THE

PHYSIOLOGICAL ANATOMY

AND

PHYSIOLOGY OF MAN.

BY

ROBERT B. TODD, WILLIAM BOWMAN,

AND

LIONEL S. BEALE,

FELLOWS OF THE ROYAL SOCIETY; FORMER AND PRESENT PROFESSORS OF PHYSIOLOGY AND OF GENERAL AND MORBID ANATOMY IN KING'S COLLEGE, LONDON.

A New Edition by the last-named Author.

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THIS edition of the original work of DR. TODD and MR. BOWMAN, has been prepared by DR. BEALE, their successor in the chair of Physiology and of General and Morbid Anatomy in King's College. His name therefore appears in the title page as joint author.

DR. BEALE had already assisted the authors in the completion of the concluding part of their second volume, but for the work in its new form he is alone responsible.

The present part, consisting of the *Introduction*, Chapter I. on *Structure*, and Chapter II. on *Chemical Composition*, is complete in itself. In the further prosecution of the work, the original plan will be adhered to as closely as possible, but the text will be modified where necessary, and numerous new figures introduced.

KING'S COLLEGE, LONDON.
June, 1866.

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INTRODUCTION.

THE aim of all natural knowledge is to ascertain the laws which control and regulate the phenomena of the universe. So numerous, and so diversified are these phenomena, that for their study a division of labour has been found not merely convenient, but absolutely necessary. The position and movements of the planetary system, the crust of the earth, and its various component strata, the treasures hidden in its womb, the abundant vegetation that grows upon its surface, or beneath its waters, and the numberless hosts of animals that dwell upon the land, or in the rivers, lakes, and seas form separate branches of scientific investigation, between which a sufficiently distinct line of demarcation is established by the nature of the objects of inquiry peculiar to each. But, in all departments of science, the same general rules for conducting the investigation prevail, and it is only by a close adherence to these that we can arrive at safe and satisfactory conclusions.

In any scientific inquiry, the first step must be to form a general notion of the characters and properties of the objects of investigation. In the next place, it is necessary to observe carefully the phenomena which they naturally present; and, if they be within our reach, to produce such variation in them by artificial means (by experiments), as may serve to throw light upon their nature. If the phenomena under observation be complex, we must analyse them with a view to ascertain the simpler ones of which they are composed. By this analysis, and by the elimination of such as are merely collateral, we arrive at a phenomenon, uncomplicated, incapable of further subdivision, and fundamental; and this we are contented to receive as an *ultimate fact*, the result of a law in constant and universal operation. The accumulation of observations and experiments affords us Experience; points out the ordinary succession of phenomena, and teaches us the ways of Nature. If these phenomena are found to present a certain uniformity, we are authorized to refer them to the operation of one common Cause, and we are thus led to the expression of the Law which regulates their occurrence. Proceeding in this way, we are enabled to explain the whole train of phenomena which have been investigated,—that is, to devise a *Theory* which develops the rationale of their occurrence.

But sometimes our experiments and observations throw an imperfect light upon the phenomena which are the subjects of investigation; or the latter are so remote, or so little under our control, as to render both observation and experiment extremely difficult, and in some cases impossible. The "instances" which we are enabled to collect are, consequently, dubious and obscure, and point darkly or not at all to ultimate facts; they present little or no general resemblance, and cannot be properly associated together. Here is no foundation on which to build a theory; but great advantage may be gained, if, with the little light we derive from these particular observations, aided by previous knowledge of general laws, we can frame an *hypothesis*, offering some explanation of the phenomena. The adoption of such an hypothesis, even for a temporary purpose, will "afford us motives for searching into analogies," may suggest new modes of observation and experiment, and "may serve as a scaffold for the erection of general laws."

Previously to the time of Lavoisier, chemists were perfectly familiar with the occurrence of combustion under various circumstances; but the opinions (hypotheses) which prevailed as to the real nature of this process, afforded a very unsatisfactory explanation of it. Subsequently, however, by the labours of Lavoisier, Davy, and others, this complex phenomenon has been observed in all its phases; it has been carefully analysed, and has been proved to occur in all cases, where substances possessed of strong chemical attractions, or different electrical relations, are brought within mutual influence. The *ultimate fact* thus arrived at is, that intense chemical combination always gives rise to the evolution of heat, and, in many instances, to that of light also.

Again, a great number of observations have shewn that bodies combine together only in certain quantities, or in multiples of them; that each body has its proper combining quantity, and that it never enters into combination except in that quantity, or some multiple of it. This is an *ultimate fact*, ascertained by numerous experiments, and indicates the law, which is so important in chemistry, that bodies unite with each other in their combining proportions only, or in multiples of them, and in no intermediate proportions. And this, again, has led to the beautiful generalization of Dalton, that the ultimate atoms of bodies are their respective combining quantities, and bear to each other the same proportion as their combining equivalents do.

Or, to take an example from the science which is to form the subject of the following pages. The function of respiration in animals is a very complex process, respecting the nature of which many unsatisfactory hypotheses had been formed, owing to the obscurity in which many of the phenomena, immediately or remotely connected with it, were involved. Until the law of the diffusion of gases, and of the permeability of membranes by them, had been developed, and until it had been shewn that carbonic acid is held in solution in venous blood, no theory of respiration could be framed adequate to explain all the phenomena. It is now proved, that, in this process, a true interchange of gases takes place through the coats of the pulmonary blood-vessels, the oxygen of the air passing through and occupying the place of the carbonic acid of the blood while the latter is diffused into the air in the pulmonary vesicles. An admirable example is thus afforded of a process most important to life taking place in obedience to a purely physical law.

Living objects are those which properly belong to the science of Physiology. These are strongly contrasted with the inanimate bodies (which have never lived), to which other branches of natural science refer. At the same time, there are many points of resemblance between them; and as both owe their origin to the same Divine Author, and are reducible (as will be seen by-and-by) to the same elementary constituents, so they are subject in a great degree to the same physical laws, and are to be investigated according to the same principles of philosophical inquiry.

In this Introduction we propose, in the first place, to consider the characters in which organized bodies agree with or differ from inanimate, mineral, or unorganized bodies, and then to refer briefly to the structure and special endowments of living beings. Next, the relation of the physical and vital forces will be briefly discussed, and we shall endeavour to show that physical are distinct from vital phenomena. Life and some of the theories of life of the greatest interest to the physiologist will then be alluded to, and the diversity of the forms of living beings, and the general differences existing between plants and animals considered. Lastly, we shall endeavour to point out the value of a knowledge of physiology, especially that of man, to the diagnosis and treatment of disease, and the modes of pursuing this branch of natural knowledge.

OF ORGANIZED AND UNORGANIZED BODIES.

Living beings have been sometimes said to be *organized* in the sense of being composed of certain distinct parts or *organs*, each having its own definite structure, and capable of fulfilling a certain end. But if the term be used in this sense its use must be restricted to the higher organisms after they have reached a certain stage of development, for every independent living organism, at the outset of its life, consists merely of a colourless, transparent semifluid matter, disclosing no structure whatever, and possessing no distinct parts or organs. Yet this matter lives; it is capable of formation, of increase, and of multiplication, and it must be regarded as an independent living *organism*, organized although exhibiting no structure. We therefore extend the term *organized* to every kind of matter endowed with these peculiar powers or capabilities. They are characteristic of life, and are manifested by living matter which came from pre-existing living matter: never have such endowments been shown to exist in relation with any inorganic unorganized matter whatever.

All organisms are composed of and are capable of producing peculiar organic matters of complex composition, and often endowed with peculiar properties.

By *proximate analysis* several different organic compounds may be obtained from every organism. By *ultimate analysis* these organic compounds may be resolved into simple elementary substances, such as constitute other objects of the universe.

The various bodies that compose the mineral kingdom, have not the same complex composition, nor do they exhibit that distinctness and variety of structure in their component parts, which is so characteristic of at least the higher organisms, nor is there any adaptation of their parts to separate functions. They never exhibit the wonderful properties characteristic of the living matter which exists in all organisms, but in these alone, and they are therefore called *unorganized* or *inorganic*. Chemical analysis resolves them into simple elements which admit of no further subdivision.

Life, Death, and Dormant Vitality.—Organized bodies are found in two states or conditions. The one, that of *life*, is a state of action, and of change. The other, that of *death*, is one in which all vital action has ceased, and to which the disintegration and chemical decomposition of the organized body succeed as a natural consequence. But it cannot be said that any living body exists which at any one moment consists entirely of *living matter*. In every living organism, at every moment, so long as its life lasts, there is matter that lives and matter that *has ceased to live.*

An organized body in a state of *active* life exhibits *growth* and *nutrition*, and resists the destructive influence of surrounding agents. Thus the development of structures is promoted, and the integrity of the body itself is preserved. The simplest thing growing, animal or vegetable, is an illustration of this remark.

But there are organized bodies in which life is said to be *dormant.* If in these, actions or changes occur, they are so slight that they cannot be observed; nevertheless, if placed under certain favourable conditions, vital activity will soon become manifest in these organized bodies. Of this we have familiar examples in a seed, and in an egg. It is well known that seeds will retain their form, size, and other properties for a very considerable period; and afterwards, if placed under favourable conditions, will exhibit the process of germination as completely as if they had been only recently separated from the parent plant. Eggs, also, may be preserved for a long time without injury to the power of development, or to the nutrition of the embryo contained within them. But neither eggs nor seeds will exhibit vital activity if kept beyond a definite period of time. This fact renders it probable that certain slow changes do occur even in this dormant state; and that when these changes have once ceased no altered conditions whatever will recall the power of germination to egg or seed.

It is worthy of observation, that those processes, which denote vital activity, may be sometimes temporarily suspended, even in fully formed animals and vegetables; and, in such instances, life may be said to *become dormant.* That is, under these altered conditions, changes occur so slowly as not to be perceptible to ordinary observation. The privation of moisture or of heat is the ordinary cause of this partial cessation, or diminished activity of, the phenomena of life. In dry weather, mosses often become desiccated, and although they *appear* quite dead, will nevertheless speedily revive on the application of moisture. The common wheel animalcule, although apparently killed by the drying up of the fluid in which it had been immersed, will speedily resume its active movements on being supplied anew with water. But this desiccation is not perfect and complete desiccation. Whenever living matter of any kind is perfectly dried, it is killed, and can never be resuscitated. The manner in which the living matter is protected renders it very difficult to dry it thoroughly, and if but the *most minute particle* remains moist, it may retain its vitality, and increase and exhibit vital actions whenever the conditions under which it is placed become favourable. Certain living organisms and tissues may be frozen without being killed, but in this case it is doubtful if the germinal or living matter itself be rendered solid, any more than by desiccation it is completely deprived of water.

Composition of Organized and Unorganized Bodies.—Inorganic bodies may be resolved by ultimate analysis into oxygen, hydrogen, nitrogen, carbon, and about fifty other substances, which chemists regard as simple, because they appear to consist of one kind of matter only; that is to say, they have hitherto resisted futher decomposition. These elements unite in certain definite proportions to form the compound inorganic substances.

Organized bodies are capable of being resolved, by *ultimate analysis*, into inorganic simple elements; but the list of simple substances which may be obtained from this source comprises only about twenty. Of the four widely-spread elements, oxygen, hydrogen, nitrogen, and carbon, two, *at least*, will be found in every organic compound; hence, as Dr Prout has suggested, these four may be conveniently distinguished as the *essential* elements of organic matter. The other simple substances are found in smaller quantities, and are less extensively diffused; these may be termed its *incidental* elements. They are sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, silicon, aluminium, iron, manganese, iodine, and bromine, and probably others; the last two are obtained almost exclusively from marine plants and animals.

Proximate Principles.—From various animal and vegetable tissues, and from their fluids, may be obtained by proximate analysis, a class of substances which have been grouped together under the head of *proximate principles*, or *organizable substances*, because they are specially concerned in nutrition. It is these substances which form the most important constituents of the *food* of man and the higher animals. The following are examples of proximate principles—*gluten*, *starch*, *lignine*, from the vegetable textures; *albumen*, *fibrine*, *casein*, from the animal ones. From the organized structure, called *muscle*, for example, we obtain by *analysis*, first *fibrine*, a proximate principle, which is its chief constituent; and, subsequently, by the analysis of fibrine, we get the *simple elements*, oxygen, hydrogen, carbon, nitrogen, and sulphur, in certain proportions. On the other hand, by *synthesis*, or the combination of certain simple inorganic elements in the organism of the plant, an organic compound, closely allied to fibrine, is produced; from which, or from allied substances forming the food of animals, the organized structure, muscle, is formed.

In many *organized bodies* the constituent particles are, as it were, artfully arranged, so as to form peculiar *textures*, destined to serve special purposes in the living mechanism of the animal or plant to which they belong. These textures exhibit peculiar *structure*, which is one of the results of vital action, although the *tissue* which has been formed may not be alive. The chemical compounds which may be obtained from these textures by analysis are devoid of any mechanical arrangement of particles.

From these again a great variety of compounds has been obtained by various chemical processes, owing to the tendency which their elements have to form new combinations. By boiling starch in dilute acids, it becomes converted into a kind of gum, and starch-sugar; and, in the germination of barley, or of the potato, a peculiar substance is formed, the contact of which with the starch of the barley or potato converts it into sugar. Innumerable examples might be quoted from various vegetable compounds, shewing that the affinity, which holds together the elements of organic substances, is so feeble, that it affords but slight resistance to their entrance into new combinations.

The proximate principles of organic substances consist for the most part of three or four of the essential simple elements, and, as many of them contain a large number of atoms, their combining proportion is represented by a very high number. Respecting the mode of combination of these elements however, the greatest uncertainty prevails, and it is indeed doubtful if many of the substances which have received special names, as *albumen*, *fibrine*, and the like, are really definite chemical substances of fixed composition. Chemists have not yet succeeded in obtaining the majority of these bodies in a state of chemical purity.

Secondary Organic Compounds.—From the blood, from the tissues, and from many of the fluids secreted by different organs of the body, by *proximate analysis*, may be obtained another class of substances derived from the process of *destruction* of the organic substances entering into the formation of the tissues, blood corpuscles, or gland cells. These have been called secondary organic compounds, and their chemical composition is far simpler than that of the proximate principles. *Urea*, *uric acid*, *kreatin*, *kreatinine*, *hippuric acid*, *leucin*, *tyrosin*, are all organic substances, which result from the oxidation and disintegration of more highly complex organic substances in the organism, and are examples of secondary organic compounds.

Of the Synthesis of Organic Compounds.—As has been remarked already, much uncertainty exists in reference to the manner of combination of the simple elements to form the higher and more complex organic compounds. It is therefore not surprising that the attempts of chemists to produce them by artificial processes should have met with so little success. No one has succeeded in the formation by synthesis of albumen, fibrine, or any of those substances (as for example, the constituent of white fibrous tissue), of which the greater part of the bodies of animals is composed. Not even starch, or the cellulose of the very lowest simplest vegetable organisms has been prepared by synthesis in the laboratory. Indeed, it is very questionable whether any of those substances which may be considered as the first or immediate result of *vital actions* will ever be produced elsewhere than in the living organism.

Of late years a vast number of those substances which result from the action of oxygen upon compounds formed in animal and vegetable organisms have been made in the laboratory from inorganic matter. The formation of urea, a *secondary organic compound*, has been effected by Wöhler from the cyanate of ammonia, by depriving it of a little ammonia through the action of heat. And it must be admitted, as no unimportant step in the synthesis of organic compounds, that nitrogen gas has been found to unite with charcoal, under the influence of carbonate of potassa at a red heat. The cyanide of potassium, which is thus formed, yields ammonia, when decomposed by water; so that cyanogen, and through cyanogen, ammonia, can be primarily derived from their respective elements contained in the inorganic world. Allantoin, an analogous compound to urea, formic, oxalic, glycolic, lactic, butyric, leucic, oleic, and a number of other organic acids, have likewise been artificially produced. No compound allied to albumen has yet been prepared artificially, but many substances bearing to it much the same relation as urea, have been produced. In short, the substances already formed in the laboratory by synthesis, correspond with those which are produced by the chemical action of oxygen upon products resulting from the disintegration of more complex chemical substances. They are allied rather to the substances included in the secondary compounds, than to the group of proximate principles. They are the results of a long series of chemical changes occurring in the organism, and are so far removed from the actual constituents of the tissues, and from the substances which immediately result from the death of living matter, that their artificial production affords no safe grounds for supposing that the former complex substances will ever be manufactured in the laboratory, or that a living organism will some day be produced by the synthesis of inorganic elements as some have not hesitated to regard as possible when organic chemistry shall have advanced to a higher state of perfection.

OF THE STRUCTURE AND SPECIAL CHARACTERS OF ORGANIZED BEINGS.

The *higher plants and animals* are composed of parts often termed organs, distinct from each other in structure and function. Entering into the formation of these organs are many different textures, each differing from the others in physical properties, in their mode of action, and in chemical composition. The existence of a great variety of textures in an animal implies a high degree of organization.

In *beings of a more simple character*, low in the scale of organization, there is comparative uniformity of structure; though often a variety of parts or organs, and tissues having different properties, exist in the fully developed organism. But, in many cases, it has been observed, that from almost any one part of the body any other portion might be developed. Thus some species of Actinia, in slowly moving over the surface of a rock, detach small pieces of the margin of the disc. From each one of these detached portions a perfect actinia, with its tentacles, external covering, gastric membrane, glands, and muscular and nervous apparatus and generative organs, is developed.

In the *lowest and simplest organisms* there is no indication of distinct parts or organs. The entire creature seems to consist only of a small mass of clear structureless material, which possesses in every part the power of moving in any direction, which absorbs nutrient matter, and grows and multiplies by portions being from time to time detached.

There is a time when every organism, even the most complex, consists of such a simple mass of colourless, growing, moving, matter. Every organ, every tissue, is represented at an early period of its development by such a simple and apparently almost homogeneous mass of plastic material. Such structureless material exists also at every period of the life even of the most complex tissues. The physical property of the tissue does not depend upon this matter, nor is its function due to it; but no tissue can be produced or be increased without it. There can be no *life* in the absence of this simple matter. In fact, the *tissue* does not grow of itself, but new tissue is produced by changes occurring in this soft, plastic matter, and it is added to the tissue which already exists. Neither does *the tissue* multiply, assimilate, form, or convert, but all these phenomena are effected by the agency of this wonderful *simple plastic matter.* It is remarkable, that as soon as this matter undergoes conversion into tissue or into any definite chemical compound it loses for ever the active powers above referred to.

From this colourless transparent material, then, everything characteristic of a living body is formed, or, in other words, the matter of which all the tissues and substances peculiar to the organism are composed, was once in this state.

A mass of any tissue at every age may be divided into *elementary parts*, each one of which contains a portion of this transparent matter within it. Each one of these elementary parts may be termed a "*cell.*" In some tissues the "cells" can be readily separated from one another, but in others, the outer part or tissue of one "cell" is continuous with that of neighbouring cells. Various forms of cells are represented in Plates I, II, III, and IV, an examination of which will enable the reader to form a clear notion of the structure of the principal kinds.

The simplest or most elementary organic form with which we are acquainted consists of a portion of this soft, transparent, colourless matter, surrounded by a layer of matter formed from it, which may be so thin as to be hardly visible. This latter results, in fact, from the action of external conditions upon the most external portion of the mass. Such an elementary part may be less than the $\frac{1}{100000}$ of an inch in diameter, and may, we believe, exist so small as to be invisible. Still it is a living, and, in a certain sense, independent organism, capable of increase and endowed with the power of giving rise to other bodies like itself. These wonderful powers, as already stated, reside not in the *formed* matter upon the surface, but in that within, which is in a *formless* but *living* state. The latter may be termed *Germinal matter.*

Such is the simple structure of the "cell"—of every cell which exists in nature at an early period of its development. Remarkable alterations in character often occur as the cell advances in age, and many very different forms of " cells" result. The nature of these differences cannot be discussed here, but they will be explained when the structure of the various tissues is considered and their development traced. The account here given of the structure and action of the cell differs from that generally received in several essential particulars, but these differences will be noticed in their proper place.

Each organized body has its appropriate and specific shape ; and to each a certain size is assigned. To observe and classify the wonderful diversity of forms of plants and animals, has given employment to Naturalists in all ages; and the sciences of Zoology and systematic Botany have been founded upon the results of their labours.

Every organized body, and every part of an organized body, is limited in its duration; it has "its time to be born and its time to die," and at death it passes by decomposition into simpler and more stable combinations of the inorganic elements. Death, however, occurs at every period of the life of an organized body. From what has just been remarked with regard to structure, it follows, that every anatomical element or cell is gradually undergoing change during life. Pabulum passes into the active matter and assumes the active state, while some of the latter becomes passive and is converted into new substance, which is added to that which was already formed, or takes the place of that which has been removed.

It is, therefore, evident, that not even the most minute cell is at any moment composed of matter in precisely the same state in every part. There is matter which is about to live, matter that is alive, matter which has ceased to live, and matter that is undergoing disintegration and is about to be cast away. The *entire cell* or elementary part is not alive. The inner matter is living—the outer formed matter has ceased to live. The inner matter alone is capable of growth, of germination. It may, therefore, be called living or germinal matter in contradistinction to the passive formed matter which envelopes it.

As each organized body has a certain end to serve in the economy of the living world, so each organ has its proper use in the animal or plant. In this adaptation of parts to the performance of certain functions, we see the strongest evidence of Design; and, amidst much apparent difference of form and obvious diversity of purpose, the anatomist recognizes a remarkable unity of plan—affording incontestable proof that the whole was devised by One Mind, infinite in wisdom, unlimited in resource.

Of the Functions.—The various processes by which are effected the ceaseless motion and changes so characteristic of living beings, are called in Physiological language, *functions.* The function is the work, or duty, or office in the economy performed or discharged by a particular tissue or organ. Contraction is the function of muscle; the secretion of bile is the function discharged by the liver; the secretion of urine that of the kidney. Digestion, or the operation of dissolving the food, is the function of the stomach, &c. The functions may be divided into two great classes: 1. *The vegetative functions;* and 2. *The animal functions.* The first class may be further subdivided into the *nutritive functions* which are connected with the preservation of the individual; and the function of generation, which is concerned in the propagation of the species. The functions specially characteristic of man and the higher animals are locomotion and innervation. They have been termed the animal functions—a definition which is not strictly accurate, but, nevertheless, practically advantageous.

Physical processes occurring in cells. Of Diffusion. Osmose, and of the Colloid state.—Physical changes of the utmost importance occur in connection with the various processes taking place in the elementary parts or cells of living organisms. By diffusion is understood the tendency which one fluid or gas manifests to mix intimately with another. Even if the specific gravity of a fluid below be far higher than that of one which is above, the latter will gradually pass upwards and the former downwards until they are equally diffused through, and intimately mixed with, each other. This tendency, therefore, does not depend upon specific gravity, but upon some peculiar properties of the matter itself. A solution of common salt has a diffusive power nearly twenty times as great as a solution of albumen of equal strength.

