the tide; the red-snow alga rarely elsewhere than in the arctic regions or among alpine peaks.

Grouping together the cases first named, in which a particular change in the circumstances of an organism is followed by a particular change in it, and the cases last named, in which the constant actions occurring within an organism imply some constant actions occurring without it; we see that in both, the changes or processes displayed by a living body are specially related to the changes or processes in its environment. And here we have the needful supplement to our conception of Life. Adding this all-important characteristic, our conception of Life becomes – The definite combination of heterogeneous changes, both simultaneous and successive, *in correspondence with external co-*

existences and sequences. That the full significance of this addition may be seen, it will be necessary to glance at the correspondence under some of its leading aspects.[17]

§ 28. Neglecting minor requirements, the actions going on in a plant pre-suppose a surrounding medium containing at least carbonic acid and water, together with a due supply of light and a certain temperature. Within the leaves carbon is being appropriated and oxygen given off; without them, is the gas from which the carbon is taken, and the imponderable agents that aid the abstraction. Be the nature of the process what it may, it is clear that there are external elements prone to undergo special re-arrangements under special conditions. It is clear that the plant in sunshine presents these conditions and so effects these re-arrangements. And thus it is clear that the changes which primarily constitute the plant's life, are in correspondence with co-existences in its environment.

If, again, we ask respecting the lowest protozoon how it lives; the answer is, that while on the one hand its substance is undergoing disintegration, it is on the other hand absorbing nutriment; and that it may continue to exist, the one process must keep pace with, or exceed, the other. If further we ask under what circumstances these combined changes are possible, there is the reply that the medium in which the protozoon is placed, must contain oxygen and food – oxygen in such quantity as to produce some disintegration; food in such quantity as to permit that disintegration to be made good. In other words – the two antagonistic processes taking place internally, imply the presence externally of materials having affinities that can give rise to them.

Leaving those lowest animal forms which simply take in through their surfaces the nutriment and oxygenated fluids coming in contact with them, we pass to those somewhat higher forms which have their tissues slightly specialized. In these we see a correspondence between certain actions in the digestive sac, and the properties of certain surrounding bodies. That a creature of this order may continue to live, it is necessary not only that there be masses of substance in the environment capable of transformation into its own tissue, but also that the introduction of these masses into its stomach, shall be followed by the secretion of a solvent fluid which will reduce them to a fit state for absorption. Special outer properties must be met by special inner properties.

When, from the process by which food is digested, we turn to the process by which it is seized, the same general truth faces us. The stinging and contractile power of a polype's tentacle, correspond to the sensitiveness and strength of the creatures serving it for prey. Unless that external change which brings one of these creatures in contact with the tentacle, were quickly followed by those internal changes which result in the coiling and drawing up of the tentacle, the polype would die of inanition. The fundamental processes of integration and disintegration within it, would get out of correspondence with the agencies and processes without it, and the life would cease.

Similarly, when the creature becomes so large that its tissue cannot be efficiently supplied with nutriment by mere absorption through its lining membrane, or duly oxygenated by contact with the fluid bathing its surface, there arises a need for a distributing system by which nutriment and oxygen may be carried throughout the mass; and the functions of this system, being subsidiary to the two

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[17] Speaking of "the general idea of *life*" M. Comte says: – "Cette idée suppose, en effet, non-seulement celle d'un être organisé de manière à comporter l'état vital, mais aussi celle, non moins indispensable, d'un certain ensemble d'influences extérieures propres à son accomplissement. Une telle harmonie entre l'être vivant et le *milieu* correspondant, caractérise evidemment la condition fondamentale de la vie." Commenting on de Blainville's definition of life, which he adopts, he says: – "Cette lumineuse définition ne me paraît laisser rien d'important à désirer, si ce n'est une indication plus directe et plus explicite de ces deux conditions fondamentales co-relatives, nécessairement inséparables de l'état vivant, un *organisme* déterminé et un *milieu* convenable." It is strange that M. Comte should have thus recognized the necessity of a harmony between an organism and its environment, as a *condition* essential to life, and should not have seen that the continuous maintenance of such inner actions as will counterbalance outer actions, *constitutes* life.[When the original edition was published Dr. J. H. Bridges wrote to me saying that in the *Politique Positive*, Comte had developed his conception further. On p. 413, denying "le prétendu antagonisme des corps vivants envers leurs milieux inorganiques," he says "au lieu de ce conflit, on a reconnu bientôt que cette relation nécessaire constitue une condition fondamentale de la vie réelle, dont la notion systématique consiste dans une intime conciliation permanente entre la spontanéité intérieure et la fatalité extérieure." Still, this "conciliation *permanente*" seems to be a "*condition*" to life; not that varying adjustment of changes which life consists in maintaining. In presence of an ambiguity, the interpretation which agrees with his previous statement must be chosen.]

primary functions, form links in the correspondence between internal and external actions. The like is obviously true of all those subordinate functions, secretory and excretory, that facilitate oxidation and assimilation.

Ascending from visceral actions to muscular and nervous actions, we find the correspondence displayed in a manner still more obvious. Every act of locomotion implies the expenditure of certain internal forces, adapted in amounts and directions to balance or out-balance certain external forces. The recognition of an object is impossible without a harmony between the changes constituting perception, and particular properties co-existing in the environment. Escape from enemies implies motions within the organism, related in kind and rapidity to motions without it. Destruction of prey requires a special combination of subjective actions, fitted in degree and succession to overcome a group of objective ones. And so with those countless automatic processes constituting instincts.

In the highest order of vital changes the same fact is equally manifest. The empirical generalization that guides the farmer in his rotation of crops, serves to bring his actions into concord with certain of the actions going on in plants and soil. The rational deductions of the educated navigator who calculates his position at sea, form a series of mental acts by which his proceedings are conformed to surrounding circumstances. Alike in the simplest inferences of the child and the most complex ones of the man of science, we find a correspondence between simultaneous and successive changes in the organism, and co-existences and sequences in its environment.

§ 29. This general formula which thus includes the lowest vegetal processes along with the highest manifestations of human intelligence, will perhaps call forth some criticisms which it is desirable here to meet.

It may be thought that there are still a few inorganic actions included in the definition; as, for example, that displayed by the mis-named storm-glass. The feathery crystallization which, on a certain change of temperature, takes place in its contained solution, and which afterwards dissolves to reappear in new forms under new conditions, may be held to present simultaneous and successive changes that are to some extent heterogeneous, that occur with some definiteness of combination, and, above all, occur in apparent correspondence with external changes. In this case vegetal life is simulated to a considerable extent; but it is *merely* simulated. The relation between the phenomena occurring in the storm-glass and in the atmosphere respectively, is not a correspondence at all, in the proper sense of the word. Outside there is a thermal change; inside there is a change of atomic arrangement. Outside there is another thermal change; inside there is another change of atomic arrangement. But subtle as is the dependence of each internal upon each external change, the connexion between them does not, in the abstract, differ from the connexion between the motion of a straw and the motion of the wind that disturbs it. In either case a change produces a change, and there it ends. The alteration wrought by some environing agency on this or any other inanimate object, does not tend to induce in it a secondary alteration which anticipates some secondary alteration in the environment. But in every living body there is a tendency towards secondary alterations of this nature; and it is in their production that the correspondence consists. The difference may be best expressed by symbols. Let A be a change in the environment, and B some resulting change in an inorganic mass. Then A having produced B, the action ceases. Though the change A in the environment is followed by some consequent change *a* in it; no parallel sequence in the inorganic mass simultaneously generates in it some change *b* that has reference to the change *a*. But if we take a living body of the requisite organization, and let the change A impress on it some change C; then, while in the environment A is occasioning *a*, in the living body C will be occasioning *c*; of which *a* and *c* will show a certain concord in time, place, or intensity. And while it is *in* the continuous production of such concords or correspondences that Life consists, it is *by* the continuous production of them that Life is maintained.

The further criticism to be expected concerns certain verbal imperfections in the definition, which it seems impossible to avoid. It may fairly be urged that the word *correspondence* will not include, without straining, the various relations to be expressed by it. It may be asked: – How can the continuous *processes* of assimilation and respiration correspond with the *co-existence* of food and oxygen in the environment? or again: – How can the act of secreting some defensive fluid correspond with some external danger which may never occur? or again: – How can the *dynamical* phenomena constituting perception correspond with the *statical* phenomena of the solid body perceived? The only reply is, that we have no word sufficiently general to comprehend all forms of this relation between the organism and its medium, and yet sufficiently specific to convey an adequate idea of the relation; and that the word *correspondence* seems the least objectionable. The fact to be expressed in all cases is that certain changes, continuous or discontinuous, in the organism, are connected after such a manner that in their amounts, or variations, or periods of occurrence, or modes of succession, they have a reference to external actions, constant or serial, actual or potential – a reference such that a definite relation among any members of the one group, implies a definite relation among certain members of the other group.

§ 30. The presentation of the phenomena under this general form, suggests that our conception of Life may be reduced to its most abstract shape by regarding its elements as relations only. If a creature's rate of assimilation is increased in consequence of a decrease of temperature in the environment, it is that the relation between the food consumed and the heat produced, is so re-adjusted by multiplying both its members, that the altered relation in the environment between the quantity of heat absorbed from, and radiated to, bodies of a given temperature, is counterbalanced. If a sound or a scent wafted to it on the breeze prompts the stag to dart away from the deer-stalker, it is that there exists in its neighbourhood a relation between a certain sensible property and certain actions dangerous to the stag, while in its body there exists an adapted relation between the impression this sensible property produces, and the actions by which danger may be escaped. If inquiry has led the chemist to a law, enabling him to tell how much of any one element will combine with so much of another, it is that there has been established in him specific mental relations, which accord with specific chemical relations in the things around. Seeing, then, that in all cases we may consider the external phenomena as simply in relation, and the internal phenomena also as simply in relation; our conception of Life under its most abstract aspect will be —*The continuous adjustment of internal relations to external relations*.[18]

While it is simpler, this formula has the further advantage of being somewhat more comprehensive. To say that it includes not only those definite combinations of simultaneous and successive changes in an organism, which correspond to co-existences and sequences in the environment, but also those structural arrangements which *enable* the organism to adapt its actions to actions in the environment, is going too far; for though these structural arrangements present internal relations adjusted to external relations, yet the *continuous adjustment* of relations cannot be held to include a *fixed adjustment* already made. Life, which is made up of *dynamical* phenomena, cannot be described in terms that shall at the same time describe the apparatus manifesting it, which presents only *statical* phenomena. But while this antithesis serves to remind us that the distinction between the organism and its actions is as wide as that between Matter and Motion, it at the same time draws attention to the fact that, if the structural arrangements of the adult are not properly included in the definition, yet the developmental processes by which those arrangements were established, are included. For that process of evolution during which the organs of the embryo are fitted to their prospective functions, is the gradual or continuous adjustment of internal relations to external relations. Moreover, those structural modifications of the adult organism which, under change of climate, change of occupation, change of food, bring about some re-arrangement in the organic balance, may similarly be regarded as progressive or continuous adjustments of internal relations to external relations. So that not only does the definition, as thus expressed, comprehend all those activities, bodily and mental, which constitute our ordinary idea of Life; but it also comprehends

[18] In further elucidation of this general doctrine, see *First Principles*, § 25.

both those processes of development by which the organism is brought into general fitness for such activities, and those after-processes of adaptation by which it is specially fitted to its special activities.

Nevertheless, so abstract a formula as this is scarcely fitted for our present purpose. Reserving it for use where specially appropriate, it will be best commonly to employ its more concrete equivalent – to consider the internal relations as "definite combinations of simultaneous and successive changes;" the external relations as "co-existences and sequences;" and the connexion between them as a "correspondence."

CHAPTER VI. THE DEGREE OF LIFE VARIES AS THE DEGREE OF CORRESPONDENCE

§ 31. Already it has been shown respecting each other component of the foregoing definition, that the life is high in proportion as that component is conspicuous; and it is now to be remarked, that the same thing is especially true respecting this last component – the correspondence between internal and external relations. It is manifest, *a priori*, that since changes in the physical state of the environment, as also of those mechanical actions and those variations of available food which occur in it, are liable to stop the processes going on in the organism; and since the adaptive changes in the organism have the effects of directly or indirectly counter-balancing these changes in the environment; it follows that the life of the organism will be short or long, low or high, according to the extent to which changes in the environment are met by corresponding changes in the organism. Allowing a margin for perturbations, the life will continue only while the correspondence continues; the completeness of the life will be proportionate to the completeness of the correspondence; and the life will be perfect only when the correspondence is perfect. Not to dwell in general statements, however, let us contemplate this truth under its concrete aspects.

§ 32. In life of the lowest order we find that only the most prevalent co-existences and sequences in the environment, have any simultaneous and successive changes answering to them in the organism. A plant's vital processes display adjustment solely to the continuous co-existence of certain elements and forces surrounding its roots and leaves; and vary only with the variations produced in these elements and forces by the Sun – are unaffected by the countless mechanical movements and contacts occurring around; save when accidentally arrested by these. The life of a worm is made up of actions referring to little else than the tangible properties of adjacent things. All those visible and audible changes which happen near it, and are connected with other changes that may presently destroy it, pass unrecognized – produce in it no adapted changes: its only adjustment of internal relations to external relations of this order, being seen when it escapes to the surface on feeling the vibrations produced by an approaching mole. Adjusted as are the proceedings of a bird to a far greater number of co-existences and sequences in the environment, cognizable by sight, hearing, scent, and their combinations: and numerous as are the dangers it shuns and the needs it fulfils in virtue of this extensive correspondence; it exhibits no such actions as those by which a human being counterbalances variations in temperature and supply of food, consequent on the seasons. And when we see the plant eaten, the worm trodden on, the bird dead from starvation; we see alike that the death is an arrest of such correspondence as existed, that it occurred when there was some change in the environment to which the organism made no answering change, and that thus, both in shortness and simplicity, the life was incomplete in proportion as the correspondence was incomplete. Progress towards more prolonged and higher life, evidently implies ability to respond to less general co-existences and sequences. Each step upwards must consist in adding to the previously-adjusted relations of actions or structures which the organism exhibits, some further relation parallel to a further relation in the environment. And the greater correspondence thus established, must, other things equal, show itself both in greater complexity of life, and greater length of life: a truth which will be fully perceived on remembering the enormous mortality which prevails among lowly-organized creatures, and the gradual increase of longevity and diminution of fertility which we meet with on ascending to creatures of higher and higher developments.

It must be remarked, however, that while length and complexity of life are, to a great extent, associated – while a more extended correspondence in the successive changes commonly implies increased correspondence in the simultaneous changes; yet it is not uniformly so. Between the two great divisions of life – animal and vegetal – this contrast by no means holds. A tree may live a thousand years, though the simultaneous changes going on in it answer only to the few chemical affinities in the air and the earth, and though its serial changes answer only to those of day and night, of the weather and the seasons. A tortoise, which exhibits in a given time nothing like the number of internal actions adjusted to external ones that are exhibited by a dog, yet lives far longer. The tree by its massive trunk and the tortoise by its hard carapace, are saved the necessity of responding to those many surrounding mechanical actions which organisms not thus protected must respond to or die; or rather – the tree and the tortoise display in their structures, certain simple statical relations adapted to meet countless dynamical relations external to them. But notwithstanding the qualifications suggested by such cases, it needs but to compare a microscopic fungus with an oak, an animalcule with a shark, a mouse with a man, to recognize the fact that this increasing correspondence of its changes with those of the environment which characterizes progressing life, habitually shows itself at the same time in continuity and in complication.

Even were not the connexion between length of life and complexity of life thus conspicuous, it would still be true that the life is great in proportion as the correspondence is great. For if the lengthened existence of a tree be looked upon as tantamount to a considerable amount of life; then it must be admitted that its lengthened display of correspondence is tantamount to a considerable amount of correspondence. If, otherwise, it be held that notwithstanding its much shorter existence, a dog must rank above a tortoise in degree of life because of its superior activity; then it is implied that its life is higher because its simultaneous and successive changes are more complex and more rapid – because the correspondence is greater. And since we regard as the highest life that which, like our own, shows great complexity in the correspondences, great rapidity in the succession of them, and great length in the series of them; the equivalence between degree of life and degree of correspondence is unquestionable.

§ 33. In further elucidation of this general truth, and especially in explanation of the irregularities just referred to, it must be pointed out that as the life becomes higher the environment itself becomes more complex. Though, literally, the environment means all surrounding space with the co-existences and sequences contained in it: yet, practically, it often means but a small part of this. The environment of an entozoon can scarcely be said to extend beyond the body of the animal in which the entozoon lives. That of a freshwater alga is virtually limited to the ditch inhabited by the alga. And, understanding the term in this restricted sense, we shall see that the superior organisms inhabit the more complicated environments.