Closely related to the physical process of *diffusion* is *osmose*, in which the two fluids or gases are separated from one another by a porous diaphragm, and the result is influenced by the different degrees of adhesion exerted by the fluids or gases to the septum. Dutrochet, who first studied this process, showed that if a little alcohol were placed above a piece of bladder tied over the extremity of a funnel connected with a long tube, while the under surface of the bladder were allowed to touch the surface of water, the water, owing to its greater power of wetting the bladder, would enter into its pores, and thus pass upwards into the alcohol. This process continuing, the mixture of water and alcohol would gradually rise in the tube against the force of gravity, and would at last overflow. Here *endosmose*, the flowing inwards, of the water, greatly exceeds *exosmose*, the flowing outwards, of the spirit. The phenomena concerned in the process have been investigated by Graham, who has shown that alkaline solutions exhibit a remarkable *endosmotic* power (positive osmose), while acids exhibit the contrary, or *exosmotic* tendency (negative osmose).

In cells, and in various secreting organs, we have not only the most favourable conditions for osmose and diffusion but the means for maintaining these conditions. The process never comes to a standstill, as in our osmometers, because new acid or alkaline fluid is continually being generated to take the place of that which is removed, while the mixed and altered fluids are carried away. There is also provision for the preservation of the integrity of the porous septum, and for its reproduction.

By the recent researches of Professor Graham many very interesting points with reference to the physical constitution of several substances entering into the formation of the living body have been brought to light. He has shown that substances exist in the organism in what is termed a *colloid state*, in which condition they will not permeate a porous diaphragm; while, on the other hand, crystalloid substances will readily pass through such a diaphragm when in a state of solution in water. The fact is one of great practical importance, and has been most successfully employed for the purpose of separating poisonous matters of a crystalloid nature from their solution in the animal fluids (dialysis). The crystalloids readily diffuse themselves through a large quantity of water, while the diffusive tendency of colloids is very low.

It might be said, that the "living matter" of the cell in which such wonderful powers are supposed to reside is simply matter in a colloid state, and it may be admitted that some of the phenomena which have been observed in connection with this matter result from or are determined by its mere physical constitution. But living matter does not possess the same properties or powers in every part of its mass, and when magnified very highly, it is seen to be composed of spherical particles, varying somewhat in size. Colloidal matter, on the other hand, exhibits no such peculiarities, so that there is a great visible difference to be *observed* between this living matter and matter in a colloid state,—to say nothing of the changes occurring in the living matter, which distinguish it in the most marked manner from matter in every other known state.

Professor Graham has shown that certain *mineral* substances exist in a colloid as well as crystalloid form. Hydrated silicic acid and soluble alumina are examples. Perhaps the most interesting example in the living organism of an organic body, which may exist in both conditions, is the material of which the red blood corpuscle is composed, which sometimes, as in the case of the Guinea-pig, passes from the colloid to the crystalloid condition soon after it has been removed from the circulation and allowed to become stationary.

Of Assimilation and Excretion.—Organized bodies can appropriate and assimilate to their own textures other substances, whether inorganic or organic. This process is that which is most characteristic of living creatures: in virtue of it, animals and plants are continually adding to their textures new matter, by which they are nourished. Plants appropriate their nutriment from the inorganic kingdom, as well as from decaying organic matter; animals, chiefly from organic matters, whether animal or vegetable. Both possess the wonderful power of rearranging the constituents of these substances into forms identical with those of the elements of their various tissues—and of thus making them part and parcel of themselves.

Together with a process of supply, there is one of waste continually in operation. Animals and plants are ever throwing off effete particles from their organisms. These, under the name of *excretions*, appear in various forms—either as inorganic compounds, or as secondary organic products. Thus carbonic acid is given off in large quantities from animals; water, likewise, forms a considerable portion of their excreted matter, and serves to hold in solution salts, and secondary organic compounds, which result from the waste of the tissues. In this way, also, urea, uric acid, and biliary matters are excreted. In plants, water is excreted from the leaves, a phenomenon which has been compared to the perspiration of animals; and various other excretions, which are sometimes made to serve an additional purpose in the economy of the vegetable, besides that of getting rid of superfluous matter, are doubtless formed by the secondary combinations of the effete particles of their textures.

These two processes, *excretion*, or the expulsion of effete particles, and *assimilation* of substances from without, are necessarily mutually dependent. The *work* performed depends upon the destruction of particles whose place must be occupied by new ones, for were excretion alone to go on, the destruction of the organism must speedily ensue, by the gradual waste of the tissues; and as long as new matter is being appropriated, old particles must be thrown off, otherwise growth would be unlimited. In both processes new combinations are taking place, as it were, in opposite directions; in the one from the simple to the complex to form organized parts, in the other, from the complex constituents of the textures to the simple organic, or inorganic compounds.

Origin. Reproduction.—Organized bodies are always derived from similar ones. Some have supposed that out of decaying vegetable or animal matter minute animals or plants of other kinds may be formed: but it is most probable that in those cases in which they had been supposed to be formed, the seeds or eggs, or even the new beings themselves, had been concealed in the decaying matter, or conveyed to it from the surrounding atmosphere. Neither vegetation nor the development of animalculæ will go on in fluids which have been subjected to such processes as must inevitably kill whatever germs may have been diffused around or throughout them. Every year new facts are discovered which add to the overwhelming evidence in favour of the Harveian maxim, "Omne vivum ex ovo," using here the word *ovum* in the wide sense of a germinal element derived from a parent. The progress of Anatomical knowledge is every day revealing to us the mode of generation in the minutest and the least conspicuous forms of vegetable and animal life; and thus the hypothesis, which assumes that living objects may arise by a sort of conjunction of the inorganic elements of decomposing organic matter, becomes more and more untenable.

Of Spontaneous Generation or Heterogenesis.—Of late years the doctrine of spontaneous generation has been revived in more than one form, but, the conclusions in favour of such an origin of living beings are unsupported by sufficient evidence. Nor would it be possible were our highest magnifying powers increased tenfold, or even a hundred, or a thousand fold, to *see* the actual particles of matter combining to form part of a living structure. Those who assert that they have *seen* particles aggregating together to form a living being profess to have actually observed by a comparatively low power that which certainly cannot be seen under a power magnifying ten times more, and with advantages of demonstration which were not at their disposal.

Observations made by the use of the highest magnifying powers, and great improvements in the means of investigation not only render the doctrine of spontaneous generation less and less tenable, but demonstrate the origin of living beings from pre-existing ones in so many instances that the most sceptical ought to be convinced "that every living particle comes from a pre-existing living particle," "Omne vivum e vivo."

How beautiful is the provision which this power, possessed by organized bodies, of generating others, affords, for preserving a perpetual succession of living beings over the globe! The command, "Increase and multiply," has never ceased to be fulfilled from the moment it was uttered. Every hour, nay, every minute, brings into being countless myriads of plants and animals, to supply in lavish profusion the havoc which death is continually making; and it is impossible to suppose that the earth can cease to be in this way replenished, until the same Almighty Power, that gave the command, shall see fit to oppose some obstacle to its fulfilment.

In addition to this power of propagation, organized bodies enjoy one of conservation and reproduction of parts. Solutions of continuity, the loss of particular textures, whether resulting from injury or from disease, can be repaired. Parts, that have been removed, may be restored by a process of growth in the plant or animal, and in some animals the reproductive power is so energetic, that if an individual be divided, each segment will become a perfect being. This power of reproduction is greater, the more simple the structure of the organized body; the more similar to each other are the constituent parts, the more easy will reproduction be. Numerous examples of this power may be adduced, — the healing of wounds, the adhesion of divided parts are familiar to every one. New individuals are developed from the cutting of plants: the division of the hydra into two, gives rise to the production of two new individuals. If a Planaria be cut into eight or ten parts, according to Dugès, each part will assume an independent existence.

The power of reproducing single parts only, is possessed by animals higher in the scale. In snails, part of the head, with the antennæ, may be reproduced, provided the section have been made so as not to injure the cerebral ganglion. Crabs and lobsters can regenerate their claws, when the separation has taken place at an articulation; and spiders enjoy the same power. In lizards, the tail, or a limb, can be restored, and in salamanders the same phenomenon has been frequently witnessed; and even in man certain tissues may be reproduced.

In the reproduction of lost parts, it must be borne in mind that changes precisely similar to those which take place during the development of the textures in the embryo, occur; in fact, the new tissues are developed from amorphous living matter. In all cases masses of simple structureless germinal matter exist, and grow, and multiply before any form or structure is manifested.

Of Putrefaction.—Dead organized matter is speedily dissipated under certain conditions. These are the presence of air, moisture, and a certain temperature, or contact with an organic substance which is itself undergoing decomposition. The conditions under which the integrity of the organic substance was preserved, have become altered, it is destroyed, and its elements are set free to obey new affinities and form new compounds.

When we consider the large number of equivalents which enter into the formation of each molecule of organic compounds, it need not excite surprise that a great variety of products results from the decomposition of animal and vegetable matter.

This decomposition is usually accompanied by *fermentation* or *putrefaction*. It used to be supposed that these were purely chemical changes, due to what was considered catalytic action, but it is now known that in both processes living organisms play a most essential part. The process of *fermentation* is dependent upon the growth and multiplication of vegetable organisms, and it is probable that the carbonic acid and alcohol so characteristic of one kind of fermentation result from the death of living particles under the conditions present. In the process of putrefaction, the researches of Pasteur have shown that so far from oxygen being necessary to the life of the simple living beings concerned, there are certain forms of infusoria which not only pass their lives without oxygen, but are killed by its presence.

All experiments have proved that the germs from which these organisms are developed gain entrance from without. The size and transparency of some of these particles are such that they are only just visible by an exceedingly good power which magnifies upwards of 5,000 diameters.* It is certain that germs exist far more minute than these. They may even exist in the interior of the higher organisms. We know they are present in great number on the surfaces of mucous membranes, and even in the interior of glands. It is probable that such germs exist in the blood, and would multiply rapidly if the state of the fluid once became favourable. Nor are cases wanting in which the decomposition of tissues, and of the blood, and the multiplication of such low forms of life, have occurred in the living body itself,—the change of course being soon followed by death. The matter, however, which is the seat of this change is dead. The life of the tissue does not become the life of the infusoria, as some have maintained, but the tissue becomes disintegrated, and the infusoria, derived from infusoria that lived before them, live upon the products, just as other organisms may live upon the matters resulting from the death of the infusoria. Living matter never lives upon living matter by the life of one organism being converted into the life of another, as some have speculated. Living matter must itself die ere it can pass as food to form part of any living organism.

* How to work with the Microscope, 3rd edit., p. 217.

In form, in size, in duration, the contrast between organized bodies and inorganic substances is most striking. The inorganic matters are aëriform, liquid, or solid: they are prone to assume the crystalline form, and to exhibit surfaces bounded by right lines, and uniting to form angles. No distinction of parts, or organs, is to be found in the mineral substance; its minutest fragment is in every respect of the same nature with the largest mass. A portion of sand not weighing a grain contains particles of the same form and size as those of the largest sand-banks known. Inorganic substances, as compared with organic, are unlimited in size and duration. Their bulk is indefinite and they retain the same condition for ages, without augmentation or waste, provided no external agent be brought to act upon them. None of those internal actions or processes, which have been described in the organized body, occur in the unorganised one; there is no inherent motion, no power of reproducing lost or injured parts, no growth, no excretion, no conversion, no formation of substances which did not exist before, no generation. From age to age the mineral remains unchanged, obedient only to the common laws of matter, and unable to modify their operation by any inherent power.

OF FORCE.

Correlation of Forces.—Force, which is constantly associated with matter in all its states, is as indestructible as the matter itself. The state or condition of the matter may be changed, but matter cannot be *generated* or *annihilated.* In like manner the form or mode of force may be altered in such a way that one form of force, as motion, may be converted into another, as heat, electricity, chemical affinity, and the like, and either of the latter may be made to resume the form of simple energy or motion. It is probable that all the physical forces are mutually convertible, but it is certain that force cannot be *produced anew* or *annihilated.*

Gravitation, Elasticity, Cohesion, Adhesion, Heat, Electricity, Magnetism, Light, Chemical action, are different forms or modes of one and the same force. The labours of Helmholtz, Grove, Mayer, and others, have proved conclusively the mutual relation, or "*correlation,*" of the physical forces. Just as very different quantities of different kinds of matter represent, or are equivalent to one another in combination, so it has been conclusively proved that one kind of force gives rise to an equal quantity of the same kind of force which produced it, or to an equivalent amount, which is constant, of some other kind of force. The exact amount of heat produced by the conversion of motion into heat has been estimated, and the mechanical equivalent of heat has been determined by the labours of Mr. Joule. A certain fixed amount of heat is always set free by the same mechanical action, lasting for the same period of time. The "motion" becomes the "heat." So the chemical combination of certain equivalent quantities of elementary substances is equivalent to the force of gravitation by which a certain quantity of matter is attracted towards, or tends to combine mechanically with other matter according to its mass; and in this mechanical combination a definite amount of heat is produced at the moment of the mechanical contact. What was *motion* is now *heat.*

The same laws apply to the physical phenomena occurring in the living organism. Chemical combination there becomes converted into heat, and the latter into motion. The amount of *work* performed by the muscles is probably due to chemical change, and particularly to oxidation occurring in the nervous system. This mechanical action of the muscle, there can be no doubt, is one of the sources of animal heat. But it must not be forgotten that a far greater amount of *work* results from the same amount of chemical change in the animal economy than can be obtained by any known machinery. The wasted force in the most perfect mechanical instrument is far greater than the force which results in actual work. In muscular action, on the other hand, we have an actual amount of work performed, which seems perfectly marvellous, when the very small weight of the machinery and the very small amount of chemical change required to keep it in action are considered. Still there can be no doubt that muscular contraction is a physical process, although physiologists have hitherto failed in their endeavours to ascertain the precise nature of the change which occurs.

Relation of Physical Forces to Vital Power.—It has been said that there exists not only a correlation between the physical forces themselves, but between the *vital* and *physical* forces. The forces, however, which have been denominated *vital* by those who take this view, are really only physical forces manifested in living things. The sun is the source of all the physical forces operating in living beings. Living plants collect or absorb this force, and store it up in the various substances which are produced in their organisms. These, in their turn, become the food of animals, and thus the solar energy in the form of light and heat and chemical rays collected by plants, and retained by them in a quiescent state in the form of chemical combination, again becomes resolved into mechanical and other forces in the animal, and is the source of those active movements which distinguish animals from vegetables in such a remarkable degree. All the work performed by our muscles, all the heat developed in our bodies—all the chemical actions resulting from the union of oxygen with carbon, hydrogen, and other substances in the animal body, have their original source in solar energy.

Nor is it surprising, that many who have studied these matters should have fallen into the error of concluding that *life* itself was but another mode of force; and although this inference has been carefully avoided by Helmholtz and Mayer, and some other philosophers, many have expressed themselves as if they considered that we might for *life* substitute *solar energy*, *heat*, or *motion*.

Although there are some authorities who would not hesitate to affirm that every plant and animal is the mere result of changes in matter brought about by solar energy alone, it cannot be, even in a very loose sense, affirmed that a watch or a steam-engine was formed or built by the sun. And yet, to the physiologist, what poor imperfect contrivances the latter must seem, for, in spite of all the mighty human efforts required for their production, they cannot even repair themselves, much less perpetuate their race!

Hitherto not the slightest approach towards the formation by artificial means of anything having the properties of the lowest and simplest form of living matter has been made. Between the living laboratory and the chemists' laboratory there is scarcely any real analogy, for the former builds itself, and the elements therein appear to place themselves in the exact positions required for the production of the particular substance which is to be formed. This self-constructing, self-maintaining, and self-propagating power, is referred to a something which is certainly but temporarily associated with the matter that exhibits it, and which seems totally distinct from ordinary force, since it compels the elements to take up the required special relations. The something to the influence of which all these apparently spontaneous operations is due, may be termed *vital power*.

OF LIFE.

Within every living organism, and within every elementary part or cell, are ceaseless motion and change. The absorption of new lifeless material, its conversion into living matter, the removal of that which has ceased to live, comprise a continual succession of actions in which organization and disorganization—life and death—are unceasing. But in these actions are comprised phenomena of two distinct classes, different in their very nature—*physical* phenomena, which also occur in the external world; and phenomena truly *vital*, the nature of which is not to be so explained. The *spontaneity* of the actions of the *living* structure, its self-formation and its power of multiplication, distinguish the simplest organism from the most perfect mechanism of human construction.

Life cannot be manifested without the co-operation of matter and the physical forces, but it does not therefore follow, as some have maintained, that the physical force, any more than the matter with which it is associated, is the *life*. Nor do heat, light, chemical affinity, &c., *evoke, excite*, or *increase* vital action, but they only accelerate certain physical changes in the lifeless matter which surrounds and protects the living matter that is within (Plates I and II), in consequence of which the passage of the nutrient pabulum through this protecting envelope, and its access therefore to the living matter are greatly accelerated. In this way the influence of heat and moisture in promoting the development of seeds may be most easily explained.

Again, the LIFE of a complex organism, as usually defined, is made up of phenomena much more complex than those exhibited in the LIFE of a single "cell." Instead of commencing the discussion by referring to the changes which take place in the most simple living organism in the simplest condition of its existence, some observers, and especially physicists, have passed at once to the consideration of the phenomena as they occur in a fully developed animal, or more generally in man himself. As would be supposed, the utmost confusion has resulted. The terms *physical* and *vital* have been used indiscriminately, and, gradually, many seem to have convinced themselves that *all* the changes occurring in living beings are physical.

It is not to be wondered at, that those who have taken up a view so obviously opposed to broad facts as this is, should have refrained from attempting to discuss in detail the changes which occur in a single cell; or that by some, the existence of the processes of formation, growth, and multiplication, as they take place in all living matter, has been almost ignored. These are truly vital phenomena, and occur in living beings only, but the development of heat, light, electricity, and the like, are physical phenomena, whether they occur in living organisms or in inanimate matter. Strange to say, the latter phenomena have been called *vital* when they occur in living beings, *physical* when they take place in the inanimate world; but, as they are essentially the same in all cases, it is obvious that the same terms should be applied to them. The living or germinal matter alone is the seat of *vital actions*, while in the lifeless *formed material* physical and chemical phenomena only are in operation. (See Figs. in Plates I to IV).

Matter derives *vital* powers or properties in all instances from a previously existing organism. The vital part of the impregnated egg consists of living matter, which results from living matter belonging to the organisms of the beings that produced it. It manifests a life independent of that of its parents, and undergoes development if the requisite physical conditions are supplied. Thus is life in its mysterious association with matter transmitted from one living being to another; and the life of a present generation of animals and plants has its source in that of a previous generation.

From a very early period in the history of natural science, there has been a tendency to ascribe these effects to an imaginary principle, or Entity, possessing powers and properties which (however men may try to impress themselves with a contrary notion) would entitle it to rank as an intelligent agent. It is true, that, according to most of the advocates of this doctrine, this power is supposed to be superintended and controlled by the Deity himself, and, by this supposition, they have screened themselves against the accusation of attributing to a creature the powers of the Creator.

A little examination of this doctrine will shew that it has no pretensions to the title of a theory.

Aristotle attributed the organization of animals and vegetables, and the vital actions exhibited by them, to a series of *animating principles* (ψυχαι), differing according to the nature of the organized bodies constructed by them, and acting under the direction of the Supreme animating principle (φυσις). He supposed that each particular kind of organized body had its proper animating principle or ψυχη, and that the variety of the former really depended upon certain original differences in the nature of the latter, so that every distinct species of animating principle would necessarily have its appropriate species of body.

Harvey, likewise, assumes the existence of an *animating principle*, by which every organism is moulded into shape, out of materials furnished by the parent, and which, pervading the substance, regulates the various functions of its corporeal residence. But, at a subsequent stage of his inquiries, in assigning the blood as the special seat of this principle, he advances another supposition totally at variance with his previous hypothesis; namely, that as, during the development of the chick in ovo, the blood is formed and is moved, before any vessel, or any organ of motion exists, so in it and from it originate, not only motion and pulsation, but animal temperature, the vital spirit, and *even the principle of life itself.* So completely biassed were the views of this illustrious man, by his exaggerated notions respecting the nature and properties of the blood! Nor are many writers, in our own days, free from such vague notions. One who endeavours to introduce a new vital philosophy talks about the brain cells being the highest *parasites* (*!*) which live upon the *life of the blood.* And very many persons speak of the blood as distributing "life" to the tissues, as if life were something that could be caused to circulate in solution in a fluid, and be separated from it, and absorbed by this or that tissue!

The celebrated John Hunter, who does not appear to have been acquainted wi^th the views expressed by Harvey, revived a somewhat similar hypothesis; and it is curious that the same fact should have so attracted the attention of both as to have given the first impulse to their speculations. This fact was, that a prolific egg will remain sweet in a warm atmosphere, while an unfecundated one will putrefy. The views of Hunter were received with very general favour by English physiologists.

Hunter ascribes the phenomena of life to a *materia vitæ*, diffused throughout the solids and the fluids of the body. This *materia vitæ* he considers to be "similar to the materials of the brain;" he distinguishes it from the brain by the title "*materia vitæ diffusa*," while he calls that organ "*materia vitæ coacervata*," and supposes that it communicates with the former through the nerves, the *chordæ internunciæ*. And Mr. Abernethy, in commenting upon these views, explains Mr. Hunter's *materia vitæ* to be a subtile substance, of a quickly and powerfully mobile nature, which is superadded to organization and pervades organized bodies; and this he regards as, at least, of a nature similar to electricity. Such doctrines need no comment.

Müller advocated the presence of an "*organic force*," resident in the whole organism, on which the existence of each part was supposed to depend, and which had the property of generating from organic matters the individual organs necessary to the whole. "This rational creative force is exerted in every animal strictly in accordance with what the nature of each requires; it exists already in the germ, and *creates* in it the essential parts of the future animal."

An hypothesis, not dissimilar to the last mentioned, was advocated by Dr. Prout, and he supposed that a certain *organic agent* (or agents) exists, the intimate nature of which is unknown, but to which very extraordinary powers are ascribed. It is superior to those agents whose operations we witness in the inorganic world; it possesses the power of controlling and directing the operations of those inferior agents. "If," says Dr. Prout, "the existence of one such organic agent be admitted, the admission of the existence of others can scarcely be withheld; *for the existence of one only is quite inadequate to explain the infinite diversity among plants and animals.*" "In all cases it must be considered an ultimate principle, endowed by the Creator with a faculty little short of intelligence, by means of which it is enabled to construct such a mechanism from natural elements and by the aid of natural agencies, as to render it capable of taking further advantage of their properties, and of making them subservient to its use."

The hypotheses of Aristotle, Müller, and Prout, and the earlier of those proposed by Harvey, seem all alike; they assume that organization and life are directed and controlled by an Entity, or Power, "endowed with a faculty little short of intelligence," the ψυχη of Aristotle, the animating principle of Harvey, the organic force of Müller, and the organic agent of Prout. What the mechanism may be by which this entity acts, they do not determine; but it is evidently such as bears no analogy to any known natural agency. Its existence is independent of the organism, for it has directed both the organising process and the living actions of the being. Whence then is it derived? According to Müller, from the parent, for it exists in the germ,—it derives its powers from the same source, and its pedigree may therefere be traced to the first created individual of each species of animal or plant. Are we to conclude, then, that organic agents generate organic agents, and transmit their powers to their offspring? Or must we assume, that, for each newly generated animal or plant, a special organic agent is deputed "to control and direct" its organization, development, and growth?

But many phenomena of the utmost importance to living beings, as already shown, are in their nature physical and chemical, and the laws under which they occur are well understood. The changes effected in the air and in the blood by respiration, the phenomena of absorption, and, in some degree, those of secretion, are the results of purely physical processes. It is in the highest degree probable that many of the actions of the nervous system are due to physical changes in the two kinds of nervous matter, substances of complex constitution and high equivalent number, and therefore prone to change. The generation of heat is due to the same chemical phenomenon as will give rise to it in the inorganic world; and electricity is also similarly developed within the body. How entirely dependent on physical changes are the senses of vision and hearing, and how completely are their organs adapted to the laws of light and sound.

The resistance which living animals introduced into the stomach are capable of offering to its solvent powers, and the digestion of the walls of the stomach by its own gastric juice, after sudden and violent death, seemed to denote that the dead animal or dead stomach had lost a something which previously protected them against the influence of the gastric fluid. This something, according to Hunter, was the *materia vitæ*, according to Prout, the organic agent. But such a result as this can be explained in a very simple way according to the view of structure given in Chapter I. In the texture still connected with the body of a living animal, and for a certain time after its removal, currents of fluid are continually passing through every part of the formed matter or tissue, to and from the masses of germinal or living matter, which are regularly distributed through it. This slow circulation of fluid derived from the blood, continues in a definite direction as long as the germinal matter remains alive; and while it continues the tissue cannot be permeated by another fluid. When the germinal matter dies, however, all these currents cease, and any fluid with solvent properties in which the tissue may be immersed, as the gastric juice, soon permeates it and dissolves it. So that the tissue is not prevented from being dissolved, by the influence of any vital force or power, but simply by the presence of fluids which permeate it in definite directions while it still lives; the flow of these fluids ceasing as soon as the living matter of the tissues dies. Thus it is that a living tissue resists the action of the gastric juice, and a dead tissue, or more correctly speaking a tissue, the germinal matter of which has ceased to live, and to and from which currents have in consequence ceased to flow, is soon dissolved by it. The process of digestion itself is probably only chemical solution.

So much for the dependence of life and organization on a controlling and directing *entity*. John Hunter rejected this doctrine entirely, but, as has been stated, went so far as to assume the presence of a peculiar *material of life*, which he maintained pervaded the organism and gave vital properties to solids and fluids. If, however, such a constituent existed in the body, it ought to be demonstrable by chemical or other means. Mr. Abernethy's doctrine that this *materia vitæ* was electricity or something akin to it is opposed to obvious facts. Electricity requires for its development the reciprocal action of different kinds of matter, and it is abundantly evolved in various changes taking place in living beings as the necessary result of the action of well known chemical laws. If, therefore, organization and vital operations were due to electricity, this agent would at once be *formed by, and govern and direct* the formation of, each organism.

On the whole, we may conclude, then, that the theory which attributes the phenomena occurring in living organisms to the action of physical and chemical forces alone, rests upon no secure foundation, and is indeed controverted by important facts, and that the opposite doctrine, which supposes the existence of a *materia vitæ*, or of a *subtile* organic *agent*, possessing powers little short of reason, is equally untenable.

We have seen that the phenomena usually termed vital really comprise two distinct classes of actions—actions purely *physical and chemical*, and actions purely *vital.*

The truly vital actions which have been alluded to can only be accounted for by attributing them to the influence of some peculiar power totally distinct in its nature from any form of ordinary force. This is not a power which exists as it were in a concentrated state in the germ, and gradually expends itself as the tissues are evolved, or as the development of the race proceeds, but it is a power which is temporarily associated with, and influences for a brief period of time, every particle of matter which becomes living. It is a power which may be transmitted infinitely through the infinite multiplication of living matter without any increase or diminution in its intensity. As soon as tissue or any of the peculiar compounds result from the changes occurring in this living matter, its wonderful vital powers have ceased for ever.

Of the so-called vital stimuli. Many suppose that organized bodies being acted upon by certain vital stimuli develop vital actions. Thus heat is supposed to be the vital stimulus which *excites* the changes resulting in the development of the chick, light is supposed to excite or stimulate certain changes going on in the vegetable organism, nay, lifeless inorganic matter is regarded as an excitant to increased vital action in certain cases. A particle of sand falling upon the conjunctiva is followed by increased action as shown by the more rapid growth of cells, and increased vascularity. It is said the particle of sand has *excited* these changes. It is an *irritant*. But the heat, light, and particle of inorganic matter are probably all perfectly passive. They have not been instrumental in actively *exciting* changes, but the conditions under which life was carried on before, have been altered, and the alteration is really due to changes not in the living matter, but in the formed lifeless matter by which it is surrounded. In consequence it permits pabulum to flow towards the living matter *more readily* than before. The living matter is not *excited* to live faster, but in consequence of more pabulum having access to it, more matter becomes living within the same period of time. The influence of the *excitant* is therefore of a passive character. It does not excite dormant energies or evoke vital actions, but by it some of the restrictions under which the matter lived previously are removed.

It is remarkable in these days, when the explanation of phenomena by hypothetical agencies, forces, or powers is assailed on all hands, that even some of those observers who have been specially distinguished for their opposition to any doctrine which admits the influence of vital as distinct from physical force, should pertinaciously insist, and without attempting to explain by what mysterious means, that a living cell can exert a modifying influence upon the action of cells around it. A cell undergoing increased action is supposed to excite increased action in those cells in its immediate neighbourhood. For example, Professor Virchow asserts that cells may be *incited* by a *stimulus* directly applied to them to take up an increased quantity of material. He maintains that every vital action presupposes an excitation or irritation. The illustration he gives for the purpose of explaining what he means by *irritation* will perhaps enable the reader to form a clearer notion of the views entertained upon these matters in the present day than a long exposition of the doctrines themselves. "Suppose three people were sitting quietly on a bench, and suddenly a stone came and injured one of them, the *others* would be *excited*, not only by the sudden appearance of the stone, but also by the injury done to their companion, to whose help they would feel bound to hasten. Here the stone would be the *irritant*, the injury the *irritament*, the help an expression of the *irritation* called forth in the bystanders." So that not only have the uninjured cells a power of sympathising with their less fortunate companions, but they manifest a desire to hasten to afford them active assistance in their difficulty!

Such a doctrine is perhaps not more untenable or more unsupported by evidence than that which gives to insoluble inanimate matter the power of *exciting increased action* in living things. In every one of the cases in which this increased action occurs, it may be explained by the increased facility of access of pabulum to the living matter which is brought about by the so-called irritant or excitant. When a particle of sand, falling upon the conjunctiva, causes the removal of a portion of the outer layers of cells which in the normal state form a smooth membranous investment of uniform thickness, the thickness of this tissue protecting the vessels is diminished at the seat of injury, and as a matter of course a larger quantity of nutrient matter will permeate the thin layer which remains in a given time.

Again it must be remarked that even in the present day many observers admit the existence of some sort of power or force or agency which *directs or controls* the operation of the various actions going on in different parts of an organism, and is supposed to exert its influence through cell walls and other tissues, and to be capable of governing and regulating if not determining, the changes which take place in matter situated at some distance, and in the formation of which it has taken no part. Dr. Carpenter speaks of a power manifesting itself in organisms, which, according to him, exerts upon the cells and other structures, as well as upon the forces concerned in their production, a control which may be compared with that exercised by the "superintendent builder who is charged with the working out of the design of the architect." The germ supplies the "directive agency" and a distinction is made between *directive agency* and *constructive force*, which last is maintained to be but another mode of *heat.* Dr. Carpenter also speaks of "germinal capacity," but this, according to him, is a *condition* which, although transmitted from one organism to another, has its parallel in the inorganic world, in the fundamental difference in properties which constitute the difference between one substance, whether elementary or compound, and another! Now those phenomena which are ascribed by Dr. Carpenter to what is termed Germinal Capacity and Directive Agency, are not peculiar to the germ, for there is not a living cell in any organism at any period of life in which such phenomena are not manifested in some degree. Moreover, long before any tissue is produced, a mass of living matter may be removed from an organism and carried far away from the influence of "directive agency," and may nevertheless give rise to tissues like those of the organism from which it was derived. Is the directive agency capable of being divided and subdivided, each subdivision having an influence equal to that of the whole? If so it can hardly be compared to the control exercised by the superintendent builder.

Mr. G. H. Lewes defines life as "a series of definite and successive changes, both of structure and composition, which take place within an individual without destroying its identity." It is doubtful if a *series* of changes is necessary to life; all we know is that lifeless matter passes into living matter and lives. Living matter exhibits no structure whatever, so that life may certainly exist without involving changes of structure. The definition seems to apply to the life of man and the higher animals rather than to living things generally. There are many masses of living matter which cannot be regarded as individuals. A white blood corpuscle or a pus-corpuscle is alive but it exhibits no structure and we know nothing of its composition while it lives. It cannot be regarded as an individual unless an individual may consist of millions of individuals, and many of these individuals differ from one another in very many essential points. Moreover, when a mass of living matter takes pabulum, increases in size and divides into numerous masses, what becomes of its identity? Such words as "individual" and "identity" would destroy the value of any definition.

Mr. Herbert Spencer proposes to define life as "The definite combination of heterogeneous changes, both simultaneous and successive, in correspondence with external co-existences and sequences." While this definition does not exclude lifeless machines it is doubtful if it would include many things which possess life although apparently quiescent. This writer, however, admits "the *tendency* to assume the specific form, inherent in all parts of the organism," which is peculiar to living things. He does not, however, attempt to explain the nature of the *tendency*, or why living matter alone exhibits it. What causes the tendency? We know that the particles do actually arrange themselves in a very peculiar and special manner which cannot be imitated, and we want to know why they do so. Is it unreasonable to suppose that they take up their peculiar and constrained position in consequence of being influenced by a very peculiar force or power? It is difficult to help calling for an hypothesis to account for the tendency to assume specific form, which is admitted.

It has often been suggested that the movements of living beings are due to physical changes, but it must be borne in mind that different classes of movements are observed in connection with living beings. Under the head of *contractility* have been described several phenomena differing in their essential nature. For instance, the contractility of muscle, the vibration of cilia, and the oscillations of the spermatozoa, are different in their nature from the movements observed in the white blood corpuscle, pus and mucus corpuscle, and in many of the lowest and most simple organisms, such as the amœba, the foraminifera, &c. These and other movements will be considered in Chapter III; but with reference to the latter class of movement it may be at once remarked that they cannot be accounted for by physics, nor are they to be explained by any chemical changes occurring in the matter itself. They have been referred to osmosis, and to diffusion, but no such movements as these occur when conditions favourable to diffusion exist, while, even if they had been shown to depend upon these processes, we should still have to learn how the substance concerned in these movements was produced. The motion does not at all resemble any other kind of motion whatever. The moving power seems to reside in the particles themselves, and if such a moving mass be divided into several small portions, each portion will exhibit movements, while any very sudden shock, as of electricity, will at once destroy the capacity for movement, and at the same time cause all those phenomena which we regard as evidence of life to cease for ever. It has been assumed that these movements are peculiar to certain cells or bodies, and they have been termed "amœbiform cells" in consequence, but it will be shown that such movements occur in every form of living matter. They are peculiar to living matter, but not to any special organisms.

It is to be regretted that many who have recently written upon the subject of *life* have not expressed themselves clearly. Not unfrequently assertions are met with which are incompatible with one another, and even in the writings of the best modern thinkers there is much that is obscure and indefinite. Almost every writer seems to avoid stating in what points the simplest living things resemble, and in what they differ from, inorganic matter, and instead of discussing in the first place the nature and causes of the phenomena occurring in a mass of the simplest living matter, and then proceeding to the consideration of those observed in more complex organisms, the latter are almost exclusively referred to. Very different classes of phenomena are often included under the same head, and futile attempts made to account for opposite and antagonistic actions by the same hypothesis.

Although we are quite unable to say what sort of force vital power is, to isolate it, to examine it, or to give any satisfactory account of the exact manner in which it exerts its peculiar influence upon inanimate matter, we seem compelled to admit the existence of such a power, because the facts observed cannot be explained without such an admission. Every attempt hitherto made to account for the various phenomena which occur in living beings by physical actions alone has signally failed, and although some physiologists still hold to this view, they are compelled to ignore those phenomena which they cannot explain, and to discuss only those which occur *after* the peculiar (vital) actions have ceased to manifest themselves. They in fact describe as *vital acts* the destruction of peculiar substances which subtances resulted from the death of living matter, which occurred perhaps a long time before.

Strange as it may seem, it has been argued that as these unquestionably physical changes were formerly considered to be due to vital forces, physical forces only are concerned in vital phenomena. If those who hold such opinions would follow out the changes which occur throughout the life of the simplest organism, or even single cell, they would probably soon be convinced that something more than physical agency was required to account for the results observed.

It is unsatisfactory to many minds to be thus compelled to admit the action of a force or power of the nature of which nothing is yet known, but it is better to do so than to pretend to be able to give a satisfactory explanation of phenomena which science in its present state is incompetent to account for.

Nevertheless an attempt has been made here, to assign to the word *vital* a definite meaning, and to distinguish *vital* from *physical* actions. It has been shown that besides the actions which may be explained upon the same principle as actions taking place in inanimate matter there are changes in every living being, and in every cell, which cannot be so explained or accounted for, which are peculiar to matter derived from living beings. Whatever the real nature of these changes may be, they cannot result from the action of any ordinary force, nor do they obey the same laws. The seat of these peculiar actions has been pointed out, and has been distinguished from the seat of the physical and chemical changes.

It will be remarked that the view of the vital processes advocated in these pages differs from others in the very essential point, that the assumed vital power is supposed to influence only particles of matter with which it is associated, and its association with matter is but temporary. The power bears neither a qualitative, nor as far as can be at present proved, a quantitative relation to the matter. It cannot act upon matter at a distance, nor upon the same particles for any length of time. The particles are influenced by it, but soon pass from its control. If their place is not soon succeeded by new particles, vital action must cease, but as long as new particles come into contact with those which live already, the action is transmitted, and so on for ever (not simply transferred from particle to particle so that one gains what another has lost). The direction and control exerted, are exerted upon particle after particle. The various particles are not placed in this or that place by a controlling power, ordering and influencing all, but each particle for the time being seems to direct and control itself, and its power is transmitted to new particles without loss or diminution in intensity, and sometimes with actual increase.

Certain physical conditions interfere with the manifestation of this power. The action of air, and various external circumstances, cause death. In fact it would seem that inanimate matter to become living, must come into contact with that which lives, only in exceedingly minute portions at a time. If much lifeless matter comes into contact with living matter, the latter dies. Death is simply the cessation of the vital changes, and is due alone to the action of physical conditions. Physical forces invariably cause death, but they cannot give rise to life. Ordinary force and life seem to be opposed.

OF THE DIVERSITY OF FORMS OF LIVING BEINGS.

How shall we explain the strange process of organization, in the production of that infinite diversity of forms, that "insatiable variety of Nature," which is so conspicuous in the vegetable and animal kingdoms? The view that has been most generally entertained is, that the living matter of each species of animal or vegetable was created to propagate after a certain fashion, and after that only; the living matter of which these organisms consist in the early stages of development, must have the power of evolving the adult tissues of animal or plant of its own species only; the simple volvox develops, from its interior, matter which becomes volvoces; and the cell which forms the important part of the ovum of the elephant or the mouse, is able, by an inherent power of multiplication, to evolve the tissues and organs peculiar to each of those animals respectively.

The particular endowments of the organic matter, composing the various tribes of animals and plants, are transmitted from parent to offspring. But, as is well known, they admit of certain modifications under the influence of circumstances affecting the parents, as is proved both in the animal and vegetable kingdoms in the production of hybrids, and of forms differing in certain characters from either parent. "Two distinct species of the same genus of plants," says Dr. Lindley, "will often together produce an offspring intermediate in character between themselves, and capable of performing all its vital functions as perfectly as either parent, with the exception of its being unequal to perpetuating itself permanently by seed; should it not be absolutely sterile, it will become so after a few generations. It may, however, be rendered fertile by the application of the pollen of either of its parents; in which case its offspring assumes the character of the parent by which the pollen was supplied." The same thing precisely occurs among animals, and the mule, produced by the union of different species, is incapable of breeding with another mule, although it may produce offspring with an animal of the same species as either of its parents,

Various facts show that physical agencies exert an important influence in modifying organic development. The most potent cause of these changes has been climate; but particular customs and usages, connected with the uncivilized state, have not been without their influence. Climate also produces considerable modifications in the size and other characters of the lower animals. The very striking alterations in character which are known to result from the influence of such external conditions has led many observers to suspect that still more important modifications may really be due to these causes alone, and that possibly two or more different species may have been produced by the action of dissimilar physical conditions upon the descendants of different members of the same original stock. It is true that the mind attempts in vain to realize the direct immediate creation of a living being out of inorganic matter, and it is therefore not to be wondered at that from time to time strong opposition to the old view, regarding the origin by separate special creations, of all the countless beings which surround us, should have arisen, or that attempts should have been made to substitute for it some theory which should account satisfactorily for the phenomena, without the necessity of accepting a dictum, or adopting an assumption which cannot be proved. But it is remarkable that some of the strongest opponents of the old account of the creation, experience no difficulty in accepting the doctrine of the spontaneous or fortuitous origin of organic particles, and their aggregation to form living organisms. No one attempts to explain how the atoms composing the first living particle, brought themselves together, any more than the nature of the forces associated with the inorganic atoms prior to their concourse, or the condition of the matter at a still earlier period than this, to say nothing of the origin of the matter itself.

Of late years the idea has been gaining ground that all the different plants and animals which exist, and which have existed from the beginning, have resulted entirely from the constantly modifying influence of continually altering external circumstances upon what was originally a very simple form. And although the facts of the case compel the admission of inherent forces, acting as it were, from within living beings, the internal changes themselves have been attributed to the influence of pre-existing external conditions.

The origin of a single, growing, multiplying mass of formless, structureless, organic matter being admitted, it is said that countless modifications in structure and function of the masses resulting from it, and their descendants, are easily explained by the modifying influence of the different external conditions to which these must be subjected as the numbers increased, and necessarily became removed from the spot where the first concourse of inorganic particles, with its mysterious result, occurred.

Of all the views ever advanced in this direction, those of Mr. Darwin, "On the Origin of Species, by the process of Natural Selection," published in 1859, have received the warmest support, and although we cannot attempt to give more than a very rough outline of this view, the hypothesis is so full of interest, and is so fertile of investigation, that we shall draw attention to it in few words, and refer the reader for further information to the work itself.

The offspring of living beings, it has been truly observed, exhibit a tendency to inherit the characters of those from which they sprung. This is termed *atavism.* But there is also a tendency in the offspring to vary in certain particulars from the original stock, and an alteration having occurred is transmitted to the descendants. Now if it so happens that any of these modifications from the primitive type give advantages to their possessors over those which have them not, it follows that in the struggle for existence individuals of a species which vary in a way advantageous to themselves, possessing perhaps greater facilities for obtaining food, or greater power of resisting external destructive agencies, will survive and multiply, while their less fortunate fellows will gradually die out. In this way the former will be "naturally selected" from the latter, and by the strong tendency to inheritance, any variety thus selected will propagate its newly-acquired form. The tendency to the production of new characters, and the tendency to transmit these to the descendants, working through infinite time, must, it is argued, produce great differences in the character of the various organisms descended from the same primary stock. The modifying influences of external circumstances, climate, food, temperature, acting through infinite time, and varying remarkably in places remote from one another, and in the same places, in successive epochs, will undoubtedly account for changes in character. Peculiarities thus arising, it is obvious may be further developed or diminished, according as the conditions by which they were induced persist, or become replaced by new ones. Although Mr. Darwin himself does not attempt to explain how many of these peculiarities arose, some seem to have regarded them as the result of accident occurring at a very early period of embryonic life, while many, who do not seem to admit that the supposed original simple living form, or forms, were endowed with any internal powers whatever at the time of their origin, attribute them to the influence of external circumstances alone.

By selective breeding, in certain cases, for many generations, very different forms undoubtedly result, so different, indeed, that a superficial observer might consider them at least as distinct as many creatures, admitted upon all hands, to be truly distinct species; and if the same modifying causes continued, it is difficult to conceive to what extent the modifications might proceed. It is urged there is no limit to the continuance and augmentation of changes thus induced. But all the instances hitherto adduced differ from true species in one very important particular. Members of different species seldom breed with one another, and in the few instances in which this does take place, the resulting mules or hybrids, if they are not absolutely barren, never breed with mules of the same kind, so that there is this most important fact opposed to the application of conclusions arrived at from observations upon varieties of one or more domestic species to the production of the various and undoubtedly distinct species of animals and plants now existing. The offspring of mere varieties is fertile, and they breed one with another, and there seems no limit to the varieties that may be produced in certain cases, but for this reason they must be considered varieties and not species.

It must not, however, be forgotten that the tendency to vary under altered conditions is not manifested in very many species of existing animals. The slightest alteration in external conditions, at once destroys certain animals and plants. They do not live long enough to be modified by physical agencies. The capacity for existence, under a variety of different conditions, and tendency to gradual structural alteration, in consequence, seems indeed to be limited to comparatively few of the existing species of animals and plants. It would appear as if the life of the great majority of living beings was almost *dependent* upon the persistence of the particular external circumstances under which they happen to live. Moreover, the degree of change which actually occurs in different animals, which are capable of being domesticated, is very great. A familiar and very striking example occurs in the case of cats and dogs. How few the varieties of the former, and how comparatively slight the variation which does occur as compared with the latter. The organization of the cat is, as it were, much less plastic than that of the dog.

Looking at the facts broadly and generally, there undoubtedly seems much in favour of Mr. Darwin's view, but when we come to consider the structural changes which must occur in a single organ of one of the higher animals, it is more difficult to accept his conclusion. Changes occurring in each stage of development of a single organ seem continuously associated with others which occurred during those of a prior stage, and the changes affecting every part of one organism appear to be due to some general cause acting upon the whole from the very first. Creatures, undoubtedly very closely allied to one another, differ from each other, not in one or two, but in a vast number of characters. Although they may be much alike in form, and closely allied zoologically, they exhibit *physiological* differences of the most remarkable kind; and although there is some general accordance in the life history of distinct species, the differences of detail are far more striking and remarkable than, and quite as difficult to account for as, the general resemblances which have attracted notice.

In that temporary state in which all matter exists before it assumes the structure and composition peculiar to the different tissues of different living beings, no differences can be detected by any means yet known. The living matter of an adult tissue could not be distinguished from that of an embryo. Nor could the living matter of the highest brain cell of man be distinguished from that concerned in the production of the lowest living structure. And yet how different are the results of the life of the two? This difference would be more readily accounted for upon the hypothesis of the existence of some marvellous original difference in the *power* of the different kinds of living matter, than by the action of the different external circumstances under which descendants from one and the same stock have passed, or upon the hypothesis of the inherent tendency to vary. Can we accept the conclusion, that there was no well-defined difference at an early period of the world's history between the living forms then inhabiting the earth, until we have studied in detail the structure, mode of development, and complete life history of two existing species of simple organization, which are closely allied to one another? As yet we have no history of the life of any living thing which at all approaches completeness. It should be stated that, according to the theory, as accepted by many, something which amounts to a special creation is admitted to have occurred in the case of the first living molecule. The argument is supposed to commence from this point.