Thus, contrasted with the life found on land, the lower life is that found in the sea; and it has the simpler environment. Marine creatures are affected by fewer co-existences and sequences than terrestrial ones. Being very nearly of the same specific gravity as the surrounding medium, they have to contend with less various mechanical actions. The sea-anemone fixed to a stone, and the acalephe borne along in the current, need to undergo no internal changes such as those by which the caterpillar meets the varying effects of gravitation, while creeping over and under the leaves. Again, the sea is liable to none of those extreme and rapid alterations of temperature which the air suffers. Night and day produce no appreciable modifications in it; and it is comparatively little affected by the seasons. Thus its contained fauna show no marked correspondences similar to those by which air-breathing creatures counterbalance thermal changes. Further, in respect to the supply of nutriment, the conditions are more simple. The lower tribes of animals inhabiting the water, like the plants inhabiting the air, have their food brought to them. The same current which brings oxygen to the oyster, also brings it the microscopic organisms on which it lives: the disintegrating matter and the matter to be integrated, co-exist under the simplest relation. It is otherwise with land animals. The oxygen is everywhere, but the sustenance is not everywhere: it has to be sought; and the conditions under which it is to be obtained are more or less complex. So too with that liquid by the agency of which the vital processes are carried on. To marine creatures water is ever present, and by the lowest is passively absorbed; but to most creatures living on the earth and in the air, it is made available only through those nervous changes constituting perception, and those muscular ones by which drinking is effected. Similarly, after tracing upwards from the *Amphibia* the widening extent and complexity which the environment, as practically considered, assumes – after observing further how increasing heterogeneity in the flora and fauna of the globe, itself progressively complicates the environment of each species of organism – it might finally be shown that the same general truth is displayed in the history of mankind, who, in the course of their progress, have been adding to their physical environment a social environment that has been growing ever more involved. Thus, speaking generally, it is clear that those relations in the environment to which relations in the organism must correspond, themselves increase in number and intricacy as the life assumes a higher form.

§ 34. To make yet more manifest the fact that the degree of life varies as the degree of correspondence, let me here point out, that those other distinctions successively noted when contrasting vital changes with non-vital changes, are all implied in this last distinction – their correspondence with external co-existences and sequences; and further, that the increasing fulfilment of those other distinctions which we found to accompany increasing life, is involved in the increasing fulfilment of this last distinction. We saw that living organisms are characterized by successive changes, and that as the life becomes higher, the successive changes become more numerous. Well, the environment is full of successive changes, and the greater the correspondence, the greater must be the number of successive changes in the organism. We saw that life presents simultaneous changes, and that the more elevated it is, the more marked the multiplicity of them. Well, besides countless co-existences in the environment, there are often many changes occurring in it at the same moment; and hence increased correspondence with it implies in the organism an increased display of simultaneous changes. Similarly with the heterogeneity of the changes. In the environment the relations are very varied in their kinds, and hence, as the organic actions come more and more into correspondence with them, they too must become very varied in their kinds. So again is it even with definiteness of combination. As the most important surrounding changes with which each animal has to deal, are the definitely-combined changes exhibited by other animals, whether prey or enemies, it results that definiteness of combination must be a general characteristic of the internal ones which have to correspond with them. So that throughout, the correspondence of the internal relations with the external ones is the essential thing; and all the special characteristics of the internal relations, are but the collateral results of this correspondence.

§§ 35, 36. Before closing the chapter, it will be useful to compare the definition of Life here set forth, with the definition of Evolution set forth in *First Principles*. Living bodies being bodies which display in the highest degree the structural changes constituting Evolution; and Life being made up of the functional changes accompanying these structural changes; we ought to find a certain harmony between the definitions of Evolution and of Life. Such a harmony is not wanting.

The first distinction we noted between the kind of change shown in Life, and other kinds of change, was its serial character. We saw that vital change is substantially unlike non-vital change, in being made up of *successive* changes. Now since organic bodies display so much more than inorganic bodies those continuous differentiations and integrations which constitute Evolution; and since the re-distributions of matter thus carried so far in a comparatively short period, imply concomitant re-distributions of motion; it is clear that in a given time, organic bodies must undergo changes so comparatively numerous as to render the successiveness of their changes a marked characteristic. And it will follow *a priori*, as we found it to do *a posteriori*, that the organisms exhibiting Evolution in the highest degree, exhibit the longest or the most rapid successions of changes, or both. Again, it was shown that vital change is distinguished from non-vital change by being made up of many *simultaneous* changes; and also that creatures possessing high vitality are marked off from those possessing low vitality, by the far greater number of their simultaneous changes. Here, too, there is entire congruity. In *First Principles*, § 156, we reached the conclusion that a force falling on any aggregate is divided into several forces; that when the aggregate consists of parts that are unlike, each part becomes a centre of unlike differentiations of the incident force; and that thus the multiplicity of such differentiations must increase with the multiplicity of the unlike parts. Consequently organic aggregates, which as a class are distinguished from inorganic aggregates by the greater number of their unlike parts, must be also distinguished from them by the greater number of simultaneous changes they display; and, further, that the higher organic aggregates, having more numerous unlike parts than the lower, must undergo more numerous simultaneous changes. We next found that the changes occurring in living bodies are contrasted with those occurring in other bodies, as being much more *heterogeneous*; and that the changes occurring in the superior living bodies are similarly contrasted with those occurring in inferior ones. Well, heterogeneity of function is the correlate of heterogeneity of structure; and heterogeneity of structure is the leading distinction between organic and inorganic aggregates, as well as between the more highly organized and the more lowly organized. By reaction, an incident force must be rendered multiform in proportion to the multiformity of the aggregate on which it falls; and hence those most multi-form aggregates which display in the highest degree the phenomena of Evolution structurally considered, must also display in the highest degree the multiform actions which constitute Evolution functionally considered. These heterogeneous changes, exhibited simultaneously and in succession by a living organism, prove, on further inquiry, to be distinguished by their *combination* from certain non-vital changes which simulate them. Here, too, the parallelism is maintained. It was shown in *First Principles*, Chap. XIV, that an essential characteristic of Evolution is the integration of parts, which accompanies their differentiation – an integration shown both in the consolidation of each part, and in the union of all the parts into a whole. Hence, animate bodies having greater co-ordination of parts than inanimate ones must exhibit greater co-ordination of changes; and this greater co-ordination of their changes must not only distinguish organic from inorganic aggregates, but must, for the same reason, distinguish higher organisms from lower ones, as we found that it did. Once more, it was pointed out that the changes constituting Life differ from other changes in the *definiteness* of their combination, and that a distinction like in kind though less in degree, holds between the vital changes of superior creatures and those of inferior creatures. These, also, are contrasts in harmony with the contrasts disclosed by the analysis of Evolution. We saw (*First Principles*, §§ 129-137) that during Evolution there is an increase of definiteness as well as an increase of heterogeneity. We saw that the integration accompanying differentiation has necessarily the effect of increasing the distinctness with which the parts are marked off from each other, and that so, out of the incoherent and indefinite there arises the coherent and definite. But a coherent whole made up of definite parts definitely combined, must exhibit more definitely combined changes than a whole made up of parts that are neither definite in themselves nor in their combination. Hence, if living bodies display more than other bodies this structural definiteness, then definiteness of combination must be a characteristic of the changes constituting Life, and must also distinguish the vital changes of higher organisms from those of lower organisms. Finally, we discovered that all these peculiarities are subordinate to the fundamental peculiarity, that vital changes take place in correspondence with external co-existences and sequences, and that the highest Life is reached, when there is some inner relation of actions fitted to meet every outer relation of actions by which the organism can be affected. But this conception of the highest Life, is in harmony with the conception, before arrived at, of the limit of Evolution. When treating of equilibration as exhibited in organisms (*First Principles*, §§ 173, 174), it was pointed out that the tendency is towards the establishment of a balance between inner and outer changes. It was shown that "the final structural arrangements must be such as will meet all the forces acting on the aggregate, by equivalent antagonistic forces," and that "the maintenance of such a moving equilibrium" as an organism displays, "requires the habitual genesis of internal forces corresponding in number, directions, and amounts, to the external incident forces – as many inner functions, single or combined, as there are single or combined outer actions to be met." It was shown, too, that the relations among ideas are ever in progress towards a better adjustment between mental actions and those actions in the environment to which conduct must be adjusted. So that this continuous correspondence between inner and outer relations which constitutes Life, and the perfection of which is the perfection of Life, answers completely to that state of organic moving equilibrium which we saw arises in the course of Evolution and tends ever to become more complete.

CHAPTER VI[A]. THE DYNAMIC ELEMENT IN LIFE

§ 36*a*. A critical comparison of the foregoing formula with the facts proves it to be deficient in more ways than one. Let us first look at vital phenomena which are not covered by it.

Some irritant left by an insect's ovipositor, sets up on a plant the morbid growth named a gall. The processes in the gall do not correspond with any external co-existences or sequences relevant to the plant's life – show no internal relations adjusted to external relations. Yet we cannot deny that the gall is alive. So, too, is it with a cancer in or upon an animal's body. The actions going on in it have no reference, direct or indirect, to actions in the environment. Nevertheless we are obliged to say that they are vital; since it grows and after a time dies and decomposes.

A kindred lesson meets us when from pathological evidence we turn to physiological evidence. The functions of some important organs may still be carried on for a time apart from those of the body as a whole. An excised liver, kept at a fit temperature and duly supplied with blood, secretes bile. Still more striking is the independent action of the heart. If belonging to a cold-blooded animal, as a frog, the heart, when detached, continues to beat, even until its integuments have become so dry that they crackle. Now though under such conditions its pulsations, which ordinarily form an essential part of the linked processes by which the correspondence between inner and outer actions is maintained, no longer form part of such processes, we must admit that the continuance of them implies a vital activity.

Embryological changes force the same truth upon us. What are we to say of the repeated cell-fissions by which in some types a blastula, or mulberry-mass, is formed, and in other types a blastoderm? Neither these processes nor the structures immediately resulting from them, show any correspondences with co-existences and sequences in the environment; though they are first steps towards the organization which is to carry on such correspondences. Even this extremely small fulfilment of the definition is absent in the cases of rudimentary organs, and especially those rudimentary organs which after being partly formed are absorbed. No adjustment can be alleged between the inner relations which these present and any outer relations. The outer relations they refer to ceased millions of years ago. Yet unquestionably the changes which bring about the production and absorption of these futile structures are vital changes.

Take another class of exceptions. What are we to say of a laugh? No correspondence, or part of a correspondence, by which inner actions are made to balance outer actions, can be seen in it. Or again, if, while working, an artisan whistles, the making of the sounds and the co-ordination of ideas controlling them, cannot be said to exhibit adjustment between certain relations of thoughts, and certain relations of things. Such kinds of vital activities lie wholly outside of the definition given.

But perhaps the clearest and simplest proof is yielded by contrasting voluntary and involuntary muscular actions. Here is a hawk adapting its changing motions to the changing motions of a pigeon, so as eventually to strike it: the adjustment of inner relations to outer relations is manifest. Here is a boy in an epileptic fit. Between his struggles and the co-existences and sequences around him there is no correspondence whatever. Yet his movements betray vitality just as much as do the movements of the hawk. Both exhibit that principle of *activity* which constitutes the essential element in our conception of life.

§ 36*b*. Evidently, then, the preceding chapters recognize only the *form* of our conception of life and ignore the *body* of it. Partly sufficing as does the definition reached to express the one, it fails entirely to express the other. Life displays itself in ways which conform to the definition; but it also displays itself in many other ways. We are obliged to admit that the element which is common to the two groups of ways is the essential element. The essential element, then, is that special kind of energy seen alike in the usual classes of vital actions and in those unusual classes instanced above.

Otherwise presenting the contrast, we may say that due attention has been paid to the connexions among the manifestations, while no attention has been paid to that which is manifested. When it is said that life is "the definite correspondence of heterogeneous changes, both simultaneous and successive, in correspondence with external co-existences and sequences," there arises the question – Changes of what? Within the body there go on many changes, mechanical, chemical, thermal, no one of which is the kind of change in question; and if we combine in thought so far as we can these kinds of changes, in such wise that each maintains its character as mechanical, chemical, or thermal, we cannot get out of them the idea of Life. Still more clearly do we see this insufficiency when we take the more abstract definition – "the continuous adjustment of internal relations to external relations." Relations between what things? is the question then to be asked. A relation of which the terms are unspecified does not connote a thought but merely the blank form of a thought. Its value is comparable to that of a cheque on which no amount is written. If it be said that the terms cannot be specified because so many heterogeneous kinds of them have to be included, then there comes the reply that under cover of this inability to make a specification of terms that shall be adequately comprehensive, there is concealed the inability to conceive the required terms in any way.

Thus a critical testing of the definition brings us, in another way, to the conclusion reached above, that that which gives the substance to our idea of Life is a certain unspecified principle of activity. The dynamic element in life is its essential element.

§ 36*c*. Under what form are we to conceive this dynamic element? Is this principle of activity inherent in organic matter, or is it something superadded? Of these alternative suppositions let us begin with the last.

As I have remarked, in another place, the worth of an hypothesis may be judged from its genealogy; and so judged the hypothesis of an independent vital principal does not commend itself. Its history carries us back to the ghost-theory of the savage. Suggested by experiences of dreams, there arises belief in a double – a second self which wanders away during sleep and has adventures but comes back on waking; which deserts the body during abnormal insensibility of one or other kind; and which is absent for a long period at death, though even then is expected eventually to return. This indwelling other-self, which can leave the body at will, is by-and-by regarded as able to enter the bodies of fellow men or of animals; or again, by implication, as liable to have its place usurped by the intruding doubles of fellow men, living or dead, which cause fits or other ills. Along with these developments its quality changes. At first thought of as quite material it is gradually de-materialized, and in advanced times comes to be regarded as spirit or breath; as we see in ancient religious books, where "giving up the ghost" is shown by the emergence of a small floating figure from the mouth of a dying man. This indwelling second self, more and more conceived as the real self which uses the body for its purposes, is, with the advance of intelligence, still further divested of its definite characters; and, coming in mediæval days to be spoken of as "animal spirits," ends in later days in being called a vital principle.

Entirely without assignable attributes, this something occurs in thought not as an idea but as a pseud-idea (*First Principles*, Chap. II). It is assumed to be representable while really unrepresentable. We need only insist on answers to certain questions to see that it is simply a name for an alleged existence which has not been conceived and cannot be conceived.

1. Is there one kind of vital principle for all kinds of organisms, or is there a separate kind for each? To affirm the first alternative is to say that there is the same vital principle for a microbe as for a whale, for a tape-worm as for the person it inhabits, for a protococcus as for an oak; nay more – is to assert community of vital principle in the thinking man and the unthinking plant. Moreover, asserting unity of the vital principle for all organisms, is reducing it to a force having the same unindividualized character as one of the physical forces. If, on the other hand, different kinds of organisms have

different kinds of vital principles, these must be in some way distinguished from one another. How distinguished? Manifestly by attributes. Do they differ in extension? Evidently; since otherwise that which animates the vast *Sequoia* can be no larger than that which animates a yeast-plant, and to carry on the life of an elephant requires a quantity of vital principle no greater than that required for a microscopic monad. Do they differ otherwise than in amount? Certainly; since otherwise we revert to the preceding alternative, which implies that the same quality of vital principle serves for all organisms, simple and complex: the vital principle is a uniform force like heat or electricity. Hence, then, we have to suppose that every species of animal and plant has a vital principle peculiar to itself – a principle adapted to use the particular set of structures in which it is contained. But dare anyone assert this multiplication of vital principles, duplicating not only all existing plants and animals but all past ones, and amounting in the aggregate to some millions?

2. How are we to conceive that genesis of a vital principle which must go along with the genesis of an organism? Here is a pollen-grain which, through the pistil, sends its nucleus to unite with the nucleus of the ovule; or here are the nuclei of spermatozoon and ovum, which, becoming fused, initiate a new animal: in either case failure of union being followed by decomposition of the proteid materials, while union is followed by development. Whence comes that vital principle which determines the organizing process? Is it created afresh for every plant and animal? or, if not, where and how did it pre-exist? Take a simpler form of this problem. A protophyte or protozoon, having grown to a certain size, undergoes a series of complex changes ending in fission. In its undivided state it had a vital principle. What of its divided state? The parts severally swim away, each fully alive, each ready to grow and presently to subdivide, and so on and so on, until millions are soon formed. That is to say, there is a multiplication of vital principles as of the protozoa animated by them. A vital principle, then, both divides and grows. But growth implies incorporation of something. What does the vital principle incorporate? Is it some other vital principle external to it, or some materials out of which more vital principle is formed? And how, in either case, can the vital principle be conceived as other than a material something, which in its growth and multiplication behaves just as visible matter behaves?