The anatomical differences between corresponding tissues of closely allied species are often so distinct that the anatomist familiar with them could distinguish one from the other. For example, it would be difficult to state in few words the differences between the unstriped muscular fibres of the bladder of the hyla, of the common frog, and of the newt, and yet there is a recognizable difference, and corresponding differences can be demonstrated in other textures, if a comparison be carefully instituted. So also with regard to the chemical composition of the corresponding solid matters, fluids, secretions, &c., of closely allied animals, remarkable differences are observed as may be demonstrated by a careful examination of the blood, bile, or urine, for example. Such differences affecting the minute structure, and chemical composition, of every part of the organism of creatures closely allied, are strong arguments in favour of the doctrine of the independent origin of distinct species; for it is scarcely reasonable to assume that any divergence in a few particulars, from the general characters of the common original stock, should be accompanied by, or should necessarily involve, a change in *all* these points, unless such differences can be demonstrated to have occurred in the varieties of existing species; but this is a subject which has not yet been touched upon by Mr. Darwin or by those who have embraced his views. Animals may differ in many characteristics but still retain the most striking resemblance in all essential biological characters, or they may resemble one another in external form and general characters but differ most materially in internal structure. If a careful comparison should be made of everything in connection with the formation of structures throughout the life of closely allied but distinct species and between the most different varieties of the same species, it is probable that such essential points of difference in the one case, and agreement in the other, would be demonstrated as would suffice to convince the warmest advocate of Mr. Darwin's views that more minute investigation was required before his doctrine, as applied to the origin of all species, could be admitted to rest upon a satisfactory basis.

OF PLANTS AND ANIMALS AND OF THE FUNCTIONS.

It is impossible to define precisely a boundary between the vegetable and animal kingdoms, and any attempt to lay down characters which shall distinguish plants from animals in every case must fail. The lowest animals are said to exhibit so much of the plant nature that naturalists are as yet undecided as to the true location of some species. The common sponge, for instance, a short time since was claimed for each kingdom, but there can now be no doubt of its animal nature. The important phenomena of plant and animal life are, in fact, the same in their essential nature. Still it will be advantageous to recount briefly some of the most important general characters in which the fully developed animal differs from, or agrees with the fully developed plant.

The first step in the nutritive functions of both plants and animals, is to form a fluid, which contains all the elements necessary to nourish the various textures, and to supply materials for the secretions. This fluid is, in plants, *the sap;* in animals, *the blood.*

In both classes of beings a process of *absorption* precedes the full development of the nutritive fluid: it is by this means that material is obtained for its formation. Within the plant or animal it becomes more completely elaborated.

In plants, the absorption takes place by the spongioles of the roots. A fluid, already prepared in the soil,—water, holding in solution carbonic acid and various mineral substances,—passes through them into the vegetable organism. In animals the food experiences much change, and a more or less elaborate process of *digestion* takes place, before a fluid is formed, capable, when absorbed, of furnishing the materials of the blood.

Plants, fixed by their roots in the soil, imbibe from it their nutriment. Animals, obtaining food from various sources, introduce it into a digestive cavity, where it is prepared for absorption.

The presence of a digestive organ, or stomach, is characteristic of animals. The only instances in which a similar organ may be supposed to exist in the vegetable kingdom, are to be found in those remarkable modifications of leaves, called pitchers (*ascidia*) in *Nepenthes*, *Sarracenia*, and *Dischidia*. In the last two plants, these organs certainly serve to retain and dissolve the bodies of insects in the fluid which partially fills them: in *Sarracenia*, according to Mr. Burnett, the fluid contained in the pitchers is very attractive to insects, which, having reached its surface, are prevented from returning by the direction of the long bristles that line the cavity. The dissolved food is then absorbed into the plant.

On the other hand, the animal kingdom affords some exceptions to the presence of a stomach. In such animals, the absorption of nutrient fluid takes place by a general surface. Many of the infusoria are destitute of a stomach. A parasite of the human body, the *Acephalocyst*, also derives its nutriment by imbibition through its walls. A familiar example is the *Acephalocystis endogena*, or pill-box hydatid of Hunter. It consists of a globular bag, closed at all points, containing a limpid fluid, capable of growth, developing upon the inner surface of the sac little organisms, also nourished by absorption, the echinococci, which are the early stage of development of what was once supposed a distinct species, the tapeworm.

Some difference may be noticed as regards the nature of the food in animals and plants. The former derive their nutriment entirely from the organized world, unless, indeed, we suppose that the nitrogen absorbed in respiration contributes to their sustenance. Plants appropriate inorganic elementary matters for food, as carbon, carbonic acid, ammonia, &c. "Inorganic matter," says Liebig, "affords food to plants; and they, on the other hand, yield the means of subsistence to animals. The conditions necessary for animal and vegetable nutrition are essentially different. An animal requires for its development, and for the sustenance of its vital functions, a certain class of substances which can only be generated by organic beings possessed of life. Although many animals are entirely carnivorous, yet their primary nutriment must be derived from plants; for the animals upon which they subsist receive their nourishment from vegetable matter. But plants find new nutritive material only in inorganic substances. Hence one great end of vegetable life is to generate matter adapted for the nutrition of animals out of inorganic substances which are not fitted for this purpose."

The nutrient fluid, however formed, is distributed throughout the textures of the plant, or animal, by vital or physical forces, or by the junction of both; and the function, by which this is effected, is called *Circulation*. In plants, this function is very simple, and is performed without the agency of a propelling organ, circulating through capillary vessels which exist in every part of the tissues of the plant. In some plants, the fluid is found to circulate, or rotate, within the interior of cells, as in *Chara* and *Vallisneria*, the fluid of one cell not communicating with that of the adjacent ones; or to pass up from the spongioles in an ascending current, and to descend in another set of vessels. In the greatest number of animals, a propelling organ, a *heart*, is the main instrument in the distribution of the blood. In animals, then, there is a true circulation; the fluid setting out from, and returning to, the same place. In many simple animals and plants, however, there is no circulation at all in special vessels, but the tissues are nourished by imbibing the elements of nutrition from the medium in which they are immersed.

The presence of atmospheric air is necessary to the existence of all organized beings. The air both passes by endosmose into their nutrient fluids, and receives from them certain deleterious gases developed in their interior. The function, by which the fluids are thus aërated, is called *respiration*. In plants, the introduction of atmospheric air conveys nutriment to the organism; carbonic acid and ammonia are thus introduced; the former is decomposed, its carbon is assimilated, and its oxygen is exchanged for a fresh supply of atmospheric air. As the agent in the decomposition of the carbonic acid is light, it is evident that the generation and the evolution of oxygen can take place only in the day-time. Consequently, during the night, the carbonic acid, with which the fluids of the plant abound, ceases to be decomposed, and is exhaled by its leaves. Hence, plants exhale oxygen in the day-time, and carbonic acid at night.

In animals, carbonic acid accumulates in the blood during its circulation; and, when the atmosphere is brought to bear upon the capillary vessels containing the blood charged with this gas, a mixture takes place through the delicate walls of the vessels, the atmospheric air passing in, and carbonic acid, with nitrogen and oxygen, in certain proportions, escaping. Thus the evolution of carbonic acid, and the absorption of oxygen and nitrogen, are the characteristic features of respiration in animals. It is highly interesting to notice, how plants are thus subservient to the well-being of animals, in the respiratory function, as well as in preparing nutriment for them. By their respiration they serve to purify the air for animals; for, in absorbing the carbonic acid from the atmosphere, they are continually depriving it of an element which, if suffered to accumulate beyond certain bounds, would prove destructive to animal life.

From the fluids of animals and plants, certain materials are separated by a singular process, nearly allied in its mechanism to nutrition, and called the function of *secretion*. The secreted matters are various, and have very different ends: in some cases being destined for some ulterior purpose in the economy; in others, forming an excrement, the continuance of which in the organism would be prejudicial to it.

The function, which has for its object the propagation of the species, *generation*, presents many points of resemblance in plants and animals. In the former it is cryptogamic, or phanerogamic; in the latter, non-sexual or sexual. In the phanerogamic and sexual, the junction of two kinds of matter furnished by the parents is necessary to the development of fertile ova. In the cryptogamic and non-sexual generation, the new individual is developed by a separation of particles from the body of the parent, by which the new formation is nourished until it has been so far matured as to be capable of an independent existence.

The functions, hitherto enumerated, may be called *organic*, as being common to all organized beings; but there are others which, as being peculiar to, and characteristic of, animals, may be appropriately designated *animal* functions.

The prominent characteristic of animals is the enjoyment of *volition* or *will*, which implies necessarily the possession of *consciousness*. Our knowledge of the share which consciousness and the will have in the production of certain phenomena of animal life, is derived from the experience which each person has of his own movements, and a comparison of them with the actions of inferior animals. We are conscious that, by a certain effort of the mind, we can excite our muscles to action; and when we see precisely similar acts performed by the lower creatures, with all the marks of a purpose, it is fair to infer that the same process takes place in them as in ourselves. Moreover, we learn by experience, that injury or disease of the nerves, which are distributed to our muscles, destroys the power of accomplishing a certain act, but does not affect the desire or the wish to perform it: and experiments tell us that the division of the nerves of a limb in a lower animal destroys its power over that member; while its ineffectual struggles to move the limb obviously indicate that the will itself is not affected by the bodily injury, though its powers are limited by it.

Again, certain external agents are capable of affecting the mind, through certain organs, thus giving rise to *sensations*. Light, sound, odour, the sapid qualities of bodies, their various mechanical properties, hardness, softness, &c., are respectively capable of producing corresponding affections of the mind, which experience leads us to associate with their exciting causes, and which may be agreeable, and produce *pleasure*, or the reverse, and give rise to *pain*.

In a similar way to that by which we learn that the will stimulates our muscles through the nerves, we can ascertain that the nerves are the channels through which our sensations also are excited. "Certain states of our bodily organs are directly followed by certain states or affections of our mind; certain states or affections of our mind are directly followed by certain states of our bodily organs. The nerve of sight, for example, is affected in a certain manner; vision, which is an affection, or state of the mind, is its consequence. I will to move my hand; the hand obeys my will so rapidly, that the motion, though truly subsequent, seems almost to accompany my volition, rather than to follow it."*

And in all the inferior animals, possessed of like organs, there can be no doubt that sensations may be produced similar to those which arise in the human mind. In many of them, indeed, the sense of sight, hearing, or smell, seems much more acute than in man, and affords examples of a beautiful and providential provision for the peculiar sphere which the creatures are destined to occupy. The unerring precision of the beast or bird of prey in pouncing upon its victim—the accuracy with which the hound tracks by its scent the object of its pursuit—or the quickness with which most of our domestic animals detect sounds and judge of their direction, are familiar illustrations of the superiority of these senses in animals whose general organization is inferior to that of man.

There are few animals, however small and insignificant, in which we cannot recognize evidence of a controlling and directing will. But even in those few, in which voluntary movements are not distinctly to be discerned, the presence of a special system of organs, with which in the higher animals volition and sensation are associated, namely, a *nervous system*, serves as a characteristic distinction from plants.

A power of perception, and a power of volition, together constitute our simplest idea of *mind;* the one excited through certain corporeal organs, the other acting on the body. Throughout the greatest part of the animal creation mental power exists, ranging from this its lowest degree—a state of the blindest instinct, prompting the animal to search for food—to the docility, sagacity, and memory of the brute; and to its highest state, the reasoning powers of man.

The phenomena of mind, even in their simplest degree of development, are so distinct from anything which observation teaches us to be produced by material agency, that we are

* Dr. Brown. Philosophy of the Human Mind, p. 106.

bound to refer them to a cause different from that to which we refer many of the phenomena of living bodies. Although associated with the body by some unknown connecting link, the mind works quite independently of it; and, on the other hand, a large proportion of the bodily acts are independent of the mind. The immortal soul of man, *divinæ particula auræ*, is the seat of those thoughts and reasonings, hopes and fears, joys and sorrows, which, whether as springs of action or motions excited by passing events, must ever accompany him through the chequered scene in which he is destined to play his part during his earthly career.

Although the animals, inferior to man, exhibit many mental acts in common with him, they are devoid of all power of abstract reasoning. "Why is it," says Dr. Alison, "that the monkeys, who have been observed to assemble about the fires which savages have made in the forests, and been gratified by the warmth, have never been seen to gather sticks and rekindle them when expiring? Not, certainly, because they are incapable of understanding that the fire which warmed them formerly will do so again, but because they are incapable of abstracting and reflecting on that *quality* of wood, and that *relation* of wood to fires already existing, which must be comprehended, in order that the action of renewing the fire may be suggested by what is properly called an effort of reason."

Yet animals are guided by *instinct* to the performance of certain acts which have reference to a determinate end: they construct various mechanical contrivances, and adopt measures of prudent foresight to provide for a season of want and difficulty. None of these acts could be effected by man without antecedent reasoning, experience, or instruction. But animals do them without previous assistance; and the young and inexperienced are as expert as those which have frequently repeated them. "An animal separated immediately after its birth from all communication with its kind, will yet perform every act peculiar to its species in the same manner, and with the same precision, as if it had regularly copied their example, and been instructed by their society. The animal is guided and governed by this principle alone, by this all its powers are limited, and to this all its actions are to be ultimately referred. An animal can discover nothing new; it can lose nothing old. The beaver constructs its habitation, the sparrow its nest, the bee its comb, neither better nor worse than they did five thousand years ago."

In plants there is no nervous system; there are no mental phenomena. The motions of plants correspond in some degree with those movements of animals in which neither consciousness nor will participate. Some of the movements undoubtedly result from physical changes produced directly in the part moved. Amongst the most interesting examples are those of the *Mimosa pudica*, the *Dionæa muscipula*, and the *Berberis*. But movements of another kind, as the movements in the interior of the cells of Vallisneria Tradescantia, &c., depend upon changes occurring in the living matter, the nature of which is not yet understood. These movements will be discussed in another place.

OF ANATOMICAL INVESTIGATION.

It is the province of physiology to investigate the manner in which the functions of living beings are carried out; and this investigation naturally involves the examination of their mechanism, of the chemical constitution, and of the properties of their component textures. The study of anatomy must always accompany that of physiology, on the principle that we must understand the construction of a machine before we can comprehend the way in which it works. The history of physiology shows that it made no advance until the progress of anatomical knowledge had unfolded the structure of the body. There is so much of obvious mechanical design in the intimate structure of the various textures and organs, that the discovery of that structure opens the most direct road to the determination of their uses. That kind of anatomy which investigates structure with a special view to function may be properly designated *Physiological Anatomy*.

In investigating the functions of the human body, the physiologist cannot do better than follow the instructions laid down by Haller in the preface to his invaluable work, "Elementa Physiologiæ Corporis Humani."

The first and most important step towards the attainment of physiological knowledge is, the study of the fabric of the human body. "Et primùm," says Haller, "cognoscenda est fabrica corporis humani, cujus penè infinitæ partes sunt. Qui physiologiam ab anatome avellere studuerunt, ii certè mihi videntur, cum mathematicis posse comparari qui machinæ alicujus vires et functiones calculo exprimere suscipiunt, cujus neque rotas cognitas habent, neque tympana, neque mensuras, neque materiam."

A knowledge of human anatomy alone is, however, not sufficient to enable us to form accurate views of the functions of the various organs. Before an exact judgment can be formed of the functions of most parts of living bodies, Haller says, that the construction of the same part must be examined and compared in men, in various quadrupeds, in birds, in fishes, and even in insects. And, in proof of the value which attaches to this knowledge of *comparative anatomy*, he shews how, from that science, it may be determined that the liver is the organ which secretes bile ; and that the bile found in the gall-bladder is not secreted by, but conveyed to, that organ ; for no animal has a gall-bladder without a liver, although many have a liver without a gall-bladder ; and, in every case where a gall-bladder is present, it has such a communication with the liver, that the bile secreted by the latter may be easily transferred to the former. "Vides adeò," he adds, "bilem hepate egere, in quo paretur, vesiculâ non egere, non ergo in vesiculâ nasci, ex hepate verò in vesiculam transire."

And Cuvier has happily compared the examination of the comparative anatomy of an organ, in its gradation from its simplest to its most complex state, to an experiment which consists in removing successive portions of the organ, with a view to determine its most essential and important part. In the animal series we see this experiment performed by the hand of nature, without those disturbances which mechanical violence must inevitably produce. We thus learn, from comparative anatomy, that the vestibule is the fundamental part of the organ of hearing ; and that the other portions, the semicircular canals, the cochlea, the tympanum and its contents, are so many additions made successively to it, according as the increasing perceptive powers of the animals rendered a more delicate acoustic organ necessary. In a similar manner we learn, that one portion of the nervous system, in those animals in which it has a definite arrangement, is pre-eminently associated with the mind, and is connected with, and presides over, the other parts. This organ, the brain, is always situate at the anterior or cephalic extremity of the animal, and with it are immediately connected the organs of the senses, the inlets to perception. We soon find that the brain exhibits a subdivision into distinct parts, and of the relative importance of these parts, and their connexion with the organs of sense, and with the intellectual functions, we derive the most important information from the study of comparative anatomy.

Haller further assigns the examination of the living animal as a valuable aid in physiological research. Many obscure points have been elucidated by experiments on living animals, and discoveries have been made which have greatly contributed to the progress of physiology. Very useful knowledge may be derived from observing the play of certain functions in living animals, or in man himself,—contrasting them in various individuals, and noting the effects of age, sex, and temperament, and ascertaining the influence which other conditions, natural or artificial, may exert upon them.

The investigation of disease, both during life and after death, is of great value in enabling us to appreciate the action of an organ in health. If, for example, as Haller remarks, a particular function be ascribed to a certain part, how can there be a more favourable opportunity of testing the accuracy of such a doctrine than by the examination of a body in which that part was affected with a disease, of which the previous history was known? If the function in question had been vitiated, or destroyed, it may be fairly presumed to have had its seat in the diseased organ. Nothing has contributed more largely to determine the functions of particular nerves, than exact histories of the symptoms during life, in cases in which they had been found, after death, in a diseased condition.

IMPORTANCE OF ANATOMY AND PHYSIOLOGY TO THE ADVANCE OF MEDICINE AND TO ITS STUDY.

A correct physiology must ever be the foundation of rational medicine. He who is ignorant of the proper construction of a watch, and of the nature of the materials of which it is made, could not find out in what part its actions were faulty, and would therefore be very unfit to be entrusted with repairing it. In medicine, the first step towards the cure of disease is to find out what the disease is, and where it is situated (*diagnosis*). Without a knowledge of the offices which various parts fulfil in the animal economy, our search to determine what organ or function is deranged must be most vague and indefinite. *Pathology* is the physiology of disease; and it is obvious, that no pathological doctrines can command confidence, which are not founded upon accurate views of the natural functions. It is also certain that improvements in pathology must follow in the wake of an advancing physiology.

The practice of medicine and surgery abounds with examples illustrating the immense benefits which physiology has conferred upon the healing art. The great advance which has been made in the pathology of nervous diseases, is mainly owing to the discoveries of Bell, and more recently to the researches of Marshall Hall, Bernard, Brown-Séquard, and others, upon the functions of various nerves, and the general doctrines of nervous actions. We may instance the case of the facial nerve—the portio dura of the seventh pair. It was supposed formerly that this nerve was the seat of that painful disease, called *tic-douloureux*, and section of it has been performed for the relief of the patient. It is now known that this nerve could not be the seat of a very painful disease, for it is itself, in a very great degree, devoid of sensibility. It need hardly be added, that the operation is discarded.

The dangerous disease, to which many children have fallen victims, *laryngismus stridulus* or *crowing inspiration*, although admirably described by practical physicians, was never properly understood until the functions of the laryngeal nerves were clearly ascertained, and until it had been shown that spasmodic actions may be excited by irritation of a remote part, or through a stimulus reflected from the nervous centre. It is now known, that this disease has not its seat in the larynx, where those spasms occur which excite so much alarm for the fate of the little patient; but that it is an irritation of a distant part, which derives its nerves from the same region of the cerebro-spinal centres as does the larynx,—that the afferent nerves of that part convey the irritation to the centre, whence it is reflected by certain efferent nerves to the muscles of the larynx.

The important observations made of late years upon the action of the sympathetic nerve upon the blood-vessels has already thrown great light upon the nature of numerous pathological changes, especially those complex phenomena which constitute what in the higher animals and man are termed congestion and inflammation. The recent researches upon the arrangement of, and course taken by, the nerves in the central organs conducted by Stilling, Lockhart Clarke, and others, are likely to lead to most important conclusions with reference to the actions of the brain and cord.

The accurate diagnosis of diseases of the heart rests entirely upon a correct knowledge of the physiology of that organ. This improvement in medicine may be said to date from the time of Harvey, for he was the first who clearly expounded the mechanism of the central organ of the circulation. But the application of auscultation to the exploration of the sounds developed in its action, and the correct interpretation of those sounds in health by the experiments and observations of the last few years, have almost completely removed whatever difficulties stood in the way of the detection of cardiac maladies.

We are not less indebted to the illustrious Englishman who discovered the circulation of the blood, for having paved the way to a rational treatment of aneurismal and wounded arteries by the modern operation of placing a ligature between the heart and the seat of the disease or injury. "The active mind of John Hunter," says Mr. Hodgson, "guided by a deep insight into the powers of the animal economy, substituted for a dangerous and unscientific operation, an improvement founded upon a knowledge of those laws which influence the circulating fluids and absorbent system; and few of his brilliant discoveries have contributed more essentially to the benefit of mankind."

THE USE OF THE MICROSCOPE.

For exploring the structure of the various textures, and the relation of the anatomical elements of the body to one another, the *Microscope* is necessary. The great improvements which modern opticians have accomplished, not only in the dioptric but also in the mechanical adjustments of this instrument, render it an invaluable adjuvant in physiological research. We shall have frequent occasion in the following pages to refer to anatomical analyses, effected by the microscope, of the utmost value to the knowledge of function. New means of preparing tissues, and the use of powers magnifying upwards of 1,000 diameters, have enabled us to investigate details with a precision and to an extent which not long since was considered impossible. It may, however, be remarked, that, as the sources of fallacy are numerous even with the best instruments, more depends upon the observer himself, in this kind of investigation, than in almost any other.

The great impediment to deriving correct inferences from microscopical observations has arisen from the discordance, too apparent, in the narrations of different observers. This discordance has been the result of a twofold cause; namely, imperfection of the instruments, and the very unequal qualifications of different observers. The former cause is now almost completely removed; the latter must remain while men imperfectly appreciate their own abilities for particular pursuits.

Many observers have placed too much reliance upon minute and elaborate description of what they have seen, and have not been at the pains to give careful representations of the structure as it appeared to them. Others, although they have given drawings, have executed them very carelessly, and have omitted to draw them to a scale, so that they cannot be compared one with another, or with the drawings of other observers. Again, the system of one anatomist endeavouring to refute the statements of another by researches upon a different object, conducted upon a different principle, only serves to increase the confusion already existing, and to postpone to a more distant period the definite settlement of most important elementary principles. If anatomical observers would select the same organisms for study, and make their drawings as accurately as possible to a fixed scale, many of the questions upon which they are now at issue would soon be determined.

To make microscopical observation really beneficial to physiological science, it should be done by those who possess two requisites: an *eye*, which practice has rendered familiar with genuine appearances as contrasted with those produced by the various aberrations to which the rays of light are liable in their passage through highly refracting media, and which can quickly distinguish the fallacious from the real form; and a *mind*, capable of detecting sources of fallacy, and of understanding the changes which manipulation, chemical re-agents, and other disturbing causes may produce in the arrangement of the elementary parts of various textures. To these we will add another requisite not more important for microscopical than for other inquiries; namely, a freedom from preconceived views or notions of particular forms of structure, and an absence of bias in favour of certain theories, or strained analogies. The history of science affords but too many instances of the baneful influence of the *idola specûs* upon the ablest minds; and it seems reasonable to expect that such creatures of the fancy would be especially prone to pervert both the bodily and the mental vision, in a kind of observation which is subject to so many causes of error as that conducted by the aid of the microscope.

Of late years, however, great improvements have been introduced in the mode of preparing specimens, and the chances of arriving at erroneous inferences very much diminished. The structures represented in the new plates, illustrating this work, have been prepared according to the same plan, and all the figures have been drawn to a scale, so that they may be compared one with the other. The methods of injecting with transparent Prussian blue fluid and staining the germinal matter of the tissues with carmine are described in detail in "How to work with the Microscope," but the student will find an outline of the plan at the end of the present chapter. This process of preparation is applicable to those specimens which require to be examined by the aid of very high magnifying powers, and it possesses this great advantage—that every tissue can be demonstrated in the same preparation.

During the last ten years we have had the advantage of the use of much higher magnifying powers than could have been obtained previously. The first $\frac{1}{25}$ ever made was the workmanship of Mr. Wenham, and was completed in June, 1856. In 1840, Messrs. Powell and Lealand succeeded in making a $\frac{1}{16}$, in 1860, a $\frac{1}{26}$, and in 1864 the same makers produced a $\frac{1}{50}$, the definition and penetrating power of all which glasses are exceedingly good. The first of these objectives magnifies about 1,500, and the last nearly 3,000 diameters linear.

PHYSICAL AND CHEMICAL INVESTIGATION.

Of late years our knowledge of physiology has been greatly advanced by physical investigation. The study of the processes of Diffusion, Osmose, and of the physical conditions of matter, has added much to our information regarding the nature of many changes occurring in the living organism. The invention of various ingenious instruments for ascertaining the force of the circulation has taught us many important principles which were unknown before. The further prosecution of investigations upon the electrical phenomena of living beings, a department in which great success has been already achieved by Matteucci, and more recently by Du Bois Reymond, promises most valuable generalizations. The still recent discoveries regarding the influence of the solar spectrum upon different substances have been already applied to the investigation of animal fluids, and important results have been obtained by Stokes, in connection with the changes occurring in the blood during the process of respiration.* Physical investigation has greatly advanced our knowledge of the wonderful phenomena of sight and hearing, and by the aid of various optical instruments we are now enabled to make a most minute examination during life of the tissues within the eye.

Haller perceived how necessary to the furtherance of physiology is a knowledge of *Organic Chemistry*; and we could adduce many instances to prove, that the attention which has of late years been paid to this subject, has been most fruitful in giving us an insight into the nature of many functions, which, without it, we could not have obtained.

In the living body the most delicate chemical processes are unceasingly going on, for the formation of new compounds and the alteration or destruction of old ones. It is evident that no progress can be made in the investigation of these invisible processes, unless we can arrive at an exact knowledge of the chemical composition of the various substances which are concerned in them.

Henceforward, in physiological research, physics, anatomy, and chemistry must go hand in hand. By the first the physical

* "On the Reduction and Oxidation of the Colouring-matter of the Blood." Proceedings of the Royal Society, No. 66, page 355, June, 1864.

phenomena, which play so important a part in the changes which take place in complex organisms, may be elucidated; by the second, the minute mechanism concerned in these phenomena is ascertained; by the third, the nature of the chemical analyses and syntheses taking place in the living organism are to be determined. Here is a wide field of research open for the employment of every kind of mind, and by devoting himself to one or other of these departments, every earnest student may contribute important aid to the advance of physiology, and thereby to the progress of medicine and surgery.

In the composition of the Introduction, the authors have to acknowledge valuable aid from the following works:—Haller, Elementa Physiologiæ Corporis Humani; Barclay on Life and Organization; Roberton on Life and Mind; Prichard on the Doctrine of a Vital Principle; Dr. Carpenter's article Life, and Dr. Alison's article Instinct, in the Cyclopædia of Anatomy and Physiology; L. Pasteur, papers in the Comptes Rendus, 1859—64; F. A. Pouchet, Hétérogénie; Joule, papers in the Phil. Trans.; Julius R. Mayer, Die Organische Bewegung; Tyndall, Heat as a Mode of Motion; Grove on the Correlation of the Physical Forces; Helmholtz, Erhaltsung der Kraft; Lectures at the Royal Institution; Carpenter on the Correlation of Physical and Vital Forces, Journal of Science, Nos. I. and II.; Graham's papers on Diffusion, Osmose, Crystalloids and Colloids, Phil. Trans. 1850—64; Darwin on the Origin of Species; Huxley, Lectures on the Origin of Species, and Elements of Comparative Anatomy; Carpenter, Principles of Physiology; Herbert Spencer's First Principles and his Principles of Biology; Beale, the Anatomy of the Tissues, the Microscope in Medicine, and papers in the Archives of Medicine and Microscopical Journal.

On the Preparation of the Tissues of Man and the higher Animals and Morbid Growths, for Microscopical Examination with high powers.

It has been thought desirable to describe briefly the general method which has been employed in preparing specimens for examination with the highest powers, in the hope that the student may be encouraged to pursue some of the inquiries entered upon in this work, and that many of the investigations may be extended still further.

In the first place, it is necessary to consider what circumstances interfere with the perfect demonstration of structure under the highest powers of the microscope, and how the disadvantageous operation of these might be prevented or diminished.

1. Of many tissues, sections sufficiently thin for high powers cannot be obtained by the processes usually adopted. In order to make the specimen thin enough, pressure must be employed, and in many instances very strong pressure is required. Even by very moderate pressure, tissues immersed in

water are destroyed completely, and experience has proved that the requisite amount of pressure can only be employed if the tissue be immersed in, and thoroughly impregnated with, a viscid medium, which is not only readily miscible with water in all proportions, but with such chemical reagents as may be required to act upon one or more constituents of the tissue for the purposes of demonstration.

2. As many structures are exceedingly delicate, and undergo change very soon after death, it is necessary that the medium in which they are examined should have the property of preventing softening and disintegration, and should act the part of a preservative fluid.

3. In order that tissues should be uniformly permeated with a fluid within a very short time after the death of the animal, it is necessary that the fluid should come quickly in contact with every part of the texture. This may be effected in two ways :—

a. By soaking very thin pieces in the fluid, or
b. By injecting the fluid into the vessels of the animal.

4. As different structures require fluids of different refractive power for their demonstration, the medium employed must be such that its refractive power can be increased or diminished, or that, for the medium fulfilling the former condition, another can be readily substituted which fulfils the latter requirements.

5. In investigations upon the changes which structure undergoes in the organism, it is necessary to distinguish between that part of the texture which is the oldest, and that which has just been produced—between matter in which active changes are going on, and matter which is in a passive state. It is only by fulfilling this requirement that the direction in which growth takes place, and the point where new matter is added, can be ascertained.

6. It is necessary, in many investigations, that the vessels should be positively distinguished from the other constituents of the tissue, and it is important that the process by which this is effected, should not interfere with the demonstration of all the tissues in the immediate vicinity of the vessels.

7. It is of the utmost importance the medium employed for demonstration should have the property of preserving the specimens, so that observers should be able to exhibit their preparations to others.

Glycerine and *syrup* fulfil the requirements mentioned in the foregoing paragraphs. Strong syrup may be made by dissolving, with the aid of heat, lump sugar in distilled water, in the proportion of about three pounds to a pint. It is necessary in many cases to employ the strongest glycerine. In this country we have had the advantage of the beautiful preparation called Price's glycerine, which is made of specific gravity 1240. It has been said that glycerine and strong syrup are not adapted for preserving soft tissues, because the tissues shrink and soft cells collapse in consequence of exosmose of their fluid contents. But I have many hundred specimens preserved in the strongest glycerine I could procure, and I should obtain advantages if glycerine could be made of still greater density. There would be no difficulty in impregnating even very soft tissues with it.

Tissues possess a considerable elastic property, and although they shrink when immersed in a medium of considerable density, they gradually regain their original volume if *left in it for some time*. In practice, the specimen is first immersed in *weak* glycerine or syrup, and the density of the fluid is gradually increased. In this way, in the course of two or three days, the softest and most delicate tissues may be made to swell out almost to their original volume. They become more transparent, but no chemical alteration is produced, and the addition of water will at any time cause the specimen to assume its ordinary characters.

The hardest textures, like bone and teeth, may be thoroughly impregnated and preserved in strong glycerine, and the softest, like cerebral tissue, delicate nervous textures like the retina, or the nerve textures of the internal ear, may be permeated by the strongest glycerine, and when fully saturated with it, dissection may be carried to a degree of minuteness which I have found impossible in any other medium. Nor is the use of glycerine and syrup confined to the tissues of man and the higher animals. I have preparations from creatures of every class. The smallest animalcules, tissues of entozoa, polyps, star fishes, mollusks, insects, crustacea, various vegetable tissues, microscopic fungi, and algæ of the most minute and delicate structure, as well as the most delicate parts of higher vegetable tissues, may all be preserved in these viscid media; so also may be preserved the slowest and most rapidly growing, the hardest and softest morbid growths, as well as embryonic structures at every period of development, even when in the softest state. I am, indeed, not acquainted with any animal or vegetable tissue which cannot with the greatest advantage be mounted thus. All that is required is, that the strength of the fluid should be increased very gradually until the whole tissue is thoroughly penetrated by the strongest that can be obtained. Glycerine has long been in use among microscopists, but my object is to show that it is universally applicable, that it or syrup may be made the basis of all solutions employed by the microscopical observer with the greatest advantage, that many points are to be demonstrated by the use of these solutions, which have hitherto escaped observation, and that there are reasons for believing that very much may yet be discovered by the use of these substances.

From these general remarks, I pass on to describe, more in detail, the particular method I have adopted during the last four years for minute investigations upon structures magnified by the highest powers yet employed. It will be necessary, in the first place, to give the composition of the different solutions which I find useful for general purposes.

1. *Weak common glycerine* of about the specific gravity 1050.

2. *The strongest Price's glycerine* that can be obtained.

3. *Syrup* made by dissolving, by the application of a gentle heat in a water-bath, 3lbs. of sugar in a pint of distilled water. A weaker solution can be prepared, as required, by mixing equal parts of syrup and water.

The two following solutions should be kept ready prepared. They will keep for a length of time. The first is required for rendering the vessels distinct. The last enables us to distinguish with certainty the *germinal* or *living* matter of every tissue from the formed material.

The Injecting Fluid.—The following mixture has succeeded admirably in my hands, and I therefore recommend it strongly. It penetrates to the finest vessels. The specimens injected with it retain their colour perfectly, and the injected tissues can also be stained with carmine.

Price's glycerine, 2 oz. by measure.
Tincture of perchloride of iron, 10 drops.
Ferrocyanide of potassium, 3 grains.
Strong hydrochloric acid, 3 drops.
Water, 1 oz.

Mix the tincture of iron with one ounce of the glycerine; and the ferrocyanide of potassium, first dissolved in a little water, with the other ounce. These solutions are to be mixed together very gradually in a bottle, and are to be well shaken during admixture. The iron solution must be added *to* the ferrocyanide of potassium. Lastly, the water and hydrochloric acid are to be added. Sometimes I add a little alcohol (2 drachms) to the above mixture.

This fluid does not deposit any sediment, even if kept for some time, and it appears like a blue solution when examined under high magnifying powers, in consequence of the insoluble particles of Prussian blue being so very minute.

The Carmine Fluid.—The following is the composition of the carmine fluid:

Carmine, 10 grains.
Strong liquor ammoniæ, ½ drachm.
Price's glycerine, 2 ounces.
Distilled water, 2 ounces.
Alcohol, ½ ounce.

The carmine in small fragments is to be placed in a test tube, and the ammonia added to it. By agitation, and with the aid of the heat of a spirit-lamp, the carmine is soon dissolved. The ammoniacal solution is to be boiled for a few seconds and then allowed to cool. After the lapse of an hour, much of the excess of ammonia will have escaped. The glycerine and water may then be added and the whole passed through a filter or allowed to stand for some time, and the perfectly clear supernatant fluid poured off and kept for use. This solution will keep for months, but sometimes a little carmine is deposited, owing to the escape of ammonia, in which case one or two drops of liquor ammoniæ to the four ounces of carmine solution may be added.

The rapidity with which the colouring of a tissue immersed in this fluid takes place, depends partly upon the character of the tissue and partly upon the excess of ammonia present in the solution. If the solution be very alkaline the colouring is too intense, and much of the soft *tissue* or imperfectly developed formed material around the germinal matter, is destroyed by the action of the alkali. If, on the other hand, the reaction of the solution be neutral, the uniform staining of tissue and germinal matter may result, and the appearances from which so much is learnt are not produced. When the vessels are injected with the Prussian blue fluid the carmine fluid requires to be sufficiently alkaline to neutralise the free acid present. The permeating power of the solution is easily increased by the addition of a little more water and alcohol.

Some tissues absorb the colour very slowly. Fibrous tissue, bone and cartilage, even in very thin sections, will require twelve hours or even more, but perfectly fresh soft embryonic tissues, and very thin sections of the liver and kidney, thin sections of morbid growths rich in cells, may be coloured in half an hour, while the cells of the above structures, placed on a glass slide, may be coloured in less than a minute. I have often coloured the germinal matter of the fresh liver cell *in a few seconds*, by simply allowing the carmine fluid to flow once over the specimen.

After the specimen has been properly stained, it is to be washed in a solution consisting of—

Strong glycerine, 2 parts.
Water, 1 part.

It is then transferred to the following acid fluid :—

Strong glycerine, 1 ounce.
Strong acetic acid, 5 drops.

After having remained in this acid fluid for three or four days, it will be found that the portions of even soft pulpy textures have regained the volume they occupied when fresh. They have swollen out again even in the strongest glycerine.

It being established as a principle that, for minute investigation, tissues must be immersed and thoroughly saturated with viscid media miscible in all proportions with water, it almost follows that reagents applied to such tissues should be dissolved in media of the same physical properties. For a long time past I have been in the habit of employing solution of potash, acetic acid, and other reagents, dissolved in glycerine instead of in water. In some cases I have found the addition of very strong solutions of certain reagents necessary. For example, the greatest advantage sometimes results from the application to a tissue of very strong acetic acid. If the acid be added to glycerine in quantity, the solution will no longer be viscid, so that another plan must be resorted to. I thicken the strongest acetic acid with sugar, a gentle heat being applied to dissolve the sugar. Thus a very strong acetic acid solution of the consistence of syrup can be most readily prepared. Strong solutions of potash, soda, and other reagents, are to be made in the same way. Thus a complete chemical examination may be conducted upon tissues, solutions, or deposits preserved in viscid media. The reactions are most conclusive, but of course take a much longer time for completion than when carried out in the ordinary manner. Ten or twelve hours must be allowed to elapse before the change is complete, and the process is expedited if the slide be placed in a warm place (about 100°).

Chromic Acid Fluid.—A most valuable fluid to the microscopist, is a solution of chromic acid in glycerine, and another solution of bichromate of potash in the same fluid. A few drops of a strong solution of chromic acid may be added, so as to give to the glycerine a pale straw colour. The bichromate of potash solution is prepared by adding from twelve to twenty drops of a strong saturated solution of bichromate of potash to an ounce of the strong glycerine. By this plan, the hardening effects of these reagents upon the finest nerve tissues are improved, while the granular appearance which is caused by aqueous solutions of these substances is much less. Sometimes advantage seems to result from mixing a little of the chromic acid with the acetic acid solution of glycerine.

If desired, sugar may be substituted for glycerine in all the fluids employed, including the carmine and injecting fluids; but glycerine, although more expensive, possesses many advantages, and, as far as I am able to judge, is the best viscid medium to employ for general purposes.

One great inconvenience of syrup arises from the growth of fungi, especially in warm weather. Camphor, creosote, carbolic acid, naphtha, prevent this to some extent; but it is a disadvantage from which strong glycerine is perfectly free. Sometimes, too, crystallisation occurs, and destroys the specimen. In using first a syrupy fluid, and then glycerine, to the same specimen, it must be remembered that the two fluids mix but slowly, so that plenty of time must be allowed for the thorough penetration of the medium used last.

I keep various tests, such as alcohol, ether, the various acids, and alkalies, and other tests in the form of viscid solutions made with glycerine or sugar. The reaction of the iodine tests for amyloid matter, starch and cellulose, is much more distinct when employed in this manner. The plan is, to allow the texture to be tested to be thoroughly saturated with the strong glycerine solutions, and then to add water. In the course of a few hours the reaction takes place very strongly.

The plan pursued for preparing the Tissue.—The general plan I follow, is the same for all tissues of all vertebrate animals and morbid growths; but I will describe the several steps of the process as they were conducted in the demonstration of the minute structure of ganglion cells, and of the structure of the papillæ of the frog's tongue.* The description given also applies to the mode of preparing specimens of muscular fibre to demonstrate the mode of distribution of the finest branches of nerve fibre, and specimens of the minute structure of the brain, spinal cord, and ganglia of man and the higher animals.

Perhaps it will be most useful to describe the mode of proceeding when a frog is to be prepared for minute inspection. My researches upon the tissues of the frog have been principally conducted upon the little green tree frog (Hyla arborea), for experience has proved to me that the tissues of this little animal are so much more favourable for investigation than those of the common frog, that it is well worth while to obtain specimens, even at the cost of 2*s.* or 2*s.* 6*d.* each. The student may, however, obtain very beautiful specimens from the common frog. The animal is killed by being dashed suddenly upon the floor, but it must first be carefully folded up in the centre of a large cloth, so that the tissues may not be bruised in the least degree. Next an opening is made in the sternum, the heart exposed, and a fine injecting pipe, after being filled with a little injection, is tied in the artery. The injection ought to be complete in from twenty minutes to half an hour, and sometimes in less time than this. The injection, being pale, cannot be very distinctly seen by the unaided eye, but if the operation has been conducted successfully, the tissues will be found swollen and the areolar tissue about the neck will be fully distended.

The injection being complete, the abdominal cavity of the frog is opened, and the viscera washed with strong glycerine. The legs may be removed, the mouth slit open upon one side, and the pharynx well washed with glycerine.

* "On the structure and formation of the so-called apolar, unipolar, and bipolar nerve cells of the frog."—Phil. Trans. May, 1863. "New Observations upon the minute anatomy of the papillæ of the frog's tongue."—Phil. Trans. June, 1864.

If it is desired to prepare one organ only, this may, of course, be removed and operated upon separately; but I generally subject the entire trunk, with all the viscera, to the action of the carmine fluid. If the brain and spinal cord are special objects of inquiry, the cranium and the spinal canal must be opened so as to expose the organs completely, before the staining process is cemmenced. Enough of the carmine solution is then placed in a little porcelain basin or gallypot, just sufficient to cover the entire trunk and viscera. The specimen is then moved about in the carmine fluid, so that every part that is exposed may be thoroughly wetted by it; sometimes slight pressure with the finger is required. It is left in the carmine fluid for a period varying from four to six or eight hours, being occasionally pressed and moved about during this time, so as to ensure the carmine fluid coming into contact with every part. By this time the blue colour of the vessels of the lungs, viscera, &c., will have almost entirely disappeared, and all the tissues will appear uniformly red. The staining is now complete. The carmine fluid is poured off and thrown away, and the preparation washed quickly with the glycerine solution. The specimen is now placed in another little basin, and some strong glycerine poured over it; it is then left for two or three hours, and a little more strong glycerine added; when, from six to twelve hours since the specimen was removed from the carmine solution have elapsed, the preparation is ready for the last preliminary operation. The glycerine used for washing it is poured off, and sufficient strong Price's glycerine added just to cover it. To this, three or four drops of strong acetic acid are added, and well mixed with the glycerine. In this acid fluid the preparation may be left for several days, when a small piece of some vascular part may be cut off, placed in a drop of glycerine, and subjected to microscopical examination. If the injected vessels are of a bright blue colour, and the nuclei of the tissues of a bright red, the specimen is ready for minute examination; but if the blue colour is not distinct, three or four more drops of acetic acid must be added to the glycerine, and the preparation soaked for a few days longer.

If the nuclei are of a dark red colour, and appear smooth and homogeneous, more especially if the tissue intervening between them is coloured red, the specimen has been soaked too long in the carmine fluid; but in this case, although parts upon the surface may be useless for further investigation, the tissues below may have received the proper amount of colour.

Another plan which I have adopted, and which, although more difficult in practice, if carried out with due care, possesses some advantages, is the following: The vessels are in the first instance thoroughly injected with the carmine fluid, and the preparation allowed to soak for four-and-twenty hours, when a little glycerine is first injected, and then the Prussian blue injecting fluid introduced until the capillary vessels are completely filled with it. The fluid must be injected very slowly, and but slight pressure employed, or the vessels will certainly be ruptured. When the second injection is complete, the textures required for investigation may be removed, washed in glycerine, and, after soaking for a day or two in acetic acid glycerine, will be ready for microscopic investigation. Beautiful and most perfect specimens of solid internal organs, like the brain and spinal cord, may be obtained by this process; and it is the most perfect plan I have adopted, although it presents many practical difficulties, and will probably fail in the hands of the student unless he has the patience to make the attempt many times; when, however, success is obtained, he is well rewarded for the trouble he has taken, and the many failures he may have experienced.

The tissues or organs to be subjected to special investigation may now be removed, and transferred to fresh glycerine; they may be kept in little corked glass tubes, and properly labelled. Generally, the tissue will contain sufficient acetic acid, but if this is not the case, one drop more may be added.

Suppose, now, the nerves with the small vessels and areolar tissue at the posterior and lower part of the abdominal cavity, have been placed in one tube, and the prepared tongue of the Hyla in another, the former specimen may be taken out of the glycerine and spread out upon a glass slide. If it be examined with an inch power, numerous microscopic ganglia may be seen. Several of these, perhaps, are close to small arteries. Those which are most free from pigment cells are selected, and removed carefully by the aid of a sharp knife, fine scissars, forceps, and a needle point. This operation may be effected while the slide is placed upon the stage of the microscope. The *transmitted light* enables the observer to see the minute pieces very distinctly; if necessary, a watchmaker's lens may be used. The pieces selected are transferred to a few drops of the strongest glycerine placed in a watch glass or small basin, or in one of the little china colour moulds, and left to soak for several hours.