3. Equally unanswerable is the question which arises in presence of life that has become latent. Passing over the alleged case of the mummy wheat, the validity of which is denied, there is experimental proof that seeds may, under conditions unfavourable to germination, retain for ten, twenty, and some even for thirty years, the power to germinate when due moisture and warmth are supplied. (*Cf.* Kerner's *Nat. Hist. of Plants*, i, 51-2). Under what form has the vital principle existed during these long intervals? It is a principle of activity. In this case, then, the principle of activity becomes inactive. But how can we conceive an inactive activity? If it is a something which though inactive may be rendered active when conditions favour, we are introduced to the idea of a vital principle of which the vitality may become latent, which is absurd. What shall we say of the desiccated rotifer which for years has seemed to be nothing more than a particle of dust, but which now, when water is supplied, absorbs it, swells up, and resumes those ciliary motions by which it draws in nutriment? Was the vital principle elsewhere during these years of absolute quiescence? If so, why did it come back at the right moment? Was it all along present in the rotifer though asleep? How happened it then to awaken at the time when the supply of water enabled the tissues to resume their functions? How happened the physical agent to act not only on the material substance of the rotifer, but also on this something which is not a material substance but an immaterial source of activity? Evidently neither alternative is thinkable.

Thus, the alleged vital principle exists in the minds of those who allege it only as a verbal form, not as an idea; since it is impossible to bring together in consciousness the terms required to constitute an idea. It is not even "a figment of imagination," for that implies something imaginable, but the supposed vital principle cannot even be imagined.

§ 36*d*. When, passing to the alternative, we propose to regard life as inherent in the substances of the organisms displaying it, we meet with difficulties different in kind but scarcely less in degree. The processes which go on in living things are incomprehensible as results of any physical actions known to us.

Consider one of the simplest – that presented by an ordinary vegetal cell forming part of a leaf or other plant-structure. Its limiting membrane, originally made polyhedral by pressure of adjacent cells, is gradually moulded "into one of cylindrical, fibrous, or tabular shape, and strengthening its walls with pilasters, borders, ridges, hooks, bands, and panels of various kinds" (Kerner, i, 43): small openings into adjacent cells being either left or subsequently made. Consisting of non-nitrogenous, inactive matters, these structures are formed by the inclosed protoplast. How formed? Is it by the agency of the nucleus? But the nucleus, even had it characters conceivably adapting it to this function, is irregularly placed; and that it should work the same effects upon the cell-wall whether seated in the middle, at one end, or one side, is incomprehensible. Is the protoplasm then the active agent? But this is arranged into a network of strands and threads utterly irregular in distribution and perpetually altering their shapes and connexions. Exercise of fit directive action by the protoplasm is unimaginable.

Another instance: – Consider the reproductive changes exhibited by the *Spirogyra*. The delicate threads which, in this low type of Alga, are constituted of single elongated cells joined end to end, are here and there adjacent to one another; and from a cell of one thread and a cell of another at fit distance, grow out prominences which, meeting in the interspace and forming a channel by the dissolution of their adjoined cell-walls, empty through it the endochrome of the one cell into the other: forming by fusion of the two a zygote or reproductive body. Under what influence is this action initiated and guided? There is no conceivable directive agency in either cell by which, when conditions are fit, a papilla is so formed as to meet an opposite papilla.

Or again, contemplate the still more marvellous transformation occurring in *Hydrodictyon utriculosum*. United with others to form a cylindrical network, each sausage-shaped cell of this Alga contains, when fully developed, a lining chromatophore made of nucleated protoplasm with immersed chlorophyll-grains. This, when the cell is adult, divides into multitudinous zoospores, which presently join their ends in such ways as to form a network with meshes mostly hexagonal, minute in size, but like in arrangement to the network of which the parent cell formed a part. Eventually escaping from the mother-cell, this network grows and presently becomes as large as the parent network. Under what play of forces do these zoospores arrange themselves into this strange structure?

Kindred insoluble problems are presented by animal organisms of all grades. Of microscopic types instance the Coccospheres and Rhabdospheres found in the upper strata of sea-water. Each is a fragment of protoplasm less than one-thousandth of an inch in diameter, shielded by the elaborate protective structures it has formed. The elliptic coccoliths of the first, severally having a definite pattern, unite to form by overlapping an imbricated covering; and of the other the covering consists of numerous trumpet-mouthed processes radiating on all sides. To the question – How does this particle of granular protoplasm, without organs or definite structure, make for itself this complicated calcareous armour? there is no conceivable answer.

Like these *Protozoa*, the lowest *Metazoa* do things which are quite incomprehensible. Here is a sponge formed of classes of monads having among them no internuncial appliances by which in higher types cooperation is carried on – flagellate cells that produce the permeating currents of water, flattened cells forming protective membranes, and amœboid cells lying free in the gelatinous mesoderm. These, without apparent concert, build up not only the horny network constituting the chief mass of their habitation, but also embodied spicules, having remarkable symmetrical forms. By what combined influences the needful processes are effected, it is impossible to imagine.

If we turn to higher types of *Metazoa* in which, by the agency of a nervous system, many cooperations of parts are achieved in ways that are superficially comprehensible, we still meet with various actions of which the causation cannot be represented in thought. Lacking other calcareous matter, a hen picks up and swallows bits of broken egg-shells; and, occasionally, a cow in calf may be seen mumbling a bone she has found – evidently scraping off with her teeth some of its mass. These proceedings have reference to constitutional needs; but how are they prompted? What generates in the cow a desire to bite a substance so unlike in character to her ordinary food? If it be replied that the blood has become poor in certain calcareous salts and that hence arises the appetite for things containing them, there remains the question – How does this deficiency so act on the nervous system as to generate this vague desire and cause the movements which satisfy it? By no effort can we figure to ourselves the implied causal processes.

In brief, then, we are obliged to confess that Life in its essence cannot be conceived in physico-chemical terms. The required principle of activity, which we found cannot be represented as an independent vital principle, we now find cannot be represented as a principle inherent in living matter. If, by assuming its inherence, we think the facts are accounted for, we do but cheat ourselves with pseud-ideas.

§ 36*e*. What then are we to say – what are we to think? Simply that in this direction, as in all other directions, our explanations finally bring us face to face with the inexplicable. The Ultimate Reality behind this manifestation, as behind all other manifestations, transcends conception. It needs but to observe how even simple forms of existence are in their ultimate natures incomprehensible, to see that this most complex form of existence is in a sense doubly incomprehensible.

For the actions of that which the ignorant contemptuously call brute matter, cannot in the last resort be understood in their genesis. Were it not that familiarity blinds us, the fall of a stone would afford matter for wonder. Neither Newton nor anyone since his day has been able to conceive how the molecules of matter in the stone are affected not only by the molecules of matter in the adjacent part of the Earth but by those forming parts of its mass 8,000 miles off which severally exercise their influence without impediment from intervening molecules; and still less has there been any conceivable interpretation of the mode in which every molecule of matter in the Sun, 92 millions of miles away, has a share in controlling the movements of the Earth. What goes on in the space between a magnet and the piece of iron drawn towards it, or how on repeatedly passing a magnet along a steel needle this, by some change of molecular state as we must suppose, becomes itself a magnet and when balanced places its poles in fixed directions, we do not know. And still less can we fathom the physical process by which an ordered series of electric pulses sent through a telegraph wire may be made to excite a corresponding series of pulses in a parallel wire many miles off.

Turn to another class of cases. Consider the action of a surface of glass struck by a cathode current and which thereupon generates an order of rays able to pass through solid matters impermeable to light. Or contemplate the power possessed by uranium and other metals of emitting rays imperceptible by our eyes as light but which yet, in what appears to us absolute darkness, will, if passed through a camera, produce photographs. Even the actions of one kind of matter on another are sufficiently remarkable. Here is a mass of gold which, after the addition of 1-500th part of bismuth, has only 1-28th of the tensile strength it previously had; and here is a mass of brass, ordinarily ductile and malleable, but which, on the addition of 1-10,000th part of antimony, loses its character. More remarkable still are the influences of certain medicines. One-hundredth of a grain of nitro-glycerine is a sufficient dose. Taking an average man's weight as 150 pounds, it results that his body is appreciably affected in its state by the 115-millionth part of its weight of this nitrogenous compound.

In presence of such powers displayed by matter of simple kinds we shall see how impossible it is even to imagine those processes going on in organic matter out of which emerges the dynamic element in Life. As no separate form of proteid possesses vitality, we seem obliged to assume that the molecule of protoplasm contains many molecules of proteids, probably in various isomeric states, all capable of ready change and therefore producing great instability of the aggregate they form. As before pointed out (§ 4), a proteid-molecule includes more than 220 equivalents of several so-called elements. Each of these undecomposed substances is now recognized by chemists as almost certainly consisting of several kinds of components. Hence the implication is that a proteid-molecule contains thousands of units, of which the different classes have their respective rates of inconceivably rapid oscillation, while each unit, receiving and emitting ethereal undulations, affects others of its kind in its own and adjacent molecules: an immensely complex structure having immensely complex activities. And this complexity, material and dynamic, in the proteid-molecule we must regard as raised to a far higher degree in the unit of protoplasm. Here as elsewhere alternative impossibilities of thought present themselves. We find it impossible to think of Life as imported into the unit of protoplasm from without; and yet we find it impossible to conceive it as emerging from the cooperation of the components.

§ 36*f*. But now, having confessed that Life as a principle of activity is unknown and unknowable – that while its phenomena are accessible to thought the implied noumenon is inaccessible – that only the manifestations come within the range of our intelligence while that which is manifested lies beyond it; we may resume the conclusions reached in the preceding chapters. Our surface knowledge continues to be a knowledge valid of its kind, after recognizing the truth that it is only a surface knowledge.

For the conclusions we lately reached and the definition emerging from them, concern the *order* existing among the actions which living things exhibit; and this order remains the same whether we know or do not know the nature of that from which the actions originate. We found a distinguishing trait of Life to be that its changes display a correspondence with co-existences and sequences in the environment; and this remains a distinguishing trait, though the thing which changes remains inscrutable. The statement that the continuous adjustment of internal relations to external relations constitutes Life as cognizable by us, is not invalidated by the admission that the reality in which these relations inhere is incognizable.

Hence, then, after duly recognizing the fact that, as pointed out above, Life, even phenomenally considered, is not entirely covered by the definition, since there are various abnormal manifestations of life which it does not include, we may safely accept it as covering the normal manifestations – those manifestations which here concern us. Carrying with us the definition, therefore we may hereafter use it for guidance through all those regions of inquiry upon which we now enter.

CHAPTER VII.
THE SCOPE OF BIOLOGY

§ 37. As ordinarily conceived, the science of Biology falls into two great divisions, the one dealing with animal life, called Zoology, and the other dealing with vegetal life, called Botany, or more properly to be called Phytology. But convenient as is this division, it is not that which arises if we follow the scientific method of including in one group all the phenomena of fundamentally the same order and putting separately in another group all the phenomena of a fundamentally different order. For animals and plants are alike in having structures; and animals and plants are alike in having functions performed by these structures; and the distinction between structures and functions transcends the difference between any one structure and any other or between any one function and any other – is, indeed, an absolute distinction, like that between Matter and Motion. Recognizing, then, the logic of the division thus indicated, we must group the parts of Biology thus: —

1. An account of the structural phenomena presented by organisms. This subdivides into: —

a. The established structural phenomena presented by individual organisms.
b. The changing structural phenomena presented by successions of organisms.

2. An account of the functional phenomena which organisms present. This, too, admits of subdivision into: —

a. The established functional phenomena of individual organisms.
b. The changing functional phenomena of successions of organisms.

3. An account of the actions of Structures on Functions and the re-actions of Functions on Structures. Like the others, this is divisible into: —

a. The actions and re-actions as exhibited in individual organisms.
b. The actions and re-actions as exhibited in successions of organisms.

4. An account of the phenomena attending the production of successions of organisms: in other words – the phenomena of Genesis.

Of course, for purposes of exploration and teaching, the division into Zoology and Botany, founded on contrasts so marked and numerous, must always be retained. But here recognizing this familiar distinction only as much as convenience obliges us to do, let us now pass on to consider, more in detail, the classification of biologic phenomena above set down in its leading outlines.

§ 38. The facts of structure shown in an individual organism, are of two chief kinds. In order of conspicuousness, though not in order of time, there come first those arrangements of parts which characterize the mature organism; an account of which, originally called Anatomy, is now called Morphology. Then come those successive modifications through which the organism passes in its progress from the germ to the developed form; an account of which is called Embryology.

The structural changes which any series of individual organisms exhibits, admit of similar classification. On the one hand, we have those inner and outer differences of shape, that arise between the adult members of successive generations descended from a common stock – differences which, though usually not marked between adjacent generations, become great in course of multitudinous generations. On the other hand, we have those developmental modifications, seen in the embryos, through which such modifications of the descended forms are reached.

Interpretation of the structures of individual organisms and successions of organisms, is aided by two subsidiary divisions of biologic inquiry, named Comparative Anatomy (properly Comparative Morphology) and Comparative Embryology. These cannot be regarded as in themselves parts of Biology; since the facts embraced under them are not substantive phenomena, but are simply incidental to substantive phenomena. All the truths of structural Biology are comprehended under the two foregoing subdivisions; and the comparison of these truths as presented in different classes of organisms, is simply a *method* of interpreting them.

Nevertheless, though Comparative Morphology and Comparative Embryology do not disclose additional concrete facts, they lead to the establishment of certain abstract facts. By them it is made manifest that underneath the superficial differences of groups and classes and types of organisms, there are hidden fundamental similarities; and that the courses of development in such groups and classes and types, though in many respects divergent, are in some essential respects, coincident. The wide truths thus disclosed, come under the heads of General Morphology and General Embryology.

By contrasting organisms there is also achieved that grouping of the like and separation of the unlike, called Classification. First by observation of external characters; second by observation of internal characters; and third by observation of the phases of development; it is ascertained what organisms are most similar in all respects; what organisms otherwise unlike are like in important traits; what organisms though apparently unallied have common primordial characters. Whence there results such an arrangement of organisms, that if certain structural attributes of any one be given, its other structural attributes may be *empirically* predicted; and which prepares the way for that interpretation of their relations and genesis, which forms an important part of *rational* Biology.

§ 39. The second main division of Biology, above described as embracing the functional phenomena of organisms, is that which is in part signified by Physiology: the remainder being distinguishable as Objective Psychology. Both of these fall into subdivisions that may best be treated separately.

That part of Physiology which is concerned with the molecular changes going on in organisms, is known as Organic Chemistry. An account of the modes in which the force generated in organisms by chemical change, is transformed into other forces, and made to work the various organs that carry on the functions of Life, comes under the head of Organic Physics. Psychology, which is mainly concerned with the adjustment of vital actions to actions in the environment (in contrast with Physiology, which is mainly concerned with vital actions apart from actions in the environment) consists of two quite distinct portions. Objective Psychology deals with those functions of the nervo-muscular apparatus by which such organisms as possess it are enabled to adjust inner to outer relations; and includes also the study of the same functions as externally manifested in conduct. Subjective Psychology deals with the sensations, perceptions, ideas, emotions, and volitions that are the direct or indirect concomitants of this visible adjustment of inner to outer relations. Consciousness under its different modes and forms, being a subject-matter radically distinct in nature from the subject-matter of Biology in general; and the method of self-analysis, by which alone the laws of dependence among changes of consciousness can be found, being a method unparalleled by anything in the rest of Biology; we are obliged to regard Subjective Psychology as a separate study. And since it would be very inconvenient wholly to dissociate Objective Psychology from Subjective Psychology, we are practically compelled to deal with the two as forming an independent science.

Obviously, the functional phenomena presented in successions of organisms, similarly divide into physiological and psychological. Under the physiological come the modifications of bodily actions that arise in the course of generations, as concomitants of structural modifications; and these may be modifications, qualitative or quantitative, in the molecular changes classed as chemical, or in the organic actions classed as physical, or in both. Under the psychological come the qualitative and quantitative modifications of instincts, feelings, conceptions, and mental processes in general, which occur in creatures having more or less intelligence, when certain of their conditions are changed. This, like the preceding department of Psychology, has in the abstract two different aspects – the objective and the subjective. Practically, however, the objective, which deals with these mental modifications as exhibited in the changing habits and abilities of successive generations of creatures, is the only one admitting of investigation; since the corresponding alterations in consciousness cannot be immediately known to any but the subjects of them. Evidently, convenience requires us to join this part of Psychology along with the other parts as components of a distinct sub-science.

Light is thrown on functions, as well as on structures, by comparing organisms of different kinds. Comparative Physiology and Comparative Psychology, are the names given to those collections of facts respecting the homologies and analogies, bodily and mental, disclosed by this kind of inquiry. These classified observations concerning likenesses and differences of functions, are helpers to interpret functions in their essential natures and relations. Hence Comparative Physiology and Comparative Psychology are names of methods rather than names of true subdivisions of Biology.