The microscopical examination of the specimen may now be carried out. One of the small pieces is placed upon a glass slide, in a drop of fresh glycerine, and covered with thin glass. The glass slide may be gently warmed over the lamp, and the thin glass pressed down upon the preparation by slight taps with a needle point. The specimen may now be examined with a quarter, and afterwards with the twelfth of an inch object glass. A good deal of granular matter will possibly obscure the delicate points in the structure. The slide is again gently warmed, and, with the aid of a needle, the thin glass is made to slide over the surface of the specimen, without the position of the latter being altered, and then removed and cleaned. The specimen is then washed by the addition of drop after drop of strong glycerine containing five drops of acetic acid to the ounce. The slide can be slightly inclined while it is warmed gently over the lamp, in such a manner that the drops of glycerine slowly pass over the specimen and wash away the débris from its surface. The most convenient instrument for dropping the glycerine on the specimen is a little bottle, of two ounces capacity, with a syphon tube drawn to a point, and a straight tube, with an expanded upper part, over which is tied a piece of stout sheet vulcanized India-rubber. Upon compressing the air, by pressing down the India-rubber, the glycerine is forced drop by drop through the syphon tube and allowed to fall upon the specimen.*

When several drops of pure glycerine have been allowed to flow over the specimen, the thin glass cover, after having been cleaned, is re-applied and pressed upon the specimen very gradually, but more firmly than before. If

* These little bottles, as well as any other instruments or apparatus required, can be obtained of Mr. Matthews, Carey-street, Lincoln's Inn-fields; Mr. G. King, 190, Great Portland-street, or Mr. Highley, Green-street, Leicester-square.

the preparation looks pretty clear when examined with the twelfth, the glass cover may be cemented down with Bell's cement, and the specimen left for many days in a quiet place. It may then be re-examined, the process of washing with glycerine repeated, and further pressure applied until it is rendered as thin as is desired. When this point has been reached, more glycerine with acetic acid is to be added, and a plate of mica or the *thinnest glass cover* applied, when it may be examined with the twenty-fifth. The process of flattening may be pushed still further if desirable,—and if only carried out very slowly by gentle taps or careful pressure with the finger and thumb *from day to day*, the elements of the tissues are gradually separated without being destroyed. If there be much connective tissue, which interferes with a clear view of the finest nerve or muscular fibres, it may be necessary to immerse the specimen for some days in the acetic acid syrup, and then transfer it to fresh glycerine. The success of this process depends upon the care and patience with which it is carried out. The most perfect results are obtained in cases where the washing, pressure, and warming have been very slowly conducted, and it is most interesting to notice the minute points of structure which are gradually rendered clearer by the application of a gentle heat, subjecting the specimen to a little firmer pressure or by soaking it in a little fresh glycerine placed in a watch-glass.

Specimens of tissue prepared in this way can be transferred from slide to slide, and no matter how thin they may be, after having been allowed to soak in fresh glycerine they may always be laid out again perfectly flat upon another slide, by the aid of needles.* The action of these viscid fluids is most valuable, and I feel sure that by the process here given, retaining the principle, but modifying the details in special cases, many new and important anatomical facts will be discovered. Until this process is carried out successfully by other observers, I have little hope of my own observations being confirmed.

Suppose the observer desires to study the papillæ of the frog's tongue. Small pieces of the mucous membrane being removed by sharp scissors, they are transferred to glycerine, subjected to the same very gradually increased pressure, until the individual papillæ are themselves slightly flattened. It is possible from a specimen to remove a number of the separate papillæ on a needle point, transfer them to glycerine or to the acetic acid syrup, and then mount them for examination with the $\frac{1}{25}$th object-glass. All the points I have described and figured in my paper may then be demonstrated in several papillæ.

Thin sections of brain, spinal cord, &c., may be subjected to the same process for examination with the highest powers. The tissues of man in health and disease and various morbid growths may be prepared in precisely the same manner. Even the vessels of a small portion of a solid organ, like the brain, liver, or kidney, or those of a small tumour, may be very readily injected. The escape of the injection from divided vessels may be prevented by tying them or by pressure, but considerable escape from the divided vessels does not prevent some of the capillaries being perfectly filled. The most delicate preparations retain their characters for many months, and some

* I often mount these specimens upon a circle of thin glass about $\frac{3}{4}$ of an inch in diameter, instead of upon a glass slide. The circle is then placed in a wooden slide in the centre of which a hole has been drilled of the proper dimensions to receive it. It is fixed in its place by a ring of gummed paper.

for several years, so that in many cases the very preparations from which my drawings have been made, have been preserved.

Method of preparing specimens of Bone and Teeth and other hard tissues.—By the methods generally employed for demonstrating the structure of bone, teeth, and other hard tissues, we are enabled to form a notion of the dead and dried tissue only. The soft material is dried up before the section is made.

And yet this very soft material, which is not represented in the drawings published in different works, is that which makes the only difference between the dried bone or tooth in our cabinets and that which still remains an integral part of the living body. So far from this soft matter being unimportant, it is the most important of all the structures of the hard texture. It is by this alone that all osseous and dental tissues are formed and nourished, and from the arrangement of this soft matter not having been recognized the most erroneous ideas have prevailed, and still prevail, upon the formation and nutrition of the osseous and dental tissues.

Even now it is generally believed that the dentinal tubes are real tubular passages for conveying *fluids* to all parts of the dentine, and are thus subservient to its "nutrition," and yet it is more than eight years since Mr. Tomes proved most conclusively that these so-called "tubes" were occupied in the recent state by a moist but tolerably firm material ("Phil. Trans.," Feb., 1856).

I have verified Mr. Tomes' description, and am quite certain that the so-called dentinal tubes are not channels for the mere flowing up and down of nutrient fluid.*

Suppose a tooth is to be prepared for minute microscopical investigation, we may proceed as follows. The same plan is applicable to bone and shell.

1. As soon as possible after extraction, the tooth may be broken by a hammer into fragments, so as to expose clean surfaces of the tissues. Pieces of dentine with portions of pulp still adhering to them may then be selected and immersed in the carmine fluid, and placed in a vessel lightly covered with paper, so as to exclude the dust. The whole may be left in a warm room for from twenty-four to forty-eight hours.

2. The carmine solution may then be poured off, and a little plain dilute glycerine added, as already described in the case of soft tissues.

3. After the fragments of teeth have remained in this fluid for five or six hours, the excess, now coloured with the carmine, may be poured off, and replaced by a little strong glycerine and acetic acid.

4. After having remained in this fluid for three or four days, it will be found that the portions of soft pulp have regained the volume they occupied when fresh. They have swollen out again even in the strongest glycerine.

5. I have found that in many cases, when it is desired to study the arrangement of the nerves, it is necessary to harden the pulp by immersion in glycerine solution, made by adding to an ounce of the glycerine solution of acetic acid two or three drops of a strong solution of chromic acid. The fragments may remain in this solution for three or four days, and then be transferred to the acetic acid solution, in which they may be preserved for years with all the soft parts perfect.

* On the structure of recent bone and teeth, see my lectures on "The structure and growth of the tissues." Delivered at the Royal College of Physicians, 1860.

6. The specimens are now ready for examination. Thin sections are *cut* with a knife from the fractured surfaces of the dentine, including a portion of the soft pulp. The knife should be strong, but sharp. In practice I have found the double-edged scalpels made for me by the Messrs. Weiss and Son, of the Strand, answer exceedingly well for this purpose, nor will the edge of the knife be destroyed so soon as would be supposed.

7. The minute fragments of sections thus obtained are placed upon a slide and immersed in a drop of pure strong glycerine, in which they may be allowed to soak for an hour or more, and then examined by a low power (an inch). The best pieces are then to be selected by the aid of a fine needle, and removed to a drop of glycerine containing two drops of acetic acid to the ounce, and placed upon a clean slide. Lastly the thin glass cover is carefully applied, and the specimen may be examined with higher powers.

8. If it is desired to retain the specimen, the excess of glycerine fluid is absorbed by small pieces of blotting-paper, and the glass cover cemented to the slide by carefully painting a narrow ring of Bell's cement round it. When this first thin layer is dry, the brush may be carried round a second time, and after the lapse of a few days, more may be applied. Mounted in this way the specimen will retain its character for years.

Hard tissues, like bone, dentine, and enamel, become somewhat softened by prolonged maceration in glycerine, and if a few drops of acetic acid are added, the softening process may be carried to a greater extent, and yet without the calcareous matter being dissolved out to any perceptible extent. If desired, of course the calcareous matter may be in part or entirely removed by increasing the strength of the acid fluid in which the preparation is immersed. But, far short of this, the hard, brittle texture is so altered that thin sections may be *cut* without any difficulty. Specimens prepared in this way may be examined by the highest magnifying powers yet made,—by which statement I mean, of course, to imply that more may be learned by the use of such high powers (1,000 to 3,000 linear) than by employing ordinary object glasses.

Contrary to general opinion, many of the softest textures may be investigated with the greatest facility after having been soaked in strong glycerine. In preparing these, the same steps which have been described must be carried out, but the glycerine used at first must be weaker, and its strength must be very slowly and gradually increased. Young embryos may be injected with the Prussian blue fluid. The pipe cannot be tied in the vessels, as they are extremely soft. But if it is simply inserted, much of the injection will run onwards into the capillaries, and the escape of a certain quantity by the side of the pipe is a matter of no moment.

I have beautiful preparations of the most delicate embryonic tissues, preserved in the strongest glycerine. It is often advantageous to harden the tissues slightly by the addition of a little of the chromic acid glycerine solution. When once the tissues have been fully permeated by glycerine, they may be dissected and manipulated in a manner which before was impossible.

[L. S. B.]

CHAPTER I.

OF STRUCTURE.—OF THE TISSUES GENERALLY.—OF THE CELL, OR ELEMENTARY PART.—DIFFERENT FORMS OF CELLS.—OF INTERCELLULAR SUBSTANCE.—OF THE LIVING OR GERMINAL MATTER OF THE CELL.—OF THE DEVELOPMENT AND MULTIPLICATION OF CELLS.—OF THE CHANGES IN THE CELL IN DISEASE.

IN certain tissues we are unable, even with the aid of the highest powers, to demonstrate any structural peculiarities whatever. But it must be borne in mind that in some apparently perfectly homogeneous textures distinct structure may be demonstrated by special methods of investigation. Various plans of tinting have been employed for this purpose, and solutions of rosanilin dye, nitrate of silver and other soluble colouring matters have been found very useful. It is, therefore, not improbable that future research will prove that many tissues which are now considered perfectly structureless and homogeneous possess distinct structure.

The different physical properties of tissues seem to be due in part to their chemical composition and partly to peculiarities in what may be termed the build of the texture. The differences in structure and properties of the various tissues must not be attributed merely to a difference in the composition of the nutrient material which takes part in their production, for, from the same pabulum, matter different in physical properties and chemical composition may be produced through the agency of structureless living matter. Nor can we trace the cause of the difference in structure of the tissues to difference in structural character, or chemical composition of the germinal matter from which they are formed. So far from this being the case it seems that the very different textures in the body all result from changes in germinal matter having, as far as can yet be ascertained by *observation*, precisely the same characters. And we know that all the masses of germinal matter concerned in the process have the same origin. It seems, therefore, upon the whole, more probable that the masses of germinal matter of the different tissues produce from the same nutrient constituents, substances differing in composition and in texture by virtue of some peculiar inherent power, than that each selects from a common fluid those particular materials most nearly corresponding to the substance to be formed, and causes them to combine. The constituents of the tissues are not constituents of the blood which are merely selected and separated from it, but they are actually *formed* through the agency of the germinal or living matter. The formative power of this germinal or living matter seems to be of far greater importance than its power of selection. Indeed, this supposed selective power, considered by some sufficient to account for the observed facts, has been assumed rather than proved to be one of the most important properties of the cell.

Granules, Globules, Fibres, Membranes.—In certain textures, and suspended in the fluids of the animal body, different structural elements may be observed which have received definite names. *Granules* are minute particles which exhibit no definite form or magnitude when examined under very high magnifying powers. Granules are represented in plate I. fig. 1. *Globules* are small bodies of spherical or oval form, composed throughout of the same substance, exhibiting a clear centre and a distinct outline, the apparent thickness of which varies according as the medium in which the globule is placed differs in refractive power from the material of which the globule itself is composed. So that the outline of the same globule may appear to be *very thick and black* in water, and *as a very thin line* in oil, turpentine, or Canada balsam. Granules and globules vary in chemical composition. They may be composed of *albuminous matter*, *fatty matter*, or *earthy matter*, and these substances may be distinguished by the application of chemical tests.* Globules are represented in plate I. fig. 2. A very good idea of the general appearance of globules may be formed by examining a drop of milk under a magnifying power of 200 diameters.

Fibres may appear as exceedingly fine *lines*, the diameter of which cannot be measured, or as distinct *cylindrical threads*, or *flattened bands*, having a definite diameter. The fibres may be straight, or wavy, or much curved. They may be arranged parallel to one another or they may cross one another at every

* Globules of albuminous matter are rendered transparent by acetic acid and are dissolved by potash and soda. Fat globules are soluble in ether and not altered by acetic acid. Globules of earthy matter are dissolved by acids but are not changed by alkalies.

possible angle. Not unfrequently there is an indication of fine lines although no distinct fibres separable from one another can be demonstrated. This is spoken of as a fibrous appearance as is represented in fibrous tissue, plate I. fig. 3 *a*.

Membrane.—Membrane may be so perfectly transparent and homogeneous that we are only able to demonstrate its existence by the plaits or folds which it forms. Sometimes membrane appears granular or exhibits a fibrous appearance, and not unfrequently calcareous particles are deposited in its substance. Membrane sometimes consists of an insoluble material allied to albumen, but some membranes are composed of a substance which in its physical and chemical characters agrees with yellow elastic tissue. Clear, transparent, and structureless membrane is represented in plate I. fig. 4.

OF THE TISSUES.

Although fully developed tissues might be classified according to the peculiarities of structure they exhibit, the classification would be defective in so many particulars that little advantage could result from the attempt to arrange the tissues of man or those of animals and plants in several artificial groups. Nevertheless such an arrangement as that given below, though far from perfect, may be of some assistance to the student:—

TABULAR VIEW OF THE TISSUES OF THE HUMAN BODY.

1. Simple membrane, homogeneous, or nearly so, employed alone, or in the formation of compound membranes.	Examples.—Posterior layer of the cornea.—Capsule of the lens.—Sarcolemma of muscle.
2. Filamentous tissues, the elements of which are real or apparent filaments.	White and yellow fibrous tissues.—Areolar or connective tissue.
3. Compound membranes, composed in some cases, of simple membrane, and a layer of cells, of various forms (epithelium or epidermis), in others of areolar or connective tissue and epithelium only.	Mucous membrane.—Skin.—True or secreting glands.—Serous and synovial membranes.
4. Tissues which exhibit a cellular structure in their fully developed state.	Cuticle. Nails. Hair.—Gland, pigment, and fat cells.—Cartilage.
5. Tissues hardened by calcareous salts.	Bone.—Teeth.
6. Compound tissues.	
a. Composed of two different kinds of tissues of simple structure.	Connective tissue.—Fibro-cartilage. Certain forms of elastic tissue.
b. Tissues composed of material which possesses special endowments.	Muscle.—Nerve.
c. Tubes for distributing nutrient matter.	Blood vessels.—Absorbent vessels.

Of the Tissues generally.—The first texture enumerated in this table is an example of the simplest form of membrane. Its principal character is extension; but as to the arrangement of its ultimate particles nothing is known; for, under the highest powers of the microscope it appears homogeneous, that is, without visible limits to its particles, or, at most, irregularly and very indistinctly granular. The capsule of the lens, the posterior layer of the cornea, the uriniferous tubes, and the walls of many "cells" are composed of it; and it enters into the formation of muscle, nerve, and the adipose and tegumentary tissues. It is not peculiar to living beings, for a structureless fibre or membrane may be produced artificially.

The filamentous tissues are extensively used for connecting different parts, or for associating the elements of other tissues. The ligaments of joints, for instance, are composed of the white or yellow fibrous tissues; and areolar or connective tissue surrounds and connects the elementary parts of nerves and muscles, accompanies and supports the blood-vessels, and unites the tegumentary tissues to their subjacent parts or organs.

Under the title *compound membranes* we include those expansions, which form the external integument of the body, and are continued into the various internal passages, which, by their involutions, contribute to form the various secreting organs or glands. These are composed of the simple homogeneous membrane, covered by epidermis or epithelium, and resting upon a layer of vessels, nerves, and areolar tissue in great variety; and they constitute the skin, and mucous membranes, with the various glandular organs which open upon their surface.

To these, we may add those remarkable membranes, composed of areolar tissue and a thin indusium of epithelium, which are employed as mechanical aids to motion. These are the serous membranes which line the great cavities of the body, and the synovial membranes, which are interposed between the articular extremities of the bones in certain joints, or are connected with and facilitate the motions of tendons.

The tissues which compose the fourth class have no common character, except their adherence, in the adult state, to the primitive cellular structure, and their analogy in that particular with the vegetable tissue. Although a certain agreement, in morphological characters, allows these textures to be grouped together, none can be more dissimilar as regards their endowments. They differ materially as to the degree of cohesion between their cells: in cartilage there is generally what is spoken of as a firm and resisting intercellular substance, which, however, is not truly *inter*cellular, since it exactly corresponds to what in other tissues is spoken of as cell-wall.

The sclerous tissue (σκληρος, hard,) contains a large proportion of inorganic material, to which it owes its hardness.

The compound tissues are those, the elementary parts of which are concerned in the production of two distinct tissues. Fibro-cartilage is a compound texture, being made up of white fibrous tissue and cartilage; it is employed almost exclusively in the mechanism of the joints of the skeleton, in which it is associated with bone, cartilage, and ligaments.

Muscle and nerve are composed of parallel fibres or threads, each fibre being compound, and exhibiting a special structure; in muscle, it is composed of homogeneous membrane, disposed like a tube, containing a fleshy (*sarcous*) substance, arranged in a particular manner, which is the seat of the peculiar contractile properties of the tissue; and, in nerve, the fibres are composed of similar tubes of homogeneous membrane containing an oleo-albuminous substance, within which is a delicate band or fibre possessing the remarkable property of conducting the nerve force. The arteries, veins, and larger absorbent vessels, are also examples of compound tissues,—their walls being composed of several textures exhibiting different endowments.

All these different tissues, however, possess in the living growing state, disseminated at nearly equal distances through their substance, masses of germinal or living matter, which appear perfectly colourless, homogeneous, and almost diffluent. In this material all the essential changes take place. Each mass is spherical or oval in form, and often exhibits in its subtance one or more smaller masses (nuclei), which are somewhat less transparent than the general mass in which they are embedded. In the nuclei in many cases are other still smaller masses (nucleoli), and sometimes within these yet another series may be detected with the aid of very high magnifying powers. Thus it would seem as if centres were arranged within centres.

Although the various tissues existing in the fully developed organism differ remarkably from one another in structure, physical properties, chemical composition, and action, they all pass through a similar series of changes during their formation. The production of the matter of which the outer part of the simple cell of mildew is composed, is the result of changes probably very similar in essential nature to those which end in the production of the highest and most complex cell in the nervous system of man, and, when successive layers are to be demonstrated in the outer part of any cell, as is often the case, they have been deposited in the same order. We are as ignorant of the real cause and of the nature of the one process as the other. But it is reasonable to infer that if we could ascertain the nature of the changes which actually take place in the simplest living beings during their growth and multiplication, the modifications which occur in the most complex would very soon be understood.

Although we cannot understand or explain how phenomena, which we can observe without difficulty, result, we can demonstrate certain facts, in connection with cell formation, of the utmost interest. We may infer the course taken by the lifeless nutrient material when it is absorbed by the living elementary part or cell, because we can see coloured fluid pursuing the same course when the cell is even detached from the living body and placed under our microscopes. We can show where the inanimate pabulum becomes changed and acquires new and wonderful properties which in turn it can communicate to new inanimate matter. We can observe actions in this altered matter which we cannot explain, but which we may with reason refer to these newly-acquired powers; the actions and changes which take place in this matter are very different to anything familiar to us apart from living beings, and hence to these we limit the term *vital*. We can demonstrate where the *tissue* is first produced, and the precise position in which new tissue is added to that which already exists. We can show which is the youngest and which is the oldest portion of a tissue, and we can give some explanation of the mode in which the old tissue which has done its work is destroyed and removed. Lastly, in certain cases we can show how, after the old tissue has been removed, new and more complex structure takes its place. In short, we possess observations sufficiently complete, in some instances, to enable us to sketch, imperfectly it is true, the life history of the texture, and give an account of its development, the changes occurring in it during its fully-developed state, its gradual decay and removal, and the manner in which its place is occupied by new tissue. We can also trace in some instances the modifications occurring in these processes under certain altered and exceptional conditions which constitute disease.

OF THE CELL, OR ELEMENTARY PART.

Of the Cell.—The cell is even now considered by many to be a body consisting of certain essential definite and constant parts (*cell wall*, *cell contents*, and *nucleus*), to each of which a special office has been assigned by some writers. Some have supposed that living cells exert an influence upon matter which surrounds them, or even upon other living cells at a distance from them. Others maintain that very active powers of producing chemical and other changes reside in the *nucleus* alone. The power of producing change has been attributed in turn to the cell wall, to the matter within the cell, and to the intercellular substance. No well-ascertained facts have, however, yet been adduced in favour of the view, that any living structure whatever can influence matter at a distance from it, so as to alter its properties or composition, or in support of the notion that cell wall, cell contents, or intercellular substance possess any metabolic power whatever. The power of effecting changes in some mysterious or at least unexplained manner, has, however, been assumed to exist in the cell even by some of those observers who have most strongly advocated the physical views of life.

On the other hand, the wonderful changes occurring in the development of tissues have been spoken of as if they could be very readily imitated artificially. The formation of a cell tissue has been compared to the formation of a wall in which ready-made bricks (cells) are supposed to be cemented together by ready-made mortar (intercellular substance). The formation of the tissue has been described as if the cells were first formed and then arranged in their places, and the intercellular substance deposited between them. But how different is the process in nature! At first there are no cells at all. There are but small masses of transparent living germinal matter separated from one another by a little soft formed matter. From this anatomically simple material the fully formed tissue results by gradual changes. New masses of germinal matter are produced by the division and multiplication of those existing before, in the manner represented in figs. 5 and 6. New formed material is formed from these, and as they separate or move away from one another, it accumulates in the intervals between them. The relative proportion which the latter bears to the germinal matter gradually increases as the tissue advances towards its perfect state of development. See figs. 7 and 8. The changes go on in regular order uninterruptedly from the earliest period when there was nothing but a little formless, structureless living matter, till the tissue or organ is formed, and its structure fully developed.

It has been inferred by many writers, that in the formation of a fibre, elongated cells become joined together, and it has been supposed that in the production of a tube the walls of several cells coalesce, and thus the cavity of the resulting tube corresponds to the cavities of the original cells. In the formation of such a tissue as muscle or nerve, it has been assumed that the outer or membranous sheath is formed by coalescence of *cell walls;* while the proper material (contractile tissue, or nerve fibre) is supposed to result from a modification occurring in the cell contents. When processes are seen to project from cells, it is said that they have been *shot out* or protruded from the cell; while, in a tissue composed of stellate cells, authorities have accounted for the arrangement by supposing that the tubular processes of contiguous cells grew away till they met one another, and that when they met they coalesced, so that the cavity of one cell became connected with the cavities of neighbouring cells by tubular communicating channels. And yet no one has even attempted to explain how it happens that the processes or tubes supposed to grow from contiguous cells invariably manage to hit one another exactly, to meet, join, and at last to coalesce, without in any instance overlapping one another, or ever failing to meet in the exact line. But if we examine such a tissue at an early period of its development, we find that so far from there being any indications of cells from which outgrowths are formed, the masses of germinal matter are continuous with one another; so that, in fact, the connecting processes or tubes are connected from the first, and, as growth takes place, the connecting tubes become thinner and thinner, being as it were gradually drawn out as the masses of germinal matter become separated farther and farther from one another, in the manner shown in figs. 11, 12, 13, and 14.

Careful observation of one particular tissue at different periods of its growth will convince the observer that its formation takes place in a very simple manner, and that the formation of all tissues exhibits much in common. At no period of the life of many tissues can the arbitrary definition usually given to the cell (cell wall, cell contents, and nucleus) be correctly applied to the elementary parts of which the texture is composed, nor in any case are such bodies first produced and then arranged in special positions and united together with a connective substance so as to form a mass of tissue.

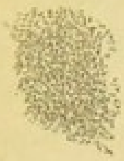
Nevertheless the term "cell" is short and convenient, and it may be still applied to the anatomical elementary part of every tissue at every period of its life, if the meaning be slightly modified. Instead of attempting to divide the cell itself into anatomical constituents, we may speak of it as consisting of matter in two very different states or stages of existence—matter which *lives* (*germinal matter*) and matter which is *formed* and has ceased to manifest purely *vital phenomena* (formed material) (see Introduction, page 11). The simplest and most minute living particle as well as the most complex cell capable of growth or multiplication consists of matter in these two states, but the relative proportions vary greatly at different periods in the life of the cell and under different conditions.

The physical and chemical properties of the formed material differ remarkably in different cases. In one case the formed material may be perfectly fluid, in another soft and viscid, in another of intense hardness, and in some tissues a comparatively soft formed material is rendered very hard by being infiltrated with calcareous or siliceous matter.

We shall now briefly describe the general structure of the principal varieties of cells at different periods of their life, and endeavour to show how the fully developed forms in different

GRANULES, GLOBULES, FIBRES, AND CELLS OR ELEMENTARY PARTS.

Fig. 1.

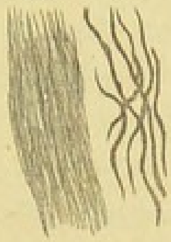


Granules p. 69

Fig. 2.

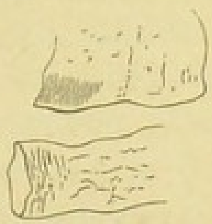
Globules. p. 69.

Fig. 3.



Fibrous appearance. Fibres. p. 69.

Fig. 4.



Membrane. p. 70.

Fig. 5.

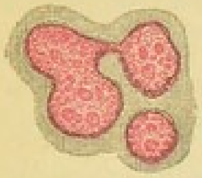


Fig. 6.

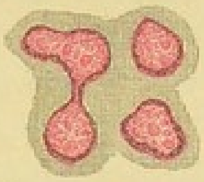


Fig. 7.

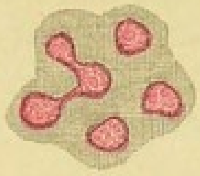
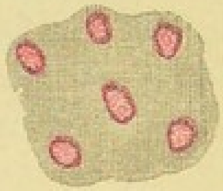


Fig. 8.



Complete division and sub-division of germinal matter, as in cartilage, and the formation of formed material. The space occupied by the three last drawings should be much larger than is represented. p. 75.

Fig. 9.

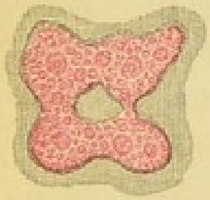


Fig. 10.

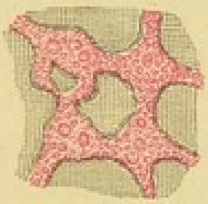


Fig. 11.

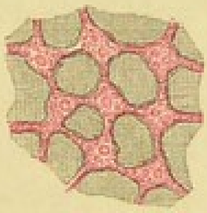
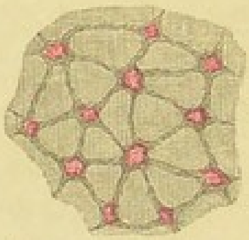


Fig. 12.



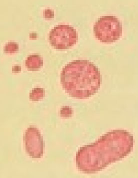
Division and sub-division of germinal matter, as in the production of a tissue with stellate cells (Pl. III, Figs. 35 & 36). Each mass for a considerable time retains its connection with the other matter,—thus are formed the 'communicating tubes' of some tissues. The space occupied by the three last Figures should be much larger than is represented. p. 76.

Fig. 13.

Fig. 14.

Sub-division of masses of germinal matter in one direction, showing how tubes and threads or filaments, differing from the ordinary formed material, may be produced. p. 76.

Fig. 15.



Most minute particles of germinal matter, of ordinary mildew visible under the $\frac{1}{25}$ of an inch. The smallest is less than the $\frac{1}{100000}$ of an inch. p. 77.

Fig. 16.

Production of formed material upon the surface of germinal matter of mildew. × 1800. p. 77.

Fig. 17.

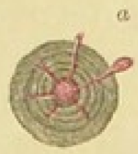


Fig. 18.

Further production of formed material in ordinary mildew. At *a*, a bud is formed by the passage of some of the germinal matter through pores in the very thick layer of formed material. × 1800. p. 78.

Harrisons' Impt.]

textures which exhibit such remarkable varieties of structure and arrangement, result.

Of the structure and formation of the simple Cell.—The low microscopic fungus which is known as common mildew is one of the simplest living things we are acquainted with, and well adapted for study. Some of the smallest particles of mildew capable of independent existence are represented in Plate I. figs 15 and 16, magnified 1800 diameters. The earliest condition of such a particle is shown in fig. 15. If the external membranous investment of a fully developed spore, or of any of the growing branches (figs. 16, 17, 18, 19) was ruptured, such minute particles would be set free in vast numbers and they constitute the living, growing matter, which may be coloured with carmine, while the envelope, or outer part of the cells, does not become coloured.

The surface of such a minute living particle becomes altered the instant it comes into contact with air or water. A thin layer upon the outer part of the particle is changed into a soft, passive, transparent, homogeneous substance, exhibiting a membranous character (cell wall), and this henceforth protects the matter within, and at the same time, being permeable to fluids, nutrient matter passes through it into the interior and undergoes conversion into living matter, which thus increases. The entire mass becomes larger. But this increase in size, it must be distinctly observed, is due not to the addition of new matter upon the *external surface*, but to the introduction of new matter into the *interior*. From this it follows that as the mass increases in size the external membrane already formed must be stretched and rendered thinner; indeed it would ultimately rupture were it not that the same conditions which led to its production cause the formation of more new material of the same kind, which is continually added within that first produced. Thus the external membranous covering is preserved, and in many cases very much strengthened by the new layers which are added. This process much resembles that by which upon a much larger scale the soft skins or hard shells of fruits are produced, and the rosy streaks upon the green covering of a young apple probably mark the tissue which was first produced, although blending so completely with the green portions which are probably of more recent formation.

From what has been already remarked it will have been inferred that the thickness which the formed material or cell membrane attains is determined mainly by the external circumstances to which the living matter is exposed. If pabulum be abundant and external conditions (temperature, moisture, &c.) favourable, it passes through the thin external membrane and the living matter increases rapidly. If, on the other hand, external conditions be unfavourable, a less proportion of pabulum passes through the membrane, and at the same time the unfavourable conditions cause the death of the living matter within, layer after layer, until at last such a condition as that represented in figs. 17 and 18 results. It will be observed that the living matter is now reduced to a very small quantity and that the less this becomes, the more strongly is that which remains protected by the increasing thickness of the envelope.

Now, if the cell in the state above referred to be exposed to the influence of a moderate temperature and moist atmosphere, and be placed under circumstances favourable to growth, the external membrane will become softened and expand. Under the influence of heat and moisture, the hard tissue will be rendered more readily permeable, and pabulum will reach the germinal matter in the interior more easily. The proportion of living matter increases, and portions make their way through natural pores now opened, fig. 17, or through chance fissures in the softened envelope, and protrude from the free surface, fig. 18. A very thin layer of the formed matter being produced on the surface of these protrusions, they are freely supplied with pabulum, which readily permeates the thin layers of formed material, and grow very quickly; and a vast extent of vegetable tissue may be produced, from what was at first a very minute particle of living matter, figs. 17, 19.

From the above observations it seems clear that the formed material of which the envelope is composed results from the death of the living matter. This passive formed material was, in fact, once germinal matter, and in many structures, especially at an early period of development, we may demonstrate the continuity of the germinal matter with the formed material. The successive layers of formed material are often very distinctly seen in vegetable tissues, as, for example, in the sea-weed, fig. 21. The oldest tissue is most external, and this now dead tissue, is already being appropriated by organisms of another kind which are growing upon the surface, while within it passes uninterruptedly into the germinal matter. Moreover from these observations it also appears certain that the living or germinal matter is alone concerned in the active changes which take place.

It may, therefore, be concluded that the smallest independent particle which exhibits vital phenomena consists partly of matter which is lifeless, but which at an earlier period was alive, and partly of matter which lives. If but the smallest particle of the latter remains in a living state, any amount of living matter, and afterwards of lifeless tissue or formed material, may result. But if, on the other hand, all the living matter be dead, and only formed material remain, this is quite incompetent to exhibit the phenomenon of increase. In fact it does not live, it does not manifest any vital properties or powers, and although it is certain that living matter must have existed a short time previously, the formed matter has ceased to live, and can never again acquire the properties it has lost.

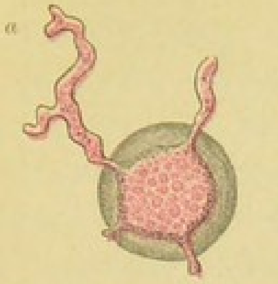
Epithelial Cells.—Epithelial cells from the surface of the human tongue are represented in various stages of existence in figs. 20, *a*, *b*, *c*, and 22, *a*, *b*, *c*, *d*. At first there is but a very thin layer of soft formed material upon the surface of the germinal matter, Fig. 20 *a*. The latter may divide, and each of the portions resulting would be invested with a layer of this soft formed material. Thus the "cells" may increase in number. Each increases in size in consequence of the absorption of nutrient pabulum, which passes through the layer of formed material, as in the case of the mildew, into the germinal matter. Thus the latter increases. But at the same time a portion of the germinal matter undergoes conversion into formed material, which accumulates, and as each new layer is formed upon the surface of the germinal matter, those layers of formed material already produced are stretched, and more or less incorporated with that last developed, fig. 20, *b* and *c*. For a time the germinal matter increases, while at the same time new formed material is produced. Both the constituent parts of the entire cell increase in amount up to a certain period of its life, fig. 22, *a*, *b*, *c*, but as new cells continue to be produced below, the cells already formed are gradually removed farther and farther from the vascular surface, while at the same time their formed material becomes more condensed and less permeable to nutrient matter. Hence each entire cell ceases to increase in size. But as the mass of germinal matter still undergoes conversion into formed material, it becomes smaller as the cell advances in age, fig. 22, *d*. So that it is possible to judge of the age of a cell, irrespective of its size, by the relative amount of its component substances. In old cells there is much formed material in proportion to the germinal matter, while young cells seem to be composed almost entirely of the latter substance. In very old cells the small portion of germinal matter still unconverted into formed material, dies, and the cell having by this time arrived at the surface, is cast off, a mass of perfectly passive lifeless formed material.

It must not, however, be supposed, that formed material always exhibits the firm character of that present in the epithelial cell upon the surface of the skin and some mucous membranes. Soluble formed material may be produced in vast quantity from certain cells, which appear to undergo but very slight change. Liver cells are represented in fig. 23, *a*, *b*, *c*, *d*. These, in health, are surrounded with a thick layer of very soft formed material, the outer part of which is gradually becoming dissolved and disintegrated, and probably oxidised; part passes off in the form of very soluble biliary constituents, while part is resolved into the albuminous matter of the cell, and amyloid matter, which probably in part becomes converted into sugar. Still even in this case, there is a formation of new cells and a casting off of old ones, proceeding in the same definite direction as in the case of the epithelium of the surface, but each individual cell, probably, lives for a much longer period of time.

In figs. 24, 25 and 26, columnar cells of epithelium are represented. The one from the mouth of the snake, in fig. 24, takes part in the secretion of that slimy mucus which is formed in such abundance in the mouths of many reptiles. Nutrient matter is taken up from the blood by the deep surface of the cell. This becomes living matter, and some of the particles of the latter upon the distal aspect, at *a*, become formed material, which pushes that which was produced before it, towards the mouth of the cell, at *b*. Straight lines are seen passing towards the extremity, and the movement of the particles, and

GERMINAL OR LIVING, AND FORMED, MATTER OF THE CELL.

Fig. 19.

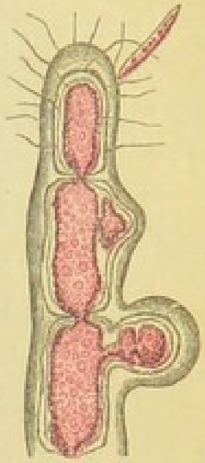


Passage of germinal matter through pores in formed material, and formation of thin layer of formed material upon germinal matter, *a*. Showing the manner in which fungi grow.
× 1800. p. 78.

Fig 20.

Production and accumulation of formed material upon the surface of germinal matter in an epithelial cell, as in cuticle.
× 700. p. 79.

Fig. 21.



Growing extremity of the stem of a sea-weed, showing the manner in which the germinal matter divides and the production of formed material, layer within layer, upon its surface. The outermost layer is the oldest, and is undergoing disintegration.
× 300. p. 78.

Fig. 22.

Drawings illustrating the production of formed material from the germinal matter in epithelial cells. p. 79.

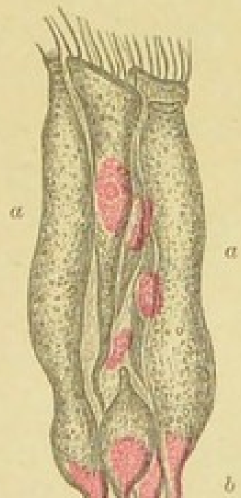
Fig. 23.

Liver Cells in different stages of growth, showing germinal matter and the production of soft formed material, which becomes resolved into several different substances (fatty, amyloid, albuminous, and biliary matters). Human subject.
× 700, p. 80.

Fig. 24.

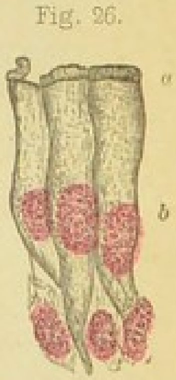
Mucus-forming Cell, from the fauces of a boa, showing germinal matter and the formed material within the envelope. The lower arrow shows the direction in which the nutrient pabulum flows towards the germinal matter, the upper one that taken by the formed material as it passes from the germinal matter. p. 81.

Fig. 25.



Ciliated and Mucus-forming Cells from the fauces of a boa.
× 700 p. 80.

Fig. 26.



Columnar Epithelial Cells, from the small intestine of a dog, showing the position of the germinal matter. *a*, the layer of highly refracting matter upon the surface.
× 700. p. 81.

the flow of nutrient matter, takes place constantly in one definite direction, as shown by the arrows. These mucus-forming cells are seen amongst the ciliated epithelial cells upon the tongue of the frog, and are very large and distinct upon the mucous membrane of the mouth of serpents, plate II, fig. 25*a*. It seems probable that the products of secretion from these cells are wafted away by the vibration of the cilia of the adjacent cells, as they issue from the open end of the cell in which they were produced.

In the case of the columnar cells covering the villi, lines are also seen, and probably depend upon the nutrient matter in the intestine being drawn towards the germinal matter of the cell in a linear direction (fig. 26*a*). These lines have been regarded by Kölliker and others, as *pores* in the layer of thick transparent material which seems to close what has been regarded as the free end of the cell, and it has been supposed that the fatty matter reduced to a state of very minute division by the process of digestion, passes through the pores in its way towards the lacteal; but from the circumstance that this thick transparent matter forms in some cases a continuous layer over the free extremity of the cells, from which it may be peeled off, and the fact that it varies very much in thickness at different periods of the digestive process, it seems probable that the material in question is not a part of the cell at all, but is merely deposited from the contents of the intestine, and caused to collect upon the free ends of the cells, perhaps by the currents of fluid which flow towards the "nucleus." The fluid passing constantly in the same direction would slowly dissolve the precipitated matter, and it would thus be transmitted to the germinal matter in the cell. That part of the germinal matter directed towards the opposite or attached extremity of the cell, would at the same time undergo change, and become converted into substances which would pass to the lacteal vessels upon the surface of the villus.

The different position of the mass of germinal matter in these columnar cells, and those mucus-secreting columnar cells from the frog's or serpent's mouth, should be noticed. In the intestinal cells, the pabulum flows *from* the free surface *towards* the attached extremity of the cells, but in the mucus-secreting cells it flows in the opposite direction, and it seems not improbable that the different situation of the germinal matter in the two classes of cells may be determined by the difference in the position of the pabulum in the two cases, figs. 25, 26*b*.

Many of the radiating lines apparent in cells seem to be due partly to the course taken by the pabulum as it flows in converging lines towards the germinal matter, and partly to the manner in which the formed material is deposited layer within layer. In large masses of germinal matter fissures or channels are sometimes seen by which the whole is mapped out into a number of smaller portions, each one of which will be bathed by the fluid as it passes along the channels. An example of the appearance alluded to is represented in plate III, fig. 27. In vegetable cells matter is deposited layer within layer, so as to thicken and strengthen the cell. This matter is, however, not deposited uniformly in every part, but the deposition is almost entirely prevented in the course taken by the currents of nutrient fluid which are continually flowing towards the germinal matter in the centre. As the process of deposition goes on, the channels gradually become narrower, but, as would be inferred, they are, except in very old cells, invariably of considerable width nearest to the germinal matter, and the "cavity" of the cell, after the drying up of the germinal matter, exhibits a stellate form, fig. 28. In fig. 32 is a portion of the thickened wall of one of the large cells in the potato which are destitute of starch, seen in fig. 31, under low power. These figures illustrate the same point.

Cells or Elementary Parts consisting of two or more kinds of formed material,—Cell-Wall and Cell-Contents.—In the mucus-secreting cells referred to in the last section, two kinds of formed material were produced from the original germinal matter of the cell, 1, that which has been called *cell-wall*, and 2, the peculiar matter found in the interior usually termed *cell-contents*. In plate III, fig. 29, are represented some of the young starch-holding cells of the potato. The so-called cell-wall is formed around, and now invests, the germinal matter, while the starch is deposited as small insoluble particles *in its substance*. In fact by the death of particles upon the surface of the living matter, the *cellulose* "cell-wall" is produced, while, in consequence of the death of some of the particles further inwards, and therefore under different conditions, *starch* results.

As the starch-holding cells increase in size, the starch granules become enlarged by deposition of layer after layer *upon their external* surface. They still lie embedded in the germinal matter, and are separated from the cell-wall by it. This outer portion of the germinal matter is known as the "*primordial utricle*" of the vegetable cell, *see* fig. 30. That the formation of the starch granules is a process closely allied to the production of the cell-wall seems proved by the circumstance that in some of the cells no starch is found in the interior, but the wall of the cell is greatly thickened by the deposition of a closely allied, but not identical material upon its internal surface, layer within layer, as represented in figs. 31 and 32.

The fat cell, or adipose vesicle, is formed in precisely the same way, and fat may be deposited amongst the germinal matter of other cells, such as the cartilage cell, and in nerve and other elementary parts in certain cases. The formation of fat in a fat cell, at different stages of development, is represented in plate III, fig. 33, *a*, *b*, *c*.

Of Stellate Cells.—It has often been said that a cell *sends* or *shoots out* branches or processes at different parts of its circumference, and thus becomes star-shaped. The processes of stellate cells are, however, never formed by any such process of growing or shooting "outwards" from the body of the cell. They are not as it were *out-growths*, which proceed from one cell and meet those protruded from neighbouring cells, but the processes are drawn out as the masses originally close together become separated, in the manner already referred to in page 75, and represented diagrammatically in plate I, figs. 9 to 12. These diagrams are not, however, strictly true, for figs. 11 and 12 would really extend over a much larger space than in the drawing, for each of the numerous masses of germinal matter in figs. 7, 8, 11 and 12, corresponds to the larger masses seen in figs. 5, 6, 9, and 10. The large pigment cells of the frog and other batrachia, and those forming the outer layer of the choroidal coat of the eye (lamina fusca), are good examples of stellate cells. The former will be found in chap. III, the latter in plate III, fig. 34.

Upon the surface of the fang of the tooth, in contact with the cementum or crusta petrosa, is a tissue of a very interesting structure, which takes part in the formation of the cementum.

It is composed entirely of branching cells, and is a most perfect example of a tissue consisting entirely of cells, the cavities of which, up to a certain period of development, *communicate with one another by tubes.* The stellate cells are here as distinct as they are in the pith of a rush. These cells and tubes do not, however, constitute an elaborate system of channels for the distribution of nutrient material to the tissue which intervenes between them, as Virchow and his school maintain. The structure is represented in plate III, fig. 35.

But perhaps the most remarkable instance of the formation of fibres by the gradual separation of cells from one another occurs in the central organs of the nervous system. The fibres are structurally continuous with the body of the cell, and become drawn out as it were, as the cells, originally continuous, become separated further and further from each other. At an early period of development the caudate cells in the cord and brain of man and animals, are represented by small and perfectly spherical cells, which lie close to one another. The small quantity of formed material between them is so transparent that no structure can be discerned in it. As yet it exhibits no indications of fibres. It is, however, very probable that fibres exist even at this early period, but their transparency and delicacy of structure render them invisible. As development advances, the masses of germinal matter become separated from one another, while at the same time they increase in size, and the fibres, which, with the outer part of the cell, constitute the formed material, become more and more drawn out in every part of their course, until they are so very thin as not to be recognizable without the use of very high magnifying powers, and a special method of preparation. The numerous interlacing nerve fibres, of which the matter intervening between the cells of the adult brain and spinal cord is almost entirely composed, are thus formed. *See* fig. 36, plate III.

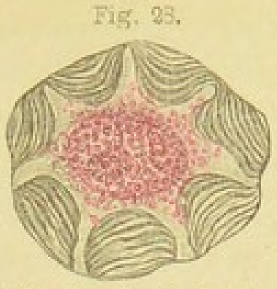
Of Spherical and Oval Nerve Cells.—A cell of highly complex structure connected with the sympathetic of the frog, is represented in plate IV, fig. 40, but the manner in which this is produced will probably be understood if the principles already advanced have been carefully considered. This "cell" exhibits two fibres proceeding from it, one being coiled spirally round the other. At an early period of development it consists only

GERMINAL OR LIVING, AND FORMED, MATTER OF THE CELL.