Here, however, as before, comparison of special truths, besides facilitating their interpretation, brings to light certain general truths. Contrasting functions bodily and mental as exhibited in various kinds of organisms, shows that there exists, more or less extensively, a community of processes and methods. Hence result two groups of propositions constituting General Physiology and General Psychology.

§ 40. In these divisions and subdivisions of the first two great departments of Biology, facts of Structure are considered separately from facts of Function, so far as separate treatment of them is possible. The third great department of Biology deals with them in their necessary connexions. It comprehends the determination of functions by structures, and the determination of structures by functions.

As displayed in individual organisms, the effects of structures on functions are to be studied, not only in the broad fact that the general kind of life an organism leads is necessitated by the main characters of its organization, but in the more special and less conspicuous fact, that between members of the same species, minor differences of structure lead to minor differences of power to perform certain actions, and of tendencies to perform such actions. Conversely, under the reactions of functions on structures in individual organisms, come the facts showing that functions, when fulfilled to their normal extents, maintain integrity of structure in their respective organs; and that within certain limits increases of functions are followed by such structural changes in their respective organs, as enable them to discharge better their extra functions.

Inquiry into the influence of structure on function as seen in successions of organisms, introduces us to such phenomena as Mr. Darwin's *Origin of Species* deals with. In this category come all proofs of the general truth, that when an individual is enabled by a certain structural peculiarity to perform better than others of its species some advantageous action; and when it bequeaths more or less of its structural peculiarity to descendants, among whom those which have it most markedly are best able to thrive and propagate; there arises a visibly modified type of structure, having a more or less distinct function. In the correlative class of facts (by some asserted and by others denied), which come under the category of reactions of function on structure as exhibited in successions of organisms, are to be placed all those modifications of structure which arise in races, when changes of conditions entail changes in the balance of their functions – when altered function externally necessitated, produces altered structure, and continues doing this through successive generations.

§ 41. The fourth great division of Biology, comprehending the phenomena of Genesis, may be conveniently separated into three subdivisions.

Under the first, comes a description of all the special modes whereby the multiplication of organisms is carried on; which modes range themselves under the two chief heads of sexual and asexual. An account of Sexual Multiplication includes the various processes by which germs and ova are fertilized, and by which, after fertilization, they are furnished with the materials, and maintained in the conditions, needful for their development. An account of Asexual Multiplication includes the various processes by which, from the same fertilized germ or ovum, there are produced many organisms partially or totally independent of one another.

The second of these subdivisions deals with the phenomena of Genesis in the abstract. It takes for its subject-matter such general questions as – What is the end subserved by the union of spermcell and germ-cell? Why cannot all multiplication be carried on after the asexual method? What are the laws of hereditary transmission? What are the causes of variation?

The third subdivision is devoted to still more abstract aspects of the subject. Recognizing the general facts of multiplication, without reference to their modes or immediate causes, it concerns itself simply with the different rates of multiplication in different kinds of organisms and different individuals of the same kind. Generalizing the numerous contrasts and variations of fertility, it seeks a rationale of them in their relations to other organic phenomena.

§ 42. Such appears to be the natural arrangement of divisions and subdivisions which Biology presents. It is, however, a classification of the parts of the science when fully developed; rather than a classification of them as they now stand. Some of the subdivisions above named have no recognized existence, and some of the others are in quite rudimentary states. It is impossible now to fill in, even in the roughest way, more than a part of the outlines here sketched.

Our course of inquiry being thus in great measure determined by the present state of knowledge, we are compelled to follow an order widely different from this ideal one. It will be necessary first to give an account of those empirical generalizations which naturalists and physiologists have established: appending to those which admit of it, such deductive interpretations as *First Principles* furnishes us with. Having done this, we shall be the better prepared for dealing with the leading truths of Biology in connexion with the doctrine of Evolution.

PART II. THE INDUCTIONS OF BIOLOGY

CHAPTER I. GROWTH

§ 43. Perhaps the widest and most familiar induction of Biology, is that organisms grow. While, however, this is a characteristic so uniformly and markedly displayed by plants and animals, as to be carelessly thought peculiar to them, it is really not so. Under appropriate conditions, increase of size takes place in inorganic aggregates, as well as in organic aggregates. Crystals grow; and often far more rapidly than living bodies. Where the requisite materials are supplied in the requisite forms, growth may be witnessed in non-crystalline masses: instance the fungous-like accumulation of carbon that takes place on the wick of an unsnuffed candle. On an immensely larger scale, we have growth in geologic formations: the slow accumulation of deposited sediment into a stratum, is not distinguishable from growth in its widest acceptation. And if we go back to the genesis of celestial bodies, assuming them to have arisen by Evolution, these, too, must have gradually passed into their concrete shapes through processes of growth. Growth is, indeed, as being an integration of matter, the primary trait of Evolution; and if Evolution of one kind or other is universal, growth is universal – universal, that is, in the sense that all aggregates display it in some way at some period.

The essential community of nature between organic growth and inorganic growth, is, however, most clearly seen on observing that they both result in the same way. The segregation of different kinds of detritus from each other, as well as from the water carrying them, and their aggregation into distinct strata, is but an instance of a universal tendency towards the union of like units and the parting of unlike units (*First Principles*, § 163). The deposit of a crystal from a solution is a differentiation of the previously mixed molecules; and an integration of one class of molecules into a solid body, and the other class into a liquid solvent. Is not the growth of an organism an essentially similar process? Around a plant there exist certain elements like the elements which form its substance; and its increase of size is effected by continually integrating these surrounding like elements with itself. Nor does the animal fundamentally differ in this respect from the plant or the crystal. Its food is a portion of the environing matter that contains some compound atoms like some of the compound atoms constituting its tissues; and either through simple imbibition or through digestion, the animal eventually integrates with itself, units like those of which it is built up, and leaves behind the unlike units. To prevent misconception, it may be well to point out that growth, as here defined, must be distinguished from certain apparent and real augmentations of bulk which simulate it. Thus, the long, white potato-shoots thrown out in the dark, are produced at the expense of the substances which the tuber contains: they illustrate not the accumulation of organic matter, but simply its re-composition and re-arrangement. Certain animal-embryos, again, during their early stages, increase considerably in size without assimilating any solids from the environment; and they do this by absorbing the surrounding water. Even in the highest organisms, as in children, there appears sometimes to occur a rapid gain in dimensions which does not truly measure the added quantity of organic matter; but is in part due to changes analogous to those just named. Alterations of this kind must not be confounded with that growth, properly so called, of which we have here to treat.

The next general fact to be noted respecting organic growth, is, that it has limits. Here there appears to be a distinction between organic and inorganic growth; but this distinction is by no means definite. Though that aggregation of inanimate matter which simple attraction produces, may go on without end; yet there appears to be an end to that more definite kind of aggregation which results from polar attraction. Different elements and compounds habitually form crystals more or less unlike in their sizes; and each seems to have a size that is not usually exceeded without a tendency arising to form new crystals rather than to increase the old. On looking at the organic kingdom as a whole, we see that the limits between which growth ranges are very wide apart. At the one extreme we have monads so minute as to be rendered but imperfectly visible by microscopes of the highest power; and at the other extreme we have trees of 400 to 500 feet high and animals of 100 feet long. It is true that though in one sense this contrast may be legitimately drawn, yet in another sense it may not; since these largest organisms arise by the combination of units which are individually like the smallest. A single plant of the genus *Protococcus*, is of the same essential structure as one of the many cells united to form the thallus of some higher Alga, or the leaf of a phænogam. Each separate shoot of a phænogam is usually the bearer of many leaves. And a tree is an assemblage of numerous united shoots. One of these great teleophytes is thus an aggregate of aggregates of aggregates of units, which severally resemble protophytes in their sizes and structures; and a like building up is traceable throughout a considerable part of the animal kingdom. Even, however, when we bear in mind this qualification, and make our comparisons between organisms of the same degree of composition, we still find the limit of growth to have a great range. The smallest branched flowering plant is extremely insignificant by the side of a forest tree; and there is an enormous difference in bulk between the least and the greatest mammal. But on comparing members of the same species, we discover the limit of growth to be much less variable. Among the *Protozoa* and *Protophyta*, each kind has a tolerably constant adult size; and among the most complex organisms the differences between those of the same kind which have reached maturity, are usually not very great. The compound plants do, indeed, sometimes present marked contrasts between stunted and well-grown individuals; but the higher animals diverge but inconsiderably from the average standards of their species.

On surveying the facts with a view of empirically generalizing the causes of these differences, we are soon made aware that by variously combining and conflicting with one another, these causes produce great irregularities of result. It becomes manifest that no one of them can be traced to its consequences, unqualified by the rest. Hence the several statements contained in the following paragraphs must be taken as subject to mutual modification.

Let us consider first the connexion between degree of growth and complexity of structure. This connexion, being involved with many others, becomes apparent only on so averaging the comparisons as to eliminate differences among the rest. Nor does it hold at all where the conditions are radically dissimilar, as between plants and animals. But bearing in mind these qualifications, we shall see that organization has a determining influence on increase of mass. Of plants the lowest, classed as Thallophytes, usually attain no considerable size. Algæ, Fungi, and the Lichens formed by association of them count among their numbers but few bulky species: the largest, such as certain Algæ found in antarctic seas, not serving greatly to raise the average; and these gigantic seaweeds possess a considerable complexity of histological organization very markedly exceeding that of their smaller allies. Though among Bryophytes and Pteridophytes there are some, as the Tree-ferns, which attain a considerable height, the majority are but of humble growth. The Monocotyledons, including at one extreme small grasses and at the other tall palms, show us an average and a maximum greater than that reached by the Pteridophytes. And the Monocotyledons are exceeded by the Dicotyledons; among which are found the monarchs of the vegetal kingdom. Passing to animals, we meet the fact that the size attained by *Vertebrata* is usually much greater than the size attained by *Invertebrata*. Of invertebrate animals the smallest, classed as *Protozoa*, are also the simplest; and the largest, belonging to the *Annulosa* and *Mollusca*, are among the most complex of their respective types. Of vertebrate animals we see that the greatest are Mammals, and that though, in past epochs, there were Reptiles of vast bulks, their bulks did not equal that of the whale: the great Dinosaurs, though as long, being nothing like as massive. Between reptiles and birds, and between land-vertebrates and water-vertebrates, the relation does not hold: the conditions of existence being in these cases widely different. But among fishes as a class, and among reptiles as a class, it is observable that, speaking generally, the larger species are framed on the higher types. The critical reader, who has mentally checked these statements in passing them, has doubtless already seen that this relation is not a dependence of organization on growth but a dependence of growth on organization. The majority of Dicotyledons are smaller than some Monocotyledons; many Monocotyledons are exceeded in size by certain Pteridophytes; and even among Thallophytes, the least developed among compound plants, there are kinds of a size which many plants of the highest order do not reach. Similarly among animals. There are plenty of Crustaceans less than *Actiniæ*; numerous reptiles are smaller than some fish; the majority of mammals are inferior in bulk to the largest reptiles; and in the contrast between a mouse and a well-grown *Medusa*, we see a creature that is elevated in type of structure exceeded in mass by one that is extremely low. Clearly then, it cannot be held that high organization is habitually accompanied by great size. The proposition here illustrated is the converse one, that great size is habitually accompanied by high organization. The conspicuous facts that the largest species of both animals and vegetals belong to the highest classes, and that throughout their various sub-classes the higher usually contain the more bulky forms, show this connexion as clearly as we can expect it to be shown, amid so many modifying causes and conditions.

The relation between growth and supply of available nutriment, is too familiar a relation to need proving. There are, however, some aspects of it that must be contemplated before its implications can be fully appreciated. Among plants, which are all constantly in contact with the gaseous, liquid, and solid matters to be incorporated with their tissues, and which, in the same locality, receive not very unlike amounts of light and heat, differences in the supplies of available nutriment have but a subordinate connexion with differences of growth. Though in a cluster of herbs springing up from the seeds let fall by a parent, the greater sizes of some than of others is doubtless due to better nutrition, consequent on accidental advantages; yet no such interpretation can be given of the contrast in size between these herbs and an adjacent tree. Other conditions here come into play: one of the most important being, an absence in the one case, and presence in the other, of an ability to secrete such a quantity of ligneous fibre as will produce a stem capable of supporting a large growth. Among animals, however, which (excepting some *Entozoa*) differ from plants in this, that instead of bathing their surfaces the matters they subsist on are dispersed, and have to be obtained, the relation between available food and growth is shown with more regularity. The *Protozoa*, living on microscopic fragments of organic matter contained in the surrounding water, are unable, during their brief lives, to accumulate any considerable quantity of nutriment. *Polyzoa*, having for food these scarcely visible members of the animal kingdom, are, though large compared with their prey, small as measured by other standards; even when aggregated into groups of many individuals, which severally catch food for the common weal, they are often so inconspicuous as readily to be passed over by the unobservant. And if from this point upwards we survey the successive grades of animals, it becomes manifest that, in proportion as the size is great, the masses of nutriment are either large, or, what is practically the same thing, are so abundant and so grouped that large quantities may be readily taken in. Though, for example, the greatest of mammals, the arctic whale, feeds on such comparatively small creatures as the acalephes and molluscs floating in the seas it inhabits, its method of gulping in whole shoals of them and filtering away the accompanying water, enables it to secure great quantities of food. We may then with safety say that, other things equal, the growth of an animal depends on the abundance and sizes of the masses of nutriment which its powers enable it to appropriate. Perhaps it may be needful to add that, in interpreting this statement, the proportion of competitors must be taken into account. Clearly, not the absolute, but the relative, abundance of fit food is the point; and this relative abundance very much depends on the number of individuals competing for the food. Thus all who have had experience in fishing in Highland lochs, know that where the trout are numerous they are small, and that where they are comparatively large they are comparatively few.

What is the relation between growth and expenditure of energy? is a question which next presents itself. Though there is reason to believe such a relation exists, it is not very readily traced: involved as it is with so many other relations. Some contrasts, however, may be pointed out that appear to give evidence of it. Passing over the vegetal kingdom, throughout which the expenditure of force is too small to allow of such a relation being visible, let us seek in the animal kingdom, some case where classes otherwise allied, are contrasted in their locomotive activities. Let us compare birds on the one hand, with reptiles and mammals on the other. It is an accepted doctrine that birds are organized on a type closely allied to the reptilian type, but superior to it; and though in some respects the organization of birds is inferior to that of mammals, yet in other respects, as in the greater heterogeneity and integration of the skeleton, the more complex development of the respiratory system, and the higher temperature of the blood, it may be held that birds stand above mammals. Hence were growth dependent only on organization, we might infer that the limit of growth among birds should not be much short of that among mammals; and that the bird-type should admit of a larger growth than the reptile-type. Again, we see no manifest disadvantages under which birds labour in obtaining food, but from which reptiles and mammals are free. On the contrary, birds are able to get at food that is fixed beyond the reach of reptiles and mammals; and can catch food that is too swift of movement to be ordinarily caught by reptiles and mammals. Nevertheless, the limit of growth in birds falls far below that reached by reptiles and mammals. With what other contrast between these classes, is this contrast connected? May we not suspect that it is connected (partially though not wholly) with the contrast between their amounts of locomotive exertion? Whereas mammals (excepting bats, which are small), are during all their movements supported by solid surfaces or dense liquids; and whereas reptiles (excepting the ancient pterodactyles, which were not very large), are similarly restricted in their spheres of movement; the majority of birds move more or less habitually through a rare medium, in which they cannot support themselves without relatively great efforts. And this general fact may be joined with the special fact, that those members of the class *Aves*, as the *Dinornis* and *Epiornis*, which approached in size to the larger *Mammalia* and *Reptilia*, were creatures incapable of flight – creatures which did not expend this excess of force in locomotion. But as implied above, and as will presently be shown, another factor of importance comes into play; so that perhaps the safest evidence that there is an antagonism between the increase of bulk and the quantity of motion evolved is that supplied by the general experience, that human beings and domestic animals, when overworked while growing, are prevented from attaining the ordinary dimensions.

One other general truth concerning degrees of growth, must be set down. It is a rule, having exceptions of no great importance, that large organisms commence their separate existences as masses of organic matter more or less considerable in size, and commonly with organizations more or less advanced; and that throughout each organic sub-kingdom, there is a certain general, though irregular, relation between the initial and the final bulks. Vegetals exhibit this relation less manifestly than animals. Yet though, among the plants that begin life as minute spores, there are some which, by the aid of an intermediate form, grow to large sizes, the immense majority of them remain small. While, conversely, the great Monocotyledons and Dicotyledons, when thrown off from their parents, have already the formed organs of young plants, to which are attached stores of highly nutritive matter. That is to say, where the young plant consists merely of a centre of development, the ultimate growth is commonly insignificant; but where the growth is to become great, there exists to start with, a developed embryo and a stock of assimilable matter. Throughout the animal kingdom this relation is tolerably manifest though by no means uniform. Save among classes that escape the ordinary requirements of animal life, small germs or eggs do not in most cases give rise to bulky creatures. Where great bulk is to be reached, the young proceeds from an egg of considerable bulk, or is born of considerable bulk ready-organized and partially active. In the class Fishes, or in such of them as are subject to similar conditions of life, some proportion usually obtains between the sizes of the ova and the sizes of the adult individuals; though in the cases of the sturgeon and the tunny there are exceptions, probably determined by the circumstances of oviposition and those of juvenile life. Reptiles have eggs that are smaller in number, and relatively greater in mass, than those of fishes; and throughout this class, too, there is a general congruity between the bulk of the egg and the bulk of the adult creature. As a group, birds show us further limitations in the numbers of their eggs as well as farther increase in their relative sizes; and from the minute eggs of the humming-bird up to the immense ones of the *Epiornis*, holding several quarts, we see that, speaking generally, the greater the eggs the greater the birds., Finally, among mammals (omitting the marsupials) the young are born, not only of comparatively large sizes, but with advanced organizations; and throughout this sub-division of the *Vertebrata*, as throughout the others, there is a manifest connexion between the sizes at birth and the sizes at maturity. As having a kindred meaning, there must finally be noted the fact that the young of these highest animals, besides starting in life with bodies of considerable sizes, almost fully organized, are, during subsequent periods of greater or less length, supplied with nutriment – in birds by feeding and in mammals by suckling and afterwards by feeding. So that beyond the mass and organization directly bequeathed, a bird or mammal obtains a further large mass at but little cost to itself.

Were exhaustive treatment of the topic intended, it would be needful to give a paragraph to each of the incidental circumstances by which growth may be aided or restricted: – such facts as that an entozoon is limited by the size of the creature, or even the organ, in which it thrives; that an epizoon, though getting abundant nutriment without appreciable exertion, is restricted to that small bulk at which it escapes ready detection by the animal it infests; that sometimes, as in the weazel, smallness is a condition to successful pursuit of the animals preyed upon; and that in some cases, the advantage of resembling certain other creatures, and so deceiving enemies or prey, becomes an indirect cause of restricted size. But the present purpose is simply to set down those most general relations between growth and other organic traits, which induction leads us to. Having done this, let us go on to inquire whether these general relations can be deductively established.

§ 44. That there must exist a certain dependence of growth on organization, may be shown *a priori*. When we consider the phenomena of Life, either by themselves or in their relations to surrounding phenomena, we see that, other things equal, the larger the aggregate the greater is the needful complexity of structure.

In plants, even of the highest type, there is a comparatively small mutual dependence of parts: a gathered flower-bud will unfold and flourish for days if its stem be immersed in water; and a shoot cut off from its parent-tree and stuck in the ground will grow. The respective parts having vital activities that are not widely unlike, it is possible for great bulk to be reached without that structural complexity required for combining the actions of parts. Even here, however, we see that for the attainment of great bulk there requires such a degree of organization as shall co-ordinate the functions of roots and branches – we see that such a size as is reached by trees, is not possible without a vascular system enabling the remote organs to utilize each other's products. And we see that such a co-existence of large growth with comparatively low organization as occurs in some of the marine *Algæ*, occurs where the conditions of existence do not necessitate any considerable mutual dependence of parts – where the near approach of the plant to its medium in specific gravity precludes the need of a well-developed stem, and where all the materials of growth being derived from the water by each portion of the thallus, there requires no apparatus for transferring the crude food materials from part to part. Among animals which, with but few exceptions, are, by the conditions of their existence, required to absorb nutriment through one specialized part of the body, it is clear that there must be a means whereby other parts of the body, to be supported by this nutriment, must have it conveyed to them. It is clear that for an equally efficient maintenance of their nutrition, the parts of a large mass must have a more elaborate propelling and conducting apparatus; and that in proportion as these parts undergo greater waste, a yet higher development of the vascular system is necessitated. Similarly with the prerequisites to those mechanical motions which animals are required to perform. The parts of a mass cannot be made to move, and have their movements so co-ordinated as to produce locomotive and other actions, without certain structural arrangements; and, other things equal, a given amount of such activity requires more involved structural arrangements in a large mass than in a small one. There must at least be a co-ordinating apparatus presenting greater contrasts in its central and peripheral parts.

The qualified dependence of growth on organization, is equally implied when we study it in connexion with that adjustment of inner to outer relations which constitutes Life as phenomenally known to us. In plants this is less striking than in animals, because the adjustment of inner to outer relations does not involve conspicuous motions. Still, it is visible in the fact that the condition on which alone a plant can grow to a great size, is, that it shall, by the development of a massive trunk, present inner relations of forces fitted to counterbalance those outer relations of forces which tend continually, and others which tend occasionally, to overthrow it; and this formation of a core of regularly-arranged woody fibres is an advance in organization. Throughout the animal kingdom this connexion of phenomena is manifest. To obtain materials for growth; to avoid injuries which interfere with growth; and to escape those enemies which bring growth to a sudden end; implies in the organism the means of fitting its movements to meet numerous external co-existences and sequences – implies such various structural arrangements as shall make possible these variously-adapted actions. It cannot be questioned that, everything else remaining constant, a more complex animal, capable of adjusting its conduct to a greater number of surrounding contingencies, will be the better able to secure food and evade damage, and so to increase bulk. And evidently, without any qualification, we may say that a large animal, living under such complex conditions of existence as everywhere obtain, is not possible without comparatively high organization.

While, then, this relation is traversed and obscured by sundry other relations, it cannot but exist. Deductively we see that it must be modified, as inductively we saw that it is modified, by the circumstances amid which each kind of organism is placed, but that it is always a factor in determining the result.

§ 45. That growth is, *cæteris paribus*, dependent on the supply of assimilable matter, is a proposition so continually illustrated by special experience, as well as so obvious from general experience, that it would scarcely need stating, were it not requisite to notice the qualifications with which it must be taken.

The materials which each organism requires for building itself up, are not of one kind but of several kinds. As a vehicle for transferring matter through their structures, all organisms require water as well as solid constituents; and however abundant the solid constituents there can be no growth in the absence of water. Among the solids supplied, there must be a proportion ranging within certain limits. A plant round which carbonic acid, water, and ammonia exist in the right quantities, may yet be arrested in its growth by a deficiency of potassium. The total absence of lime from its food may stop the formation of a mammal's skeleton: thus dwarfing, if not eventually destroying, the mammal; and this no matter what quantities of other needful colloids and crystalloids are furnished.

Again, the truth that, other things equal, growth varies according to the supply of nutriment, has to be qualified by the condition that the supply shall not exceed the ability to appropriate it. In the vegetal kingdom, the assimilating surface being external and admitting of rapid expansion by the formation of new roots, shoots, and leaves, the effect of this limitation is not conspicuous. By artificially supplying plants with those materials which they have usually the most difficulty in obtaining, we can greatly facilitate their growth; and so can produce striking differences of size in the same species. Even here, however, the effect is confined within the limits of the ability to appropriate; since in the absence of that solar light and heat by the help of which the chief appropriation is carried on, the additional materials for growth are useless. In the animal kingdom this restriction is rigorous. The absorbent surface being, in the great majority of cases, internal; having a comparatively small area, which cannot be greatly enlarged without reconstruction of the whole body; and being in connexion with a vascular system which also must be re-constructed before any considerable increase of nutriment can be made available; it is clear that beyond a certain point, very soon reached, increase of nutriment will not cause increase of growth. On the contrary, if the quantity of food taken in is greatly beyond the digestive and absorbent power, the excess, becoming an obstacle to the regular working of the organism, may retard growth rather than advance it.

While then it is certain, *a priori*, that there cannot be growth in the absence of such substances as those of which an organism consists; and while it is equally certain that the amount of growth must primarily be governed by the supply of these substances; it is not less certain that extra supply will not produce extra growth, beyond a point very soon reached. Deduction shows to be necessary, as induction makes familiar, the truths that the value of food for purposes of growth depends not on the quantity of the various organizable materials it contains, but on the quantity of the material most needed; that given a right proportion of materials, the pre-existing structure of the organism limits their availability; and that the higher the structure, the sooner is this limit reached.

§ 46. But why should the growth of every organism be finally arrested? Though the rate of increase may, in each case, be necessarily restricted within a narrow range of variation – though the increment that is possible in a given time, cannot exceed a certain amount; yet why should the increments decrease and finally become insensible? Why should not all organisms, when supplied with sufficient materials, continue to grow as long as they live? To find an answer to this question we must revert to the nature and functions of organic matter.

In the first three chapters of Part I, it was shown that plants and animals mainly consist of substances in states of unstable equilibrium – substances which have been raised to this unstable equilibrium by the expenditure of the forces we know as solar radiations, and which give out these forces in other forms on falling into states of stable equilibrium. Leaving out the water, which serves as a vehicle for these materials and a medium for their changes; and excluding those mineral matters that play either passive or subsidiary parts; organisms are built up of compounds which are stores of force. Thus complex colloids and crystalloids which, as united together, form organized bodies, are the same colloids and crystalloids which give out, on their decomposition, the forces expended by organized bodies. Thus these nitrogenous and carbonaceous substances, being at once the materials for organic growth and the sources of organic energy, it results that as much of them as is used up for the genesis of energy is taken away from the means of growth, and as much as is economized by diminishing the genesis of energy, is available for growth. Given that limited quantity of nutritive matter which the pre-existing structure of an organism enables it to absorb; and it is a necessary corollary from the persistence of force, that the matter accumulated as growth cannot exceed that surplus which remains undecomposed after the production of the required amounts of sensible and insensible motion. This, which would be rigorously true under all conditions if exactly the same substances were used in exactly the same proportions for the production of force and for the formation of tissue, requires, however, to be taken with the qualification that some of the force-evolving substances are not constituents of tissue; and that thus there may be a genesis of force which is not at the expense of potential growth. But since organisms (or at least animal organisms, with which we are here chiefly concerned) have a certain power of selective absorption, which, partially in an individual and more completely in a race, adapts the proportions of the substances absorbed to the needs of the system; then if a certain habitual expenditure of force leads to a certain habitual absorption of force-evolving matters that are not available for growth; and if, were there less need for such matters, the ability to absorb matters available for growth would be increased to an equivalent extent; it follows that the antagonism described does, in the long run, hold even without this qualification. Hence, growth is substantially equivalent to the absorbed nutriment, minus the nutriment used up in action.

This, however, is no answer to the question – why has individual growth a limit? – why do the increments of growth bear decreasing ratios to the mass and finally come to an end? The question is involved. There are more causes than one why the excess of absorbed nutriment over expended nutriment must, other things equal, become less as the size of the animal becomes greater.

In similarly-shaped bodies the masses, and therefore the weights, vary as the cubes of the dimensions; whereas the powers of bearing the stresses imposed by the weights vary as the squares of the dimensions. Suppose a creature which a year ago was one foot high, has now become two feet high, while it is unchanged in proportions and structure; what are the necessary concomitant changes? It is eight times as heavy; that is to say, it has to resist eight times the strain which gravitation puts upon certain of its parts; and when there occurs sudden arrest of motion or sudden genesis of motion, eight times the strain is put upon the muscles employed. Meanwhile the muscles and bones have severally increased their abilities to bear strains in proportion to the areas of their transverse sections, and hence have severally only four times the tenacity they had. This relative decrease in the power of bearing stress does not imply a relative decrease in the power of generating energy and moving the body; for in the case supposed the muscles have not only increased four times in their transverse sections but have become twice as long, and will therefore generate an amount of energy proportionate to their bulk. The implication is simply that each muscle has only half the power to withstand those shocks and strains which the creature's movements entail; and that consequently the creature must be either less able to bear these, or must have muscles and bones having relatively greater transverse dimensions: the result being that greater cost of nutrition is inevitably caused and therefore a correlative tendency to limit growth. This necessity will be seen still more clearly if we leave out the motor apparatus, and consider only the forces required and the means of supplying them. For since, in similar bodies, the areas vary as the squares of the dimensions, and the masses vary as the cubes; it follows that the absorbing surface has become four times as great, while the weight to be moved by the matter absorbed has become eight times as great. If then, a year ago, the absorbing surface could take up twice as much nutriment as was needed for expenditure, thus leaving one-half for growth, it is now able only just to meet expenditure, and can provide nothing for growth. However great the excess of assimilation over waste may be during the early life of an active organism, we see that because a series of numbers increasing as the cubes, overtakes a series increasing as the squares, even though starting from a much smaller number, there must be reached, if the organism lives long enough, a point at which the surplus assimilation is brought down to nothing – a point at which expenditure balances nutrition – a state of moving equilibrium. The only way in which the difficulty can be met is by gradual re-organization of the alimentary system; and, in the first place, this entails direct cost upon the organism, and, in the second place, indirect cost from the carrying of greater weight: both tending towards limitation. There are two other varying relations between degrees of growth and amounts of expended force; one of which conspires with the last, while the other conflicts with it. Consider, in the first place, the cost at which nutriment is distributed through the body and effete matters removed from it. Each increment of growth being added at the periphery of the organism, the force expended in the transfer of matter must increase in a rapid progression – a progression more rapid than that of the mass. But as the dynamic expense of distribution is small compared with the dynamic value of the materials distributed, this item in the calculation is unimportant. Now consider, in the second place, the changing proportion between production and loss of heat. In similar organisms the quantities of heat generated by similar actions going on throughout their substance, must increase as the masses, or as the cubes of the dimensions. Meanwhile, the surfaces from which loss of heat takes place, increase only as the squares of the dimensions. Though the loss of heat does not therefore increase only as the squares of the dimensions, it certainly increases at a smaller rate than the cubes. And to the extent that augmentation of mass results in a greater retention of heat, it effects an economization of force. This advantage is not, however, so important as at first appears. Organic heat is a concomitant of organic action, and is so abundantly produced during action that the loss of it is then usually of no consequence: indeed the loss is often not rapid enough to keep the supply from rising to an inconvenient excess. It is chiefly in respect of that maintenance of heat which is needful during quiescence, that large organisms have an advantage over small ones in this relatively diminished loss. Thus these two subsidiary relations between degrees of growth and amounts of expended force, being in antagonism, we may conclude that their differential result does not greatly modify the result of the chief relation.

Comparisons of these deductions with the facts appear in some cases to verify them and in other cases not to do so. Throughout the vegetal kingdom, there are no distinct limits to growth except those which death entails. Passing over a large proportion of plants which never exceed a comparatively small size, because they wholly or partially die down at the end of the year, and looking only at trees that annually send forth new shoots, even when their trunks are hollowed by decay; we may ask – How does growth happen here to be unlimited? The answer is, that plants are only accumulators: they are in no very appreciable degree expenders. As they do not undergo waste there is no reason why their growth should be arrested by the equilibration of assimilation and waste. Again, among animals there are sufficient reasons why the correspondence cannot be more than approximate. Besides the fact above noted, that there are other varying relations which complicate the chief one. We must bear in mind that the bodies compared are not truly similar: the proportions of trunk to limbs and trunk to head, vary considerably. The comparison is still more seriously vitiated by the inconstant ratio between the constituents of which the body is composed. In the flesh of adult mammalia, water forms from 68 to 71 per cent., organic substance from 24 to 28 per cent., and inorganic substance from 3 to 5 per cent.; whereas in the fœtal state, the water amounts to 87 per cent., and the solid organic constituents to only 11 per cent. Clearly this change from a state in which the force-evolving matter forms one-tenth of the whole, to a state in which it forms two and a half tenths, must greatly interfere with the parallelism between the actual and the theoretical progression. Yet another difficulty may come under notice. The crocodile is said to grow as long as it lives; and there appears reason to think that some predaceous fishes, such as the pike, do the same. That these animals of comparatively high organization have no definite limits of growth, is, however, an exceptional fact due to the exceptional non-fulfilment of those conditions which entail limitation. What kind of life does a crocodile lead? It is a cold-blooded, or almost cold-blooded, creature; that is, it expends very little for the maintenance of heat. It is habitually inert: not usually chasing prey but lying in wait for it; and undergoes considerable exertion only during its occasional brief contests with prey. Such other exertion as is, at intervals, needful for moving from place to place, is rendered small by the small difference between the animal's specific gravity and that of water. Thus the crocodile expends in muscular action an amount of force that is insignificant compared with the force commonly expended by land-animals. Hence its habitual assimilation is diminished much less than usual by habitual waste; and beginning with an excessive disproportion between the two, it is quite possible for the one never quite to lose its advance over the other while life continues. On looking closer into such cases as this and that of the pike, which is similarly cold-blooded, similarly lies in wait, and is similarly able to obtain larger and larger kinds of prey as it increases in size; we discover a further reason for this absence of a definite limit. To overcome gravitative force the creature has not to expend a muscular power that is large at the outset, and increases as the cubes of its dimensions: its dense medium supports it. The exceptional continuance of growth observed in creatures so circumstanced, is therefore perfectly explicable.

§ 46*a*. If we go back upon the conclusions set forth in the preceding section, we find that from some of them may be drawn instructive corollaries respecting the limiting sizes of creatures inhabiting different media. More especially I refer to those varying proportions between mass and stress from which, as we have seen, there results, along with increasing size, a diminishing power of mechanical self-support: a relation illustrated in its simplest form by the contrast between a dew-drop, which can retain its spheroidal form, and the spread-out mass of water which results when many dew-drops run together. The largest bird that flies (the argument excludes birds which do not fly) is the Condor, which reaches a weight of from 30 to 40 lbs. Why does there not exist a bird of the size of an elephant? Supposing its habits to be carnivorous, it would have many advantages in obtaining prey: mammals would be at its mercy. Evidently the reason is one which has been pointed out – the reason that while the weight to be raised and kept in the air by a bird increases as the cubes of its dimensions, the ability of its bones and muscles to resist the strains which flight necessitates, increases only as the squares of the dimensions. Though, could the muscles withstand any tensile strain they were subject to, the power like the weight might increase with the cubes, yet since the texture of muscle is such that beyond a certain strain it tears, it results that there is soon reached a size at which flight becomes impossible: the structures must give way. In a preceding paragraph the limit to the size of flying creatures was ascribed to the greater physiological cost of the energy required; but it seems probable that the mechanical obstacle here pointed out has a larger share in determining the limit.

In a kindred manner there results a limitation of growth in a land-animal, which does not exist for an animal living in the water. If, after comparing the agile movements of a dog with those of a cow, the great weight of which obviously prevents agility; or if, after observing the swaying flesh of an elephant as it walks along, we consider what would happen could there be formed a land-animal equal in mass to the whale (the long Dinosaurs were not proportionately massive) it needs no argument to show that such a creature could not stand, much less move about. But in the water the strain put upon its structures by the weights of its various parts is almost if not quite taken away. Probably limitation in the quantity of food obtainable becomes now the chief, if not the sole, restraint.

And here we may note, before leaving the topic, something like a converse influence which comes into play among creatures inhabiting the water. Up to the point at which muscles tear from over-strain, larger and smaller creatures otherwise alike, remain upon a par in respect of the relative amounts of energy they can evolve. Had they to encounter no resistance from their medium, the implication would be that neither would have an advantage over the other in respect of speed. But resistance of the medium comes into play; and this, other things equal, gives to the larger creature an advantage. It has been found, experimentally, that the forces to be overcome by vessels moving through the water, built as they are with immersed hinder parts which taper as fish taper, are mainly due to what is called "skin-friction." Now in two fish unlike in size but otherwise similar skin-friction bears to the energy that can be generated, a smaller proportion in the larger than in the smaller; and the larger can therefore acquire a greater velocity. Hence the reason why large fish, such as the shark, become possible. In a habitat where there is no ambush (save in exceptional cases like that of the *Lophius* or Angler) everything depends on speed; and if, other things equal, a larger fish had no mechanical advantage over a smaller, a larger fish could not exist – could not catch the requisite amount of prey.

§ 47. Obviously this antagonism between accumulation and expenditure, must be a leading cause of the contrasts in size between allied organisms that are in many respects similarly conditioned. The life followed by each kind of animal is one involving a certain average amount of exertion for the obtainment of a given amount of nutriment – an exertion, part of which goes to the gathering or catching of food, part to the tearing and mastication of it, and part to the after-processes requisite for separating the nutritive molecules – an exertion which therefore varies according as the food is abundant or scarce, fixed or moving, according as it is mechanically easy or difficult to deal with when secured, and according as it is, or is not, readily soluble. Hence, while among animals of the same species having the same mode of life, there will be a tolerably constant ratio between accumulation and expenditure, and therefore a tolerably constant limit of growth, there is every reason to expect that different species, following different modes of life, will have unlike ratios between accumulation and expenditure, and therefore unlike limits of growth.

Though the facts as inductively established, show a general harmony with this deduction, we cannot usually trace it in any specific way; since the conflicting and conspiring factors which affect growth are so numerous.

§ 48. One of the chief causes, if not the chief cause, of the differences between the sizes of organisms, has yet to be considered. We are introduced to it by pushing the above inquiry a little further. Small animals have been shown to possess an advantage over large ones in the greater ratio which, other things equal, assimilation bears to expenditure; and we have seen that hence small animals in becoming large ones, gradually lose that surplus of assimilative power which they had, and eventually cannot assimilate more than is required to balance waste. But how come these animals while young and small to have surplus assimilative powers? Have all animals equal surpluses of assimilative powers? And if not, how far do differences between the surpluses determine differences between the limits of growth? We shall find, in the answers to these questions, the interpretation of many marked contrasts in growth that are not due to any of the causes above assigned. For example, an ox immensely exceeds a sheep in mass. Yet the two live from generation to generation in the same fields, eat the same grass, obtain these aliments with the same small expenditure of energy, and differ scarcely at all in their degrees of organization. Whence arises, then, their striking unlikeness of bulk?

We noted when studying the phenomena of growth inductively, that organisms of the larger and higher types commence their separate existences as masses of organic matter having tolerable magnitudes. Speaking generally, we saw that throughout each organic sub-kingdom the acquirement of great bulk occurs only where the incipient bulk and organization are considerable; and that they are the more considerable in proportion to the complexity of the life which the organism is to lead.

The deductive interpretation of this induction may best be commenced by an analogy. A street orange-vendor makes but a trifling profit on each transaction; and unless more than ordinarily fortunate, he is unable to realize during the day a larger amount than will meet his wants; leaving him to start on the morrow in the same condition as before. The trade of the huxter in ounces of tea and half-pounds of sugar, is one similarly entailing much labour for small returns. Beginning with a capital of a few pounds, he cannot have a shop large enough, or goods sufficiently abundant and various, to permit an extensive business. He must be content with the half-pence and pence which he makes by little sales to poor people; and if, avoiding bad debts, he is able by strict economy to accumulate anything, it can be but a trifle. A large retail trader is obliged to lay out much money in fitting up an adequate establishment; he must invest a still greater sum in stock; and he must have a further floating capital to meet the charges that fall due before his returns come in. Setting out, however, with means enough for these purposes, he is able to make many and large sales; and so to get greater and more numerous increments of profit. Similarly, to get returns in thousands merchants and manufacturers must make their investments in tens of thousands. In brief, the rate at which a man's wealth accumulates is measured by the surplus of income over expenditure; and this, save in exceptionably favourable cases, is determined by the capital with which he begins business. Now applying the analogy, we may trace in the transactions of an organism, the same three ultimate elements. There is the expenditure required for the obtainment and digestion of food; there is the gross return in the shape of nutriment assimilated or fit for assimilation; and there is the difference between this gross return of nutriment and the nutriment that was used up in the labour of securing it – a difference which may be a profit or a loss. Clearly, however, a surplus implies that the force expended is less than the force latent in the assimilated food. Clearly, too, the increment of growth is limited to the amount of this surplus of income over expenditure; so that large growth implies both that the excess of nutrition over waste shall be relatively considerable, and that the waste and nutrition shall be on extensive scales. And clearly, the ability of an organism to expend largely and assimilate largely, so as to make a large surplus, presupposes a large physiological capital in the shape of organic matter more or less developed in its structural arrangements.

Throughout the vegetal kingdom, the illustrations of this truth are not conspicuous and regular: the obvious reason being that since plants are accumulators and in so small a degree expenders, the premises of the above argument are but very partially fulfilled. The food of plants (excepting Fungi and certain parasites) being in great measure the same for all, and bathing all so that it can be absorbed without effort, their vital processes result almost entirely in profit. Once fairly rooted in a fit place, a plant may thus from the outset add a very large proportion of its entire returns to capital; and may soon be able to carry on its processes on a large scale, though it does not at first do so. When, however, plants are expenders, namely, during their germination and first stages of growth, their degrees of growth *are* determined by their amounts of vital capital. It is because the young tree commences life with a ready-formed embryo and store of food sufficient to last for some time, that it is enabled to strike root and lift its head above the surrounding herbage. Throughout the animal kingdom, however, the necessity of this relation is everywhere obvious. The small carnivore preying on small herbivores, can increase in size only by small increments: its organization unfitting it to digest larger creatures, even if it can kill them, it cannot profit by amounts of nutriment exceeding a narrow limit; and its possible increments of growth being small to set out with, and rapidly decreasing, must come to an end before any considerable size is attained. Manifestly the young lion, born of tolerable bulk, suckled until much bigger, and fed until half-grown, is enabled by the power and organization which he thus gets *gratis*, to catch and kill animals big enough to give him the supply of nutriment needed to meet his large expenditure and yet leave a large surplus for growth. Thus, then, is explained the above-named contrast between the ox and the sheep. A calf and a lamb commence their physiological transactions on widely different scales; their first increments of growth are similarly contrasted in their amounts; and the two diminishing series of such increments end at similarly-contrasted limits.

§ 49. Such are the several conditions by which the phenomena of growth are determined. Conspiring and conflicting in endless unlike ways and degrees, they in every case qualify more or less differently each other's effects. Hence it happens that we are obliged to state each generalization as true on the average, or to make the proviso – other things equal.

Understood in this qualified form, our conclusions are these. First, that growth being an integration with the organism of such environing matters as are of like natures with the matters composing the organism, its growth is dependent on the available supply of them. Second, that the available supply of assimilable matter being the same, and other conditions not dissimilar, the degree of growth varies according to the surplus of nutrition over expenditure – a generalization which is illustrated in some of the broader contrasts between different divisions of organisms. Third, that in the same organism the surplus of nutrition over expenditure differs at different stages; and that growth is unlimited or has a definite limit, according as the surplus does or does not rapidly decrease. This proposition we found exemplified by the almost unceasing growth of organisms that expend relatively little energy; and by the definitely limited growth of organisms that expend much energy. Fourth, that among organisms which are large expenders of force, the size ultimately attained is, other things equal, determined by the initial size: in proof of which conclusion we have abundant facts, as well as the *a priori* necessity that the sum-totals of analogous diminishing series, must depend upon the amounts of their initial terms. Fifth, that where the likeness of other circumstances permits a comparison, the possible extent of growth depends on the degree of organization; an inference testified to by the larger forms among the various divisions and sub-divisions of organisms.

CHAPTER II. DEVELOPMENT.[19]

§ 50. Certain general aspects of Development may be studied apart from any examination of internal structures. These fundamental contrasts between the modes of arrangement of parts, originating, as they do, the leading external distinctions among the various forms of organization, will be best dealt with at the outset. If all organisms have arisen by Evolution, it is of course not to be expected that such several modes of development can be absolutely demarcated: we are sure to find them united by transitional modes. But premising that a classification of modes can but approximately represent the facts, we shall find our general conceptions of Development aided by one.

Development is primarily *central*. All organic forms of which the entire history is known, set out with a symmetrical arrangement of parts round a centre. In organisms of the lowest grade no other mode of arrangement is ever definitely established; and in the highest organisms central development, though subordinate to another mode of development, continues to be habitually shown in the changes of minute structure. Let us glance at these propositions in the concrete. Practically every plant and every animal in its earliest stage is a portion of protoplasm, in the great majority of cases approximately spherical but sometimes elongated, containing a rounded body consisting of specially modified protoplasm, which is called a nucleus; and the first changes that occur in the germ thus constituted, are changes that take place in this nucleus, followed by changes round the centres produced by division of this original centre. From this type of structure, the simplest organisms do not depart; or depart in no definite or conspicuous ways. Among plants, many of the simplest *Algæ* and *Fungi* permanently maintain such a central distribution; while among animals it is permanently maintained by creatures like the *Gregarina*, and in a different manner by the *Amœba*, *Actinophrys*, and their allies: the irregularities which are many and great do not destroy this general relation of parts. In larger organisms, made up chiefly of units that are analogous to these simplest organisms, the formation of units ever continues to take place round nuclei; though usually the nuclei soon cease to be centrally placed.

Central development may be distinguished into *unicentral* and *multicentral*; according as the product of the original germ develops more or less symmetrically round one centre, or develops without subordination to one centre – develops, that is, in subordination to many centres. Unicentral development, as displayed not in the formation of single cells but in the formation of aggregates, is not common. The animal kingdom shows it only in some of the small group of colonial *Radiolaria*. It is feebly represented in the vegetal kingdom by a few members of the *Volvocineæ*. On the other hand, multicentral development, or development round insubordinate centres, is variously exemplified in both divisions of the organic world. It is exemplified in two distinct ways, according as the insubordination among the centres of development is partial or total. We may most conveniently consider it under the heads hence arising.

Total insubordination among the centres of development, is shown where the units or cells, as fast as they are severally formed, part company and lead independent lives. This, in the vegetal kingdom, habitually occurs among the *Protophyta*, and in the animal kingdom, among the *Protozoa*. Partial insubordination is seen in those somewhat advanced organisms, that consist of units which, though they have not separated, have so little mutual dependence that the aggregate they form is irregular. Among plants, the Thallophytes very generally exemplify this mode of development. Lichens, spreading with flat or corrugated edges in this or that direction as the conditions determine,

[19] In ordinary speech Development is often used as synonymous with Growth. It hence seems needful to say that Development as here and hereafter used, means *increase of structure* and not *increase of bulk*. It may be added that the word Evolution, comprehending growth as well as Development, is to be reserved for occasions when both are implied.

have no manifest co-ordination of parts. In the *Algæ* the Nostocs and various other forms similarly show us an unsymmetrical structure. Of *Fungi* we may say that creeping kinds display no further dependence of one part on another than is implied by their cohesion. And even in such better-organized plants as the *Marchantia*, the general arrangement shows no reference to a directive centre. Among animals many of the Sponges in their adult forms may be cited as devoid of that co-ordination implied by symmetry: the units composing them, though they have some subordination to local centres, have no subordination to a general centre. To distinguish that kind of development in which the whole product of a germ coheres in one mass, from that kind of development in which it does not, Professor Huxley has introduced the words "*continuous*" and "*discontinuous*;" and these seem the best fitted for the purpose. Multicentral development, then, is divisible into continuous and discontinuous.

From central development we pass insensibly to that higher kind of development for which *axial* seems the most appropriate name. A tendency towards this is vaguely manifested almost everywhere. The great majority even of *Protophyta* and *Protozoa* have different longitudinal and transverse dimensions – have an obscure if not a distinct axial structure. The originally spheroidal and polyhedral units out of which higher organisms are mainly built, usually pass into shapes that are subordinated to lines rather than to points. And in the higher organisms, considered as wholes, an arrangement of parts in relation to an axis is distinct and nearly universal. We see it in the superior orders of Thallophytes; and in all the cormophytic plants. With few exceptions the *Cœlenterata* clearly exhibit it; it is traceable, though less conspicuously, throughout the *Mollusca*; and the *Annelida*, *Arthropoda*, and *Vertebrata* uniformly show it with perfect definiteness.

This kind of development, like the first kind, is of two orders. The whole germ-product may arrange itself round a single axis, or it may arrange itself round many axes: the structure may be *uniaxial* or *multiaxial*. Each division of the organic kingdom furnishes examples of both these orders. In such *Fungi* as exhibit axial development at all, we commonly see development round a single axis. Some of the *Algæ*, as the common tangle, show us this arrangement. And of the higher plants, many Monocotyledons and small Dicotyledons are uniaxial. Of animals, the advanced are without exception in this category. There is no known vertebrate in which the whole of the germ-product is not subordinated to a single axis. In the *Arthropoda*, the like is universal; as it is also in the superior orders of *Mollusca*. Multiaxial development occurs in most of the plants we are familiar with – every branch of a shrub or tree being an independent axis. But while in the vegetal kingdom multiaxial development prevails among the highest types, in the animal kingdom it prevails only among the lowest types. It is extremely general, if not universal, among the *Cœlenterata*; it is characteristic of the *Polyzoa*; the compound Ascidians exhibit it; and it is seen, though under another form, in certain of the inferior Annelids.

Development that is axial, like development that is central, may be either continuous or discontinuous: the parts having different axes may continue united, or they may separate. Instances of each alternative are supplied by both plants and animals. Continuous multiaxial development is that which plants usually display, and need not be illustrated further than by reference to every garden. As cases of it in animals may be named all the compound *Hydrozoa* and *Actinozoa*; and such ascidian forms as the *Botryllidæ*. Of multiaxial development that is discontinuous, a familiar instance among plants exists in the common strawberry. This sends out over the neighbouring surface, long slender shoots, bearing at their extremities buds that presently strike roots and become new individuals; and these by and by lose their connexions with the original axis. Other plants there are that produce certain specialized buds called bulbils, which separating themselves and falling to the ground, grow into independent plants. Among animals the fresh-water polype very clearly shows this mode of development: the young polypes, budding out from its surface, severally arrange their parts around distinct axes, and eventually detaching themselves, lead separate lives, and produce other polypes after the same fashion. By some of the lower *Annelida*, this multiplication of axes from an original axis, is carried on after a different manner: the string of segments spontaneously divides; and after further growth, division recurs in one or both of the halves. Moreover in the *Syllis ramosa*, there occurs lateral branching also.

Grouping together its several modes as above delineated, we see that

DEVELOPMENT is
- Central
  - Unicentral or Multicentral
    - Continuous or Discontinuous
- or
- Axial
  - Uniaxial or Multiaxial
    - Continuous or Discontinuous

Any one well acquainted with the facts, may readily raise objections to this arrangement. He may name forms which do not obviously come under any of these heads. He may point to plants that are for a time multicentral but afterwards develop axially. And from lower types of animals he may choose many in which the continuous and discontinuous modes are both displayed. But, as already hinted, an arrangement free from such anomalies must be impossible, if the various kinds of organization have arisen by Evolution. The one above sketched out is to be regarded as a rough grouping of the facts, which helps us to a conception of them in their totality; and, so regarded, it will be of service when we come to treat of Individuality and Reproduction.

§ 51. From these most general external aspects of organic development, let us now turn to its internal and more special aspects. When treating of Evolution as a universal process of things, a rude outline of the course of structural changes in organisms was given (*First Principles*, §§ 110, 119, 132). Here it will be proper to describe these changes more fully.

The bud of any common flowering plant in its earliest stage, consists of a small hemispherical or sub-conical projection. While it increases most rapidly at the apex, this presently develops on one side of its base, a smaller projection of like general shape with itself. Here is the rudiment of a leaf, which presently spreads more or less round the base of the central hemisphere or main axis. At the same time that the central hemisphere rises higher, this lateral prominence, also increasing, gives rise to subordinate prominences or lobes. These are the rudiments of stipules, where the leaves are stipulated. Meanwhile, towards the other side of the main axis and somewhat higher up, another lateral prominence arising marks the origin of a second leaf. By the time that the first leaf has produced another pair of lobes, and the second leaf has produced its primary pair, the central hemisphere, still increasing at its apex, exhibits the rudiment of a third leaf. Similarly throughout. While the germ of each succeeding leaf thus arises, the germs of the previous leaves, in the order of their priority, are changing their rude nodulated shapes into flattened-out expansions; which slowly put on those sharp outlines they show when unfolded. Thus from that extremely indefinite figure, a rounded lump, giving off from time to time lateral lumps, which severally becoming symmetrically lobed gradually assume specific and involved forms, we pass little by little to that comparatively complex thing – a leaf-bearing shoot. Internally, a bud undergoes analogous changes; as witness this account: – "The general mass of thin-walled parenchymatous cells which occupies the apical region, and forms the *growing point* of the shoot, is covered by a single external layer of similar cells, which increase in number by the formation of new walls in one direction only, perpendicular to the surface of the shoot, and thus give rise only to the *epidermis* or single layer of cells covering the whole surface of the shoot. Meanwhile the general mass below grows as a whole, its constituent cells dividing in all directions. Of the new cells so formed, those removed by these processes of growth and division from the actual apex, begin, at a greater or less distance from it, to show signs of the differentiation which will ultimately lead to the formation of the various tissues enclosed by the epidermis of the shoot. First the pith, then the vascular bundles, and then the cortex of the shoot, begin to take on their special characters." Similarly with secondary structures, as the lateral buds whence leaves arise. In the, at first, unorganized mass of cells constituting the rudimentary leaf, there are formed vascular bundles which eventually become the veins of the leaf; and *pari passu* with these are formed the other tissues of the leaf. Nor do we fail to find an essentially parallel set of changes, when we trace the histories of the individual cells. While the tissues they compose are separating, the cells are growing step by step more unlike. Some become flat, some polyhedral, some cylindrical, some prismatic, some spindle-shaped. These develop spiral thickenings in their interiors; and those, reticulate thickenings. Here a number of cells unite together to form a tube: and there they become almost solid by the internal deposition of woody or other substance. Through such changes, too numerous and involved to be here detailed, the originally uniform cells go on diverging and rediverging until there are produced various forms that seem to have very little in common.

The arm of a man makes its first appearance in as simple a way as does the shoot of a plant. According to Bischoff, it buds-out from the side of the embryo as a little tongue-shaped projection, presenting no differences of parts; and it might serve for the rudiment of some one of the various other organs that also arise as buds. Continuing to lengthen, it presently becomes somewhat enlarged at its end; and is then described as a pedicle bearing a flattened, round-edged lump. This lump is the representative of the future hand, and the pedicle of the future arm. By and by, at the edges of this flattened lump, there appear four clefts, dividing from each other the buds of the future fingers; and the hand as a whole grows a little more distinguishable from the arm. Up to this time the pedicle has remained one continuous piece, but it now begins to show a bend at its centre, which indicates the division into arm and forearm. The distinctions thus rudely indicated gradually increase: the fingers elongate and become jointed, and the proportions of all the parts, originally very unlike those of the complete limb, slowly approximate to them. During its bud-like stage, the rudimentary arm consists only of partially-differentiated tissues. By the diverse changes these gradually undergo they are transformed into bones, muscles, blood-vessels, and nerves. The extreme softness and delicacy of these primary tissues, renders it difficult to trace the initial stages of the differentiations. In consequence of the colour of their contents, the blood-vessels are the first parts to become distinct. Afterwards the cartilaginous parts, which are the bases of the future bones, become marked out by the denser aggregation of their constituent cells, and by the production between these of a hyaline substance which unites them into a translucent mass. When first perceptible, the muscles are gelatinous, pale, yellowish, transparent, and indistinguishable from their tendons. The various other tissues of which the arm consists, beginning with very faintly-marked differences, become day by day more definite in their qualitative appearances. In like manner the units composing these tissues severally assume increasingly-specific characters. The fibres of muscle, at first made visible in the midst of their gelatinous matrix only by immersion in alcohol, grow more numerous and distinct; and by and by they begin to exhibit transverse stripes. The bone-cells put on by degrees their curious structure of branching canals. And so in their respective ways with the units of skin and the rest.

Thus in each of the organic sub-kingdoms, we see this change from an incoherent, indefinite homogeneity to a coherent, definite heterogeneity, illustrated in a quadruple way. The originally-like units called cells, become unlike in various ways, and in ways more numerous and marked as the development goes on. The several tissues which these several classes of cells form by aggregation, grow little by little distinct from each other; and little by little put on those structural complexities that arise from differentiations among their component units. In the shoot, as in the limb, the external form, originally very simple, and having much in common with simple forms in general, gradually acquires an increasing complexity, and an increasing unlikeness to other forms. Meanwhile, the remaining parts of the organism to which the shoot or limb belongs, having been severally assuming structures divergent from one another and from that of this particular shoot or limb, there has arisen a greater heterogeneity in the organism as a whole.

§ 52. One of the most remarkable inductions of embryology comes next in order. And here we find illustrated the general truth that in mental evolution as in bodily evolution the progress is from the indefinite and inexact to the definite and exact. For the first statement of this induction was but an adumbration of the correct statement.

As a result of his examinations von Baer alleged that in its earliest stage every organism has the greatest number of characters in common with all other organisms in their earliest stages; that at a stage somewhat later its structure is like the structures displayed at corresponding phases by a less extensive assemblage of organisms; that at each subsequent stage traits are acquired which successively distinguish the developing embryo from groups of embryos that it previously resembled – thus step by step diminishing the group of embryos which it still resembles; and that thus the class of similar forms is finally narrowed to the species of which it is a member. This abstract proposition will perhaps not be fully comprehended by the general reader. It will be best to re-state it in a concrete shape. Supposing the germs of all kinds of organisms to be simultaneously developing, we may say that all members of the vast multitude take their first steps in the same direction; that at the second step one-half of this vast multitude diverges from the other half, and thereafter follows a different course of development; that the immense assemblage contained in either of these divisions very soon again shows a tendency to take two or more routes of development; that each of the two or more minor assemblages thus resulting, shows for a time but small divergences among its members, but presently again divides into groups which separate ever more widely as they progress; and so on until each organism, when nearly complete, is accompanied in its further modifications only by organisms of the same species; and last of all, assumes the peculiarities which distinguish it as an individual – diverges to a slight extent to the organisms it is most like.

But, as above said, this statement is only an adumbration. The order of Nature is habitually more complex than our generalizations represent it as being – refuses to be fully expressed in simple formulæ; and we are obliged to limit them by various qualifications. It is thus here. Since von Baer's day the careful observations of numerous observers have shown his allegation to be but approximately true. Hereafter, when discussing the embryological evidence of Evolution, the causes of deviations will be discussed. For the present it suffices to recognize as unquestionable the fact that whereas the germs of organisms are extremely similar, they gradually diverge widely, in modes now regular and now irregular, until in place of a multitude of forms practically alike we finally have a multitude of forms most of which are extremely unlike. Thus, in conformity with the law of evolution, not only do the parts of each organism advance from indefinite homogeneity to definite heterogeneity, but the assemblage of all organisms does the same: a truth already indicated in *First Principles*.

§ 53. This comparison between the course of development, in any creature, and the course of development in all other creatures – this arrival at the conclusion that the course of development in each, at first the same as in all others, becomes stage by stage differentiated from the courses in all others, brings us within view of an allied conclusion. If we contemplate the successive stages passed through by any higher organism, and observe the relation between it and its environment at each of these stages; we shall see that this relation is modified in a way analogous to that in which the relation between the organism and its environment is modified, as we advance from the lowest to the highest grades. Along with the progressing differentiation of each organism from others, we find a progressing differentiation of it from its environment; like that progressing differentiation from the environment which we meet with in the ascending forms of life. Let us first glance at the way in which the ascending forms of life exhibit this progressing differentiation from the environment.

In the first place, it is illustrated in *structure*. Advance from the homogeneous to the heterogeneous, itself involves an increasing distinction from the inorganic world. Passing over the *Protozoa*, of which the simplest probably disappeared during the earliest stages of organic evolution, and limiting our comparison to the *Metazoa*, we see that low types of these, as the *Cœlenterata*, are relatively simple in their organization; and the ascent to organisms of greater and greater complexity of structure, is an ascent to organisms which are in that respect more strongly contrasted with the structureless environment. In *form*, again, we see the same truth. An ordinary characteristic of inorganic matter is its indefiniteness of form; and this is also a characteristic of the lower organisms, as compared with the higher. Speaking generally, plants are less definite than animals, both in shape and size – admit of greater modifications from variations of position and nutrition. Among animals, the simplest Rhizopods may almost be called amorphous: the form is never specific, and is constantly changing. Of the organisms resulting from the aggregation of such creatures, we see that while some, as the *Foraminifera*, assume a certain definiteness of form, in their shells at least, others, as the Sponges, are very irregular. The Zoophytes and the *Polyzoa* are compound organisms, most of which have a mode of growth not more determinate than that of plants. But among the higher animals, we find not only that the mature shape of each species is very definite, but that the individuals of each species differ little in size. A parallel increase of contrast is seen in *chemical composition*. With but few exceptions, and those only partial ones, the lowest animal and vegetal forms are inhabitants of the water; and water is almost their sole constituent. Desiccated *Protophyta* and *Protozoa* shrink into mere dust; and among the Acalephes we find but a few grains of solid matter to a pound of water. The higher aquatic plants, in common with the higher aquatic animals, possessing as they do increased tenacity of substance, also contain a greater proportion of the organic elements; further they show us a greater variety of composition in their different parts; and thus in both ways are chemically more unlike their medium. And when we pass to the superior classes of organisms – land-plants and land-animals – we see that, chemically considered, they have little in common either with the earth on which they stand or the air which surrounds them. In *specific gravity* too, we may note a like truth. The simplest forms, in common with the spores and gemmules of higher ones, are as nearly as may be of the same specific gravity as the water in which they float; and though it cannot be said that among aquatic creatures, superior specific gravity is a standard of general superiority, yet we may fairly say that the higher orders of them, when divested of the appliances by which their specific gravity is regulated, differ more from water in their relative weights than do the lowest. In terrestrial organisms, the contrast becomes marked. Trees and plants, in common with insects, reptiles, mammals, birds, are all of a specific gravity considerably less than that of the earth and immensely greater than that of the air. Yet further, we see the law fulfilled in respect of *temperature*. Plants generate but extremely small quantities of heat, which are to be detected only by delicate experiments; and practically they may be considered as having the same temperature as their environment. The temperature of aquatic animals is very little above that of the surrounding water: that of the invertebrata being mostly less than a degree above it, and that of fishes not exceeding it by more than two or three degrees; save in the case of some large red-blooded fishes, as the tunny, which exceed it in temperature by nearly ten degrees. Among insects the range is from two to ten degrees above that of the air: the excess varying according to their activity. The heat of reptiles is from four to fifteen degrees more than the heat of their medium. While mammals and birds maintain a heat which continues almost unaffected by external variations, and is often greater than that of the air by seventy, eighty, ninety, and even a hundred degrees. Once more, in greater *self-mobility* a progressive differentiation is traceable. The chief characteristic by which we distinguish dead matter is its inertness: some form of independent motion is our most familiar proof of life. Passing over the indefinite border-land between the animal and vegetal kingdoms, we may roughly class plants as organisms which, while they exhibit that kind of motion implied in growth, are not only devoid of locomotive power, but with some unimportant exceptions are devoid of the power of moving their parts in relation to each other; and thus are less differentiated from the inorganic world than animals. Though in those microscopic *Protophyta* and *Protozoa* inhabiting the water we see locomotion produced by ciliary action; yet this locomotion, while rapid relatively to the sizes of their bodies, is absolutely slow. Of the *Cœlenterata* a great part are either permanently rooted or habitually stationary; and so have scarcely any self-mobility but that implied in the relative movements of parts; while the rest, of which the common jelly-fish serves as a sample, have mostly but little ability to move themselves through the water. Among the higher aquatic *Invertebrata*, – cuttlefishes and lobsters, for instance, – there is a very considerable power of locomotion; and the aquatic *Vertebrata* are, considered as a class, much more active in their movements than the other inhabitants of the water. But it is only when we come to air-breathing creatures that we find the vital characteristics of self-mobility manifested in the highest degree. Flying insects, mammals, birds, travel with velocities far exceeding those attained by any of the lower classes of animals. Thus, on contemplating the various grades of organisms in their ascending order, we find them more and more distinguished from their inanimate media, in *structure*, in *form*, in *chemical composition*, in *specific gravity*, in *temperature*, in *self-mobility*. It is true that this generalization does not hold with complete regularity. Organisms which are in some respects the most strongly contrasted with the environing inorganic world, are in other respects less contrasted than inferior organisms. As a class, mammals are higher than birds; and yet they are of lower temperature and have smaller powers of locomotion. The stationary oyster is of higher organization than the free-swimming medusa; and the cold-blooded and less heterogeneous fish is quicker in its movements than the warm-blooded and more heterogeneous sloth. But the admission that the several aspects under which this increasing contrast shows itself, bear variable ratios to each other, does not conflict with the general truth that as we ascend in the hierarchy of organisms, we meet with not only an increasing differentiation of parts but also an increasing differentiation from the surrounding medium in sundry other physical attributes. It would seem that this trait has some necessary connexion with superior vital manifestations. One of those lowly gelatinous forms, so transparent and colourless as to be with difficulty distinguished from the water it floats in, is not more like its medium in chemical, mechanical, optical, thermal, and other properties, than it is in the passivity with which it submits to all the influences and actions brought to bear upon it; while the mammal does not more widely differ from inanimate things in these properties, than it does in the activity with which it meets surrounding changes by compensating changes in itself. And between these extremes, these two kinds of contrast vary together. So that in proportion as an organism is physically like its environment it remains a passive partaker of the changes going on in its environment; while in proportion as it is endowed with powers of counteracting such changes, it exhibits greater unlikeness to its environment.[20]

If now, from this same point of view, we consider the relation borne to its environment by any superior organism in its successive stages, we find an analogous series of contrasts. Of course in respect of degrees of *structure* the parallelism is complete. The difference, at first small, between the little-structured germ and the little-structured inorganic world, necessarily becomes greater, step by step, as the differentiations of the germ become more numerous and definite. How of *form* the like holds is equally manifest. The sphere, which is the point of departure common to all organisms, is the most generalized of figures; and one that is, under various circumstances, assumed by inorganic matter. But as it develops it loses all likeness to inorganic objects in the environment; and eventually becomes distinct even from nearly all organic objects in its environment. In *specific gravity* the alteration, though not very marked, is still in the same direction. Development being habitually accompanied by a relative decrease in the quantity of water and an increase in the quantity of constituents that are heavier than water, there results a small augmentation of relative weight. In power of maintaining a *temperature* above that of surrounding things, the differentiation from the environment that accompanies development is marked. All ova are absolutely dependent for their heat on external sources. The mammalian young one is, during its uterine life, dependent on the maternal heat; and at birth has but a partial power of making good the loss by radiation. But as it advances in development it gains an ability to maintain a constant temperature above that of surrounding things: so becoming markedly unlike them. Lastly, in *self-mobility* this increasing contrast is no less decided. Save in a few aberrant tribes, chiefly parasitic, we find the general fact to be that the locomotive power, totally absent or very small at the outset, increases with the advance towards maturity. The

[20] This paragraph originally formed part of a review-article on "Transcendental Physiology," published in 1857.

more highly developed the organism becomes, the stronger grows the contrast between its activity and the inertness of the objects amid which it moves.

Thus we may say that the development of an individual organism, is at the same time a differentiation of its parts from each other, and a differentiation of the consolidated whole from the environment; and that in the last as in the first respect, there is a general analogy between the progression of an individual organism and the progression from the lowest orders of organisms to the highest orders. It may be remarked that some kinship seems to exist between these generalizations and the doctrine of Schelling, that Life is the tendency to individuation. For evidently, in becoming more distinct from one another and from their environment, organisms acquire more marked individualities. As far as I can gather from outlines of his philosophy, however, Schelling entertained this conception in a general and transcendental sense, rather than in a special and scientific one.

§ 54. Deductive interpretations of these general facts of development, in so far as they are possible, must be postponed until we arrive at the fourth and fifth divisions of this work. There are, however, one or two general aspects of these inductions which may be here conveniently dealt with deductively.

Grant that each organism is at the outset relatively homogeneous and that when complete it is relatively heterogeneous, and it necessarily follows that development is a change from the homogeneous to the heterogeneous – a change during which there must be gone through all the gradations of heterogeneity that lie between these extremes. If, again, there is at first indefiniteness and at last definiteness, the transition cannot but be from the one to the other of these through all intermediate degrees of definiteness. Further, if the parts, originally incoherent or uncombined, eventually become relatively coherent or combined, there must be a continuous increase of coherence or combination. Hence the general truth that development is a change from incoherent, indefinite homogeneity, to coherent, definite heterogeneity, becomes a self-evident one when observation has shown us the state in which organisms begin and the state in which they end.

Just in the same way that the growth of an entire organism is carried on by abstracting from the environment substances like those composing the organism; so the production of each organ within the organism is carried on by abstracting from the substances contained in the organism, those required by this particular organ. Each organ at the expense of the organism as a whole, integrates with itself certain kinds and proportions of the matters circulating around it; in the same way that the organism as a whole, integrates with itself certain kinds and proportions of matters at the expense of the environment as a whole. So that the organs are qualitatively differentiated from each other, in a way analogous to that by which the entire organism is qualitatively differentiated from things around it. Evidently this selective assimilation illustrates the general truth, set forth and illustrated in *First Principles*, that like units tend to segregate. It illustrates, moreover, the further aspect of this general truth, that the pre-existence of a mass of certain units produces a tendency for diffused units of the same kind to aggregate with this mass rather than elsewhere. It has been shown of particular salts, A and B, co-existing in a solution not sufficiently concentrated to crystallize, that if a crystal of the salt A be put into the solution, it will increase by uniting with itself the dissolved atoms of the salt A; and that similarly, though there otherwise takes place no deposition of the salt B, yet if a crystal of the salt B is placed in the solution, it will exercise a coercive force on the diffused atoms of this salt, and grow at their expense. Probably much organic assimilation occurs in the same way. Particular parts of the organism are composed of special units or have the function of secreting special units, which are ever present in them in large quantities. The fluids circulating through the body contain special units of this same order. And these diffused units are continually being deposited along with the groups of like units that already exist. How purely physical are the causes of this selective assimilation, is, indeed, shown by the fact that abnormal constituents of the blood are segregated in the same way. The chalky deposits of gout beginning at certain points, collect more and more around those points. And similarly in numerous pustular diseases. Where the component units of an organ, or some of them, do not exist as such in the circulating fluids, but are formed out of elements or compounds that exist separately in the circulating fluids, the process of differential assimilation must be of a more complex kind. Still, however, it seems not impossible that it is carried on in an analogous way. If there be an aggregate of compound atoms, each of which contains the constituents A, B, C; and if round this aggregate the constituents A and B and C are diffused in uncombined states; it may be suspected that the coercive force of these aggregated compound atoms A, B, C, may not only bring into union with themselves adjacent compound atoms A, B, C, but may cause the adjacent constituents A and B and C to unite into such compound atoms, and then aggregate with the mass.

CHAPTER II^A^.
STRUCTURE.[21]

§ 54*a*. As, in the course of evolution, we rise from the smallest to the largest aggregates by a process of integration, so do we rise by a process of differentiation from the simplest to the most complex aggregates. The initial types of life are at once extremely small and almost structureless. Passing over those which swarm in the air, the water, and the soil, and are now some of them found to be causes of diseases, we may set out with those ordinarily called *Protozoa* and *Protophyta*: the lowest of which, however, are either at once plants and animals, or are now one and now the other.

That the first living things were minute portions of simple protoplasm is implied by the general theory of Evolution; but we have no evidence that such portions exist now. Even admitting that there are protoplasts (using this word to include plant and animal types) which are without nuclei, still they are not homogeneous – they are granular. Whether a nucleus is always present is a question still undecided; but in any case the types from which it is absent are extremely exceptional. Thus the most general structural traits of protoplasts are – the possession of an internal part, morphologically central though often not centrally situated, a general mass of protoplasm surrounding it, and an inclosing differentiated portion in contact with the environment. These essential elements are severally subject to various complications.

In some simple types the limiting layer or cortical substance can scarcely be said to exist as a separate element. The exoplasm, distinguished from the endoplasm by absence or paucity of granules, is continually changing places with it by the sending out of pseudopodia which are presently drawn back into the general mass: the inner and outer, being unsettled in position, are not permanently differentiated. Then we have types, exemplified by *Lithamœba*, constituted of protoplasm covered by a distinct pellicle, which in sundry groups becomes an outer shell of various structure: now jelly-like, now of cellulose, now siliceous or calcareous. While here this envelope has a single opening, there it is perforated all over – a fenestrated shell. In some cases an external layer is formed of agglutinated sand-particles; in others of imbricated plates, as in Coccospheres; and in many others radiating spicules stand out on all sides. Throughout sundry classes the exoplasm develops cilia, by the wavings of which the creatures are propelled through the water – cilia which may be either general or local. And then this cortical layer, instead of being spherical or spheroidal, may become plano-spiral, cyclical, crosier-shaped, and often many-chambered; whence there is a transition to colonies.

Meanwhile the inclosed protoplasm, at first little more than a network or foamwork containing granules and made irregular by objects drawn in as nutriment, becomes variously complicated. In some low types its continuity is broken by motionless, vacant spaces, but in higher types there are contractile vacuoles slowly pulsing, and, as we may suppose, moving the contained liquid hither and thither; while there are types having many passive vacuoles along with a few active ones. In some varieties the protruded parts, or pseudopodia, into which the protoplasm continually shapes itself, are comparatively short and club-shaped; in others they are long and fine filaments which anastomose, so forming a network running here and there into little pools of protoplasm. Then there are kinds in which the protoplasm streams up and down the protruding spicules: sometimes inside of them, sometimes outside. Always, too, there is included in the protoplasm a small body known as a centrosome.

[21] When, in 1863, the preceding chapter was written, it had not occurred to me that there needed an accompanying chapter treating of Structure. The gap left by that oversight I now fill up. In doing this there have been included certain statements which are tacitly presupposed in the last chapter, and there may also be some which overlap statements in the next chapter. I have not thought it needful so to alter adjacent chapters as to remove these slight defects: the duplicated ideas will bear re-emphasizing.

Lastly, we have the innermost element, considered the essential element – the nucleus. According to Prof. Lankester, it is absent from *Archerina*, and there are types in which it is made visible only by the aid of special reagents. Ordinarily it is marked off from the surrounding protoplasm by a delicate membrane, just as the protoplasm itself is marked off by the exoplasm from the environment. Most commonly there is a single nucleus, but occasionally there are many, and sometimes there is a chief one with minor ones. Moreover, within the nucleus itself there have of late years been discovered remarkable structural elements which undergo complicated changes.

These brief statements indicate only the most general traits of an immense variety of structures – so immense a variety that Prof. Lankester, in distinguishing the classes, sub-classes, orders, and genera in the briefest way, occupies 37 quarto pages of small type. And to give a corresponding account of *Protophyta* would require probably something like equal space. Thus these living things, so minute that unaided vision fails to disclose them, constitute a world exhibiting varieties of structure which it requires the devotion of a life to become fully acquainted with.

§ 54*b*. If higher forms of life have arisen from lower forms by evolution, the implication is that there must once have existed, if there do not still exist, transitional forms; and there follows the comment that there *do* still exist transitional forms. Both in the plant-world and in the animal-world there are types in which we see little more than simple assemblages of *Protophyta* or of *Protozoa*– types in which the units, though coherent, are not differentiated but constitute a uniform mass. In treating of structure we are not here concerned with these unstructured types, but may pass on to those aggregates of protoplasts which show us differentiated parts —*Metaphyta* and *Metazoa*: economizing space by limiting our attention chiefly to the last.

When, half a century ago, some currency was given to the statement that all kinds of organisms, plant and animal, which our unaided eyes disclose, are severally composed of myriads of living units, some of them partially, if not completely, independent, and that thus a man is a vast nation of minute individuals of which some are relatively passive and others relatively active, the statement met, here with incredulity and there with a shudder. But what was then thought a preposterous assertion has now come to be an accepted truth.

Along with gradual establishment of this truth has gone gradual modification in the form under which it was originally asserted. If some inhabitant of another sphere were to describe one of our towns as composed exclusively of houses, saying nothing of the contained beings who had built them and lived in them, we should say that he had made a profound error in recognizing only the inanimate elements of the town and disregarding the animate elements. Early histologists made an analogous error. Plants and animals were found to consist of minute members, each of which appeared to be simply a wall inclosing a cavity – a cell. But further investigation proved that the content of the cell, presently distinguished as protoplasm, is its essential living part, and that the cell-wall, when present, is produced by it. Thus the unit of composition is a protoplast, usually enclosed, with its contained nucleus and centrosome.

§ 54*c*. As above implied, the individualities of the units are not wholly lost in the individuality of the aggregate, but continue, some of them, to be displayed in various degrees: the great majority of them losing their individualities more and more as the type of the aggregate becomes higher.

In a slightly organized Metazoon like the sponge, the subordination is but small. Only those members of the aggregate which, flattened and united together, form the outer layer and those which become metamorphosed into spicules, have entirely lost their original activities. Of the rest nearly all, lining the channels which permeate the mass, and driving onwards the contained sea-water by the motions of their whip-like appendages, substantially retain their separate lives; and beyond these there exist in the gelatinous substance lying between the inner and outer layers, which is regarded as homologous with a mesoderm, amœba-form protoplasts which move about from place to place.

Relations between the aggregate and the units which are in this case permanent, are in other cases temporary: characterizing early stages of embryonic development. For example, drawings of

Echinoderm larvæ at an early stage, show us the potential independence of all the cells forming the blastosphere; for in the course of further development some of these resume the primitive amœboid state, migrate through the internal space, and presently unite to form certain parts of the growing structures. But with the progress of organization independence of this kind diminishes.

Converse facts are presented after development has been completed; for with the commencement of reproduction we everywhere see more or less resumption of individual life among the units, or some of them. It is a trait of transitional types between *Protozoa* and *Metazoa* to lead an aggregate life as a plasmodium, and then for this to break up into its members, which for a time lead individual lives as generative agents; and sundry low kinds of plants possessing small amounts of structure, have generative elements – zoospores and spermatozoids – which show us a return to unit life. Nor, indeed, are we shown this only in the lowest plants; for it has recently been found that in certain of the higher plants – even in Phænogams – spermatozoids are produced. That is to say, the units resume active lives at places where the controlling influence of the aggregate is failing; for, as we shall hereafter see, places at which generation commences answer to this description.

These different kinds of evidence jointly imply that the individual lives of the units are subordinate to the general life in proportion as this is high. Where the organism is very inferior in type the unit-life remains permanently conspicuous. In some superior types there is a display of unit-life during embryonic stages in which the co-ordinating action of the aggregate is but incipient. With the advance of development the unit-life diminishes; but still, in plants, recommences where the disintegrating process which initiates generation shows the coercive power of the organization to have become small.

Even in the highest types, however, and even when they are fully developed, unit-life does not wholly disappear: it is clearly shown in ourselves. I do not refer simply to the fact that, as throughout the animal kingdom at large and a considerable part of the vegetal kingdom, the male generative elements are units which have resumed the primitive independent life, but I refer to a much more general fact. In that part of the organism which, being fundamentally an aqueous medium, is in so far like the aqueous medium in which ordinary protozoon life is carried on, we find an essentially protozoon life. I refer of course to the blood. Whether the tendency of the red corpuscles (which are originally developed from amœba-like cells) to aggregate into *rouleaux* is to be taken as showing life in them, may be left an open question. It suffices that the white corpuscles or leucocytes, retaining the primitive amœboid character, exhibit individual activities: send out prolongations like pseudopodia, take in organic particles as food, and are independently locomotive. Though far less numerous than the red corpuscles, yet, as ten thousand are contained in a cubic millimetre of blood – a mass less than a pin's head – it results that the human body is pervaded throughout all its blood-vessels by billions of these separately living units. In the lymph, too, which also fulfils the requirements of liquidity, these amœboid units are found. Then we have the curious transitional stage in which units partially imbedded and partially free display a partial unit-life. These are the ciliated epithelium-cells, lining the air-passages and covering sundry of the mucous membranes which have more remote connexions with the environment, and covering also the lining membranes of certain main canals and chambers in the nervous system. The inner parts of these unite with their fellows to form an epithelium, and the outer parts of them, immersed either in liquid or semi-liquid (mucus), bear cilia that are in constant motion and "produce a current of fluid over the surface they cover: " thus simulating in their positions and actions the cells lining the passages ramifying through a sponge. The partially independent lives of these units is further seen in the fact that after being detached they swim about in water for a time by the aid of their cilia.

§ 54*d*. But in the *Metazoa* and *Metaphyta* at large, the associated units are, with the exceptions just indicated, completely subordinated. The unit-life is so far lost in the aggregate life that neither locomotion nor the relative motion of parts remains; and neither in shape nor composition is there resemblance to protozoa. Though in many cases the internal protoplasm continues to carry on vital processes subserving the needs of the aggregate, in others vital processes of an independent kind appear to cease.

It will naturally be supposed that after recognizing this fundamental trait common to all types of organisms above the *Protozoa* and *Protophyta*, the next step in an account of structure must be a description of their organs, variously formed and combined – if not in detail yet in their general characters. This, however, is an error. There are certain truths of structure higher in generality than any which can be alleged of organs. We shall see this if we compare organs with one another.

Here is a finger stiffened by its small bones and yet made flexible by the uniting joints. There is a femur which helps its fellow to support the weight of the body; and there again is a rib which, along with others, forms a protective box for certain of the viscera. Dissection reveals a set of muscles serving to straighten and bend the fingers, certain other muscles that move the legs, and some inconspicuous muscles which, contracting every two or three seconds, slightly raise the ribs and aid in inflating the lungs. That is to say, fingers, legs, and chest possess certain structures in common. There is in each case a dense substance capable of resisting stress and a contractile substance capable of moving the dense substance to which it is attached. Hence, then, we have first to give an account of these and other chief elements which, variously joined together, form the different organs: we have to observe the general characters of *tissues*.

On going back to the time when the organism begins with a single cell, then becomes a spherical cluster of cells, and then exhibits differences in the modes of aggregation of these cells, the first conspicuous rise of structure (limiting ourselves to animals) is the formation of three layers. Of these the first is, at the outset and always, the superficial layer in direct contact with the environment. The second, being originally a part of the first, is also in primitive types in contact with the environment, but, being presently introverted, forms the rudiment of the food-cavity; or, otherwise arising in higher types, is in contact with the yelk or food provided by the parent. And the third, presently formed between these two, consists at the outset of cells derived from them imbedded in an intercellular substance of jelly-like consistence. Hence originate the great groups classed as epithelium-tissue, connective tissue (including osseous tissue), muscular tissue, nervous tissue. These severally contain sub-kinds, each of which is a complex of differentiated cells. Being brief, and therefore fitted for the present purposes, the sub-classification given by Prof. R. Hertwig may here be quoted; —

> "The physiological character of epithelia is given in the fact that they cover the surfaces of the body, their morphological character in that they consist of closely compressed cells united only by a cementing substance.

Конец ознакомительного фрагмента.