Fig. 27.

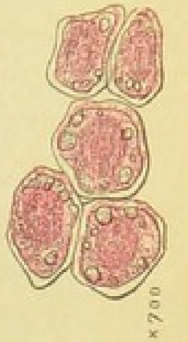
GERMINAL MATTER. Cornea of the Salamander.
× 700. p. 82.

Fig. 28.



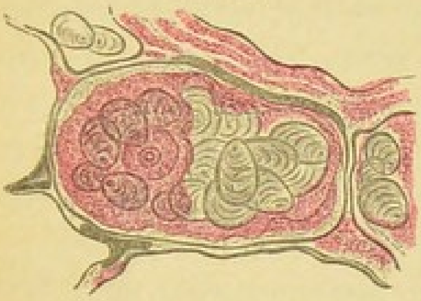
Vegetable cell, showing the manner in which secondary deposits are formed, and how the channels through which currents flow towards the 'nucleus' result.
p. 82.

Fig. 29.



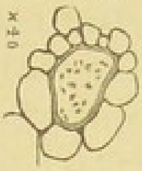
Five young starch-holding cells of the potato, showing GERMINAL MATTER, with small starch globules precipitated amongst it.
× 700. p. 82.

Fig. 30.



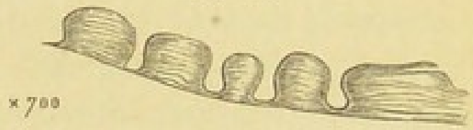
A fully formed starch-holding cell of the potato.
× 350. p. 83.

Fig. 31.



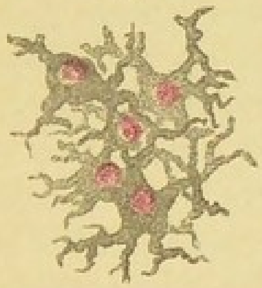
One of the large cells, with thick walls, from the potato, containing very little starch.
p. 82.

Fig. 32.



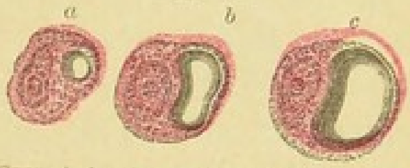
A portion of the wall of one of the cells in Fig. 31, showing how the wall is thickened by the deposition of layer within layer.
× 700. p. 82.

Fig. 34.



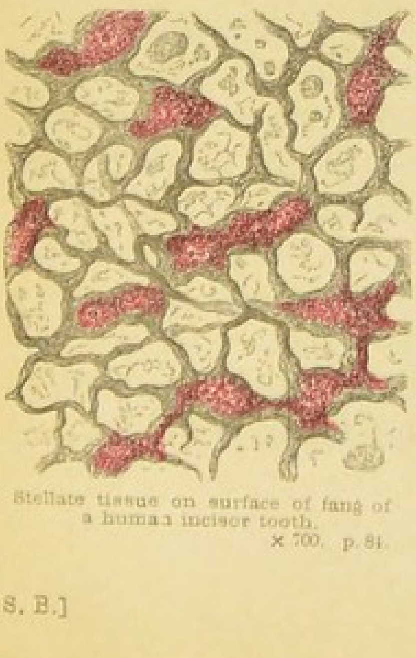
Pigment cells from the outer part of the choroid. Human.
× 130. p. 83.

Fig. 33.



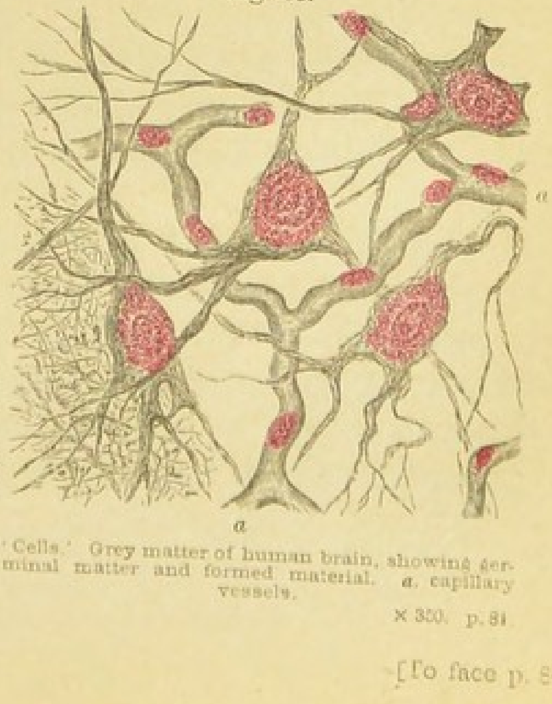
'FAT CELLS,' showing the seat of formation of the fat (formed material), and the changes occurring in the cell as it advances towards its fully developed state. Frog.
× 700. p. 83.

Fig. 35.



Stellate tissue on surface of fang of a human incisor tooth.
× 700. p. 84.

Fig. 36.



'Cells.' Grey matter of human brain, showing germinal matter and formed material. a, capillary vessels.
× 350. p. 84.

of an oval mass of germinal matter, with either extremity of which a fibre is connected. The cell moves in a direction more or less at right angles to the line of the fibres, and as it moves it probably turns round upon its own axis, in such a way that one fibre becomes coiled round the other, as represented in the drawing. This interesting form of cell will be described in the chapter upon the anatomy of nervous tissue, and it is only alluded to here as an illustration of the fact that every highly complex cell, like cells of very simple structure, consists of germinal matter and formed material. In the sympathetic ganglia of the higher vertebrata the cells are more spherical and several fibres come off from each cell, but the peculiar twisting of one fibre round the other, as in the case of the cells from the frog, and some other batrachia, has not been observed.

Of the so-called Intercellular Substance.—In cartilage, tendon, and some other tissues there is no line of separation between the portions of formed material which belong to each respective mass of germinal matter as is the case in epithelium, but the formed material throughout the entire tissue forms a continuous mass of tissue, matrix, or, as it has been termed, connective substance. From the apparent essential difference in structure, it has been supposed that tissues of this character were developed upon a principle very different to that upon which epithelial structures were produced. It has been maintained by some that in cartilage a cell-wall, distinct from the intervening transparent material, existed around each cell, and it has been very generally concluded that the matrix was deposited between the cells, and hence this was called "*inter*cellular substance."

By reference to figs. 37 and 39, plate IV, it will be seen, however, that the so-called *intercellular substance* of cartilage and tendon exactly corresponds to the formed material of the epithelial cell, fig. 22, plate II.

A "cell," or elementary part of fully formed cartilage and tendon, consists of a mass of germinal matter with a proportion of the formed material around it. A line passing midway between the different masses of germinal matter would mark roughly the point to which the formed material corresponding to each particular mass of germinal matter extended, and this would correspond with the outer part of the surface or boundary of the epithelial cell.

In order to understand the true relation of the so-called intercellular substance of the cartilage and tendon to the masses of germinal matter, it is necessary to study the tissue at different ages. At an early period of development these tissues appear to consist of masses of germinal matter only. As development advances, the formed material increases, and the masses of germinal matter become separated further and further from one another. The appearances of a cell-wall around the germinal matter in the fully-formed tissue, and other alterations which occur, and anomalous appearances which often result as age advances, can be even more readily understood upon the view here advanced, than upon the intercellular substance theory which has been so strongly supported by some observers.

The above conclusions may be confirmed by a careful examination of white fibrous tissue. If equal portions of fœtal and adult tendon be examined, the proportion of germinal matter in each will be found to be very different. There may be five or six times as much germinal matter in a certain bulk of fœtal, as in the same bulk of fully formed tendon. The tendinous matter or tissue possesses no power of absorbing nutritive material and converting it into tissue like itself. All additions to its substance take place at those points only at which germinal matter exists. Young tendon grows much faster than fully formed tendon, and in old tendon the masses of germinal matter have become reduced to very thin lines. In figs. 38 and 39, plate IV, specimens of fœtal and fully developed tendon, from the kitten and cat, are represented.

Of the Formation of the Contractile Tissue of Muscle.—A muscle "cell" or elementary part, will consist, like that of cartilage and tendon, of the so-called nucleus, with a portion of the muscular tissue corresponding to it. In general arrangement it closely resembles what is seen in tendon. The contractile material of muscle may be shown to be continuous with the germinal matter, and oftentimes a thin filament of the transversely striated tissue may be detached with the oval mass of germinal matter still connected with it, showing that, as in tendon, the germinal matter passes uninterruptedly into the formed material. In the formation of the contractile tissue, the germinal matter seems to move onwards, while posteriorly, it gradually undergoes conversion into tissue. At the same time it absorbs nutrient material, and thus there may be no loss in bulk in a mass which has been instrumental in the production of a considerable amount of contractile tissue.

The drawings represented in fig. 41, plate IV, will enable the student to understand the relation of the germinal matter to the contractile tissue, or formed material of muscle.

On the Formation of Nerve Fibres.—Nerve fibres consist of formed material which is structurally continuous with that of the cells with which they are connected. At an early period of its development a nerve fibre appears to consist of a number of masses of germinal matter, linearly arranged. As development advances, these become separated further and further from one another, and the tissue formed between them constitutes the fibre of the nerve. Fig 42, plate IV, represents a dark-bordered nerve fibre from the frog at an early period of its development.

Of Living or Germinal Matter. Of the "Nucleus" and "Nucleolus."—In the foregoing account of the structure and mode of formation of tissue it has been shown that even the smallest living organism with which we are acquainted does not consist of matter in the same state in every part, but that the material within (germinal or living matter) possesses powers or properties of which the formed material, be it solid or fluid, is entirely destitute. Each mass of germinal matter with a proportion of the formed material around it, is a cell. All living cells consist of matter in these two very different states. The one state being an active condition *vital;* the other being a passive state in which no *vital* actions are manifested.

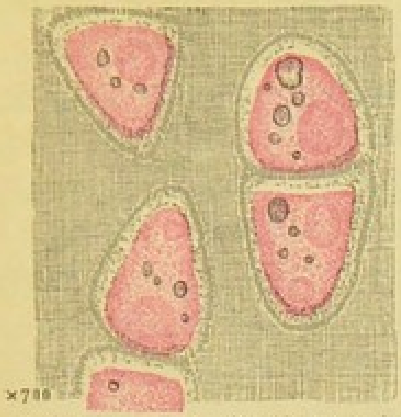
The importance of this distinction is very great, because, as will presently be shown, the matter in the first or living state is that upon which all growth, multiplication, conversion, formation, in short *life*, depends; while, in the second condition, the matter may exhibit very peculiar properties, and it may have a most complex chemical composition; but although it may increase by new matter being *added to it*, it does not grow or multiply, it does not convert or form—it does not *live.* Lastly, facts and arguments have been advanced which show that all matter in the last or formed state was once in the first or living state, so that the properties it has acquired, and the characters it possesses as formed matter, depend upon the changes which were brought about while the matter existed in the germinal or living state.

One mass of living germinal matter may divide into several, and thus cell-multiplication occurs. In all cases the multiplication of the cell is due not to a *growing in* of the wall or formed material, but entirely to changes in the germinal matter.

In many masses of germinal matter a smaller spherical mass, often appearing a mere point, is observed, and in many cases this divides before the division of the parent mass takes place. This, however, is not necessary to the process, for it takes place in cases in which no such bodies are to be seen, and it frequently happens that one or more of these smaller spots or spherical masses may appear in its substance, *after* a portion of germinal matter has been detached from the parent mass. These are to be regarded as new centres composed of living matter. Within these a second series is sometimes produced. The first have been called *nuclei*, and those within them *nucleoli*. Marvellous powers have been attributed to nuclei and nucleoli, and by many they are supposed to be the agents alone concerned in the process of multiplication and reproduction. These nuclei and nucleoli are always more intensely coloured with alkaline colouring matters than other parts of the living or germinal matter, a fact which is alone sufficient to show the difference between a true nucleolus or new centre and an oil globule, which has often been wrongly termed a nucleolus. According to the view of cell-structure here advanced, nuclei and nucleoli are but new living centres appearing in pre-existing centres, and they may be supposed to mark the commencement of another series of changes in the matter in which they appeared, differing, perhaps, in some minor particulars from the first changes which occurred. Sometimes a very defined line shows precisely the limit of the two orders of changes. Although nuclei and nucleoli are germinal or living matter, both are not undergoing conversion into formed material. The vital powers of nuclei are often not manifested at all, but under certain conditions the nucleus may increase, and exhibit all the phenomena of ordinary

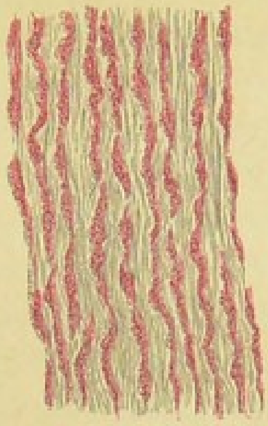
GERMINAL OR LIVING, AND FORMED, MATTER OF THE CELL.

Fig. 37.



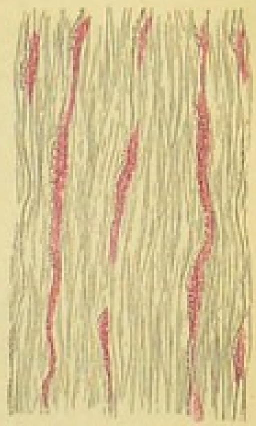
CARTILAGE. Frog. Showing germinal matter and formed material (intercellular substance, of authors), with appearances resembling a cell-wall. × 700. p. 85.

Fig. 38.



TENDON. Kitten at birth. × 215. p. 86.

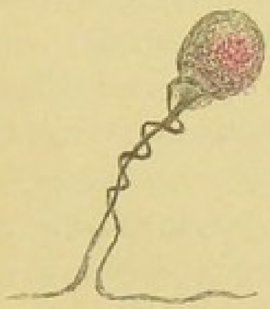
Fig. 39.



TENDON. Young cat. × 215. p. 86.

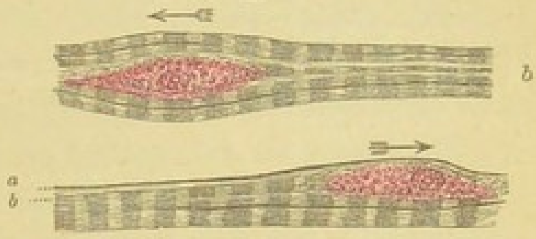
Showing germinal matter and formed material (intercellular substance, of authors) of tendon at different stages of development.

Fig. 40.



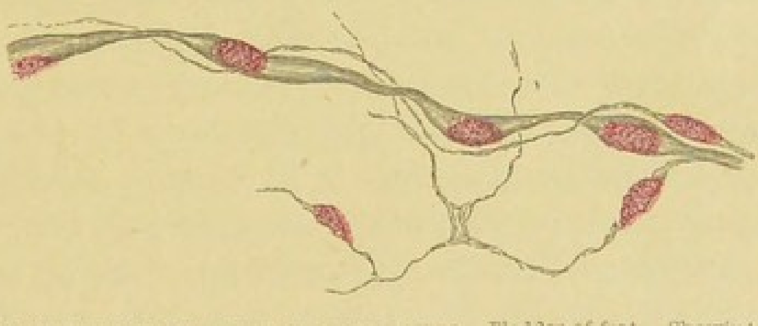
NERVE CELL, with straight and spiral fibres. Frog. p. 84.

Fig. 41.



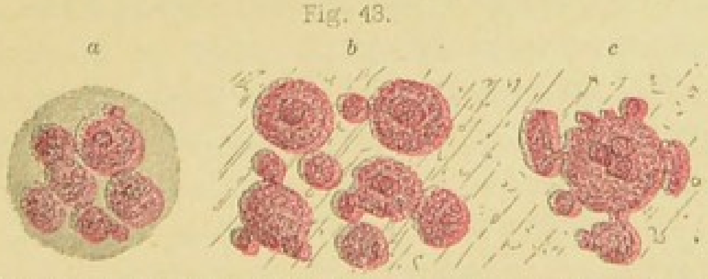
MUSCLE. Germinal matter and formed material. *a*, the sarcolemma. *b*, the contractile material. The arrows show the direction in which the masses of germinal matter are supposed to be moving. p. 87.

Fig. 42.



YOUNG DARK-BORDERED AND FINE NERVE FIBRES. Bladder of frog. Showing germinal matter and formed material of nerve cells or elementary parts. × about 1800. p. 87.

Fig. 43.



FORMATION OF PUS. To illustrate the changes resulting in the germinal matter of an epithelial cell from increased nutrition, showing the manner in which the germinal matter of a normal cell, if supplied very freely with pabulum, may give rise to pus. p. 95.

germinal matter—new nuclei may be developed within it, new nucleoli within them so that ordinary germinal matter may become formed material, its nucleus growing larger and taking its place. The original nucleolus now becomes the nucleus, and new nucleoli make their appearance in what was the original nucleolus. The whole process consists of evolution from centres, and the production of new centres within pre-existing centres. Zones of colour, of different intensity, are often observed in a cell coloured with carmine. The outermost or oldest, or that which is losing its vital powers, and becoming converted into formed material, being very slightly coloured, the most central part, or the nucleus, although furthest from the colouring solution, exhibiting the greatest intensity of colour. These points are illustrated in plate III, fig. 36, and some other figures. Germinal matter, in a comparatively quiescent state, is not unfrequently entirely destitute of nuclei, but they sometimes make their appearance if the mass be more freely supplied with nutrient matter. This fact may be noticed in the case of the connective tissue corpuscles, and the masses of germinal matter connected with the walls of vessels, nerves, muscular tissue, epithelium, &c., which often exhibit no nuclei (or according to some, nucleoli), but soon after these bodies become supplied with an increased quantity of pabulum, several small nuclei make their appearance in all parts of the germinal matter.

So far from nuclei being formed first, and the other elements of the cell deposited around them, they make their appearance in the substance of a pre-existing mass of germinal matter, as has been already stated. The true nucleus and nucleolus are not composed of special constituents differing from the germinal matter, nor do they perform any special operation. They consist of living germinal matter. Small oil-globules, which invariably result from post-mortem changes in any germinal matter, have often been mistaken for nuclei and nucleoli.

Of the increase of Cells.—Several distinct modes of cell increase or multiplication have been described, but in all cases the germinal matter divides, and is the only material in the cell actively concerned in the process of multiplication. The process of division may, however, take place according to several different plans :—1. The parent mass of germinal matter may simply divide into two equal parts, apparently in obedience to a tendency of the portions to move away from one another after the original mass has reached a certain size. During this process, a constricted part is produced between the two separating masses, and this becomes thinner and thinner. This band, reduced to the thinnest line, may still connect the two, or it may break, and thus two independent living masses result from the division of one. 2. The parent mass, instead of dividing into two, may divide into three, four, or more equal parts. 3. From every part of the parent mass, protrusions, buds, or offsets may proceed, and however small these may be, each one, when detached, soon absorbs nutrient matter, and grows until it attains the same size as its parent. The formed material of the cell is perfectly passive in the process of increase and multiplication. If soft or diffluent, a portion of this may collect around each of the masses into which the germinal matter has divided, but it does not '*grow*' or '*move in*' and form a partition as has often been stated. When a septum or partition exists, it results not from "growing in," but it is simply produced by a portion of the germinal matter undergoing conversion into the formed material of which it is composed.

If the formed material of the cell be hard and firm and unyielding, the germinal matter may make its way through some orifice in it, or at the weakest point, and escape in small particles which pass forth into the surrounding medium, or the separating portions may remain attached to the parent for a longer or shorter period of time, in the form of processes or outgrowths, as represented in plate II, fig. 19. In either case its outer part becomes converted into formed material, which protects it and modifies its rate of increase; so that in no case can it be said that the cell, as a whole, divides, but the germinal matter alone is the material which is concerned in this as well as in all other active phenomena characteristic of cell life. If these simple facts be carefully borne in mind, the differences observed in the fully formed textures, and the alterations occurring in disease, receive a ready explanation.

Of Development.—The greater number of living beings result from changes occurring in a minute body of apparently very simple structure, which is formed within the organism of the female parent, and in which active changes commence immediately after its impregnation has taken place. This body is the *ovum* or *egg*, which in many cases is provided with a store of nutrient matter, to be appropriated by the embryo during the early period of its development. The essential portion of the ovum is exceedingly minute. It consists of germinal matter which, besides exhibiting special and peculiar characteristics in the course of its development, presents at every period of existence the same general characters, and possesses the same general properties as every other kind of germinal matter. The complete ovum or egg of man and the higher animals exhibits a somewhat complex structure, and certain special parts have received distinct names which it may be well to give. Most externally is the homogeneous *vitelline or yolk membrane*, which contains besides the yolk the essential parts, called the *germinal vesicle*, within which is the *germinal spot*, but these last probably correspond to parts found in the ordinary "cell"—the centre of germinal or living matter, termed the *nucleus*, within which is another centre termed the *nucleolus*. Before an embryo can be developed from the true ovum, impregnation must take place. It is now certain that in this process the male element (including the minute mass of germinal matter it contains?) penetrates quite into the substance of this small mass of living matter, and exerts an influence upon all the phenomena which are to succeed in it. The germinal matter of the ovum having thereby acquired new powers, divides and subdivides, and many series of new masses of germinal matter successively come into existence, disappear, and give place to new ones, each series being however the descendant of that which existed before, until at last a number of masses result, from which the earliest traces of the new being or embryo are evolved. But there are many instances of beings of comparatively simple organisation from which a new organism may result without the formation of a true ovum. Certain masses, and, in some cases, every mass of germinal matter in the body, may give rise to the formation of new and complete organisms. To this process there is some analogy even in the highest animals, and at all periods of life, in the development of simple masses of living matter into new tissues of very complex structure.

We are quite unable to offer any clear and satisfactory explanation of the phenomena of development of a tissue or organ. It has been shown that the successive generations of cells produced are lineal descendants of the original cell or cells constituting the germ-cell, while the arrangement, structure, and composition of the elementary tissue formed, differ materially as the development of the texture or organ advances. The successive production of formed material differing in composition and properties from that previously produced may be accounted for upon the supposition that the successive series of masses of germinal matter possess different powers, but whether this power is acquired during the process of their development or transmitted directly from the original germinal matter we have at present no positive evidence to show. That the new living centres which are developed within pre-existing living masses of germinal matter exhibit powers or properties not possessed by those within which they originated is certain, and it is probable that this origin of new centres within pre-existing ones takes place in all cases, and is an essential phenomenon in development. It is interesting to observe, that a mass of germinal matter which remains *quiescent* for a certain period of time and absorbs scarcely any pabulum, or perhaps actually none, may give origin to descendants from which special and complex structures and organs not previously formed may be produced; while if this very same mass were to be too freely supplied with pabulum, it would grow and multiply, and would exhibit the greatest activity, but not one of its very numerous descendants would be capable of giving rise to any structure. After existing for a very brief period they would die without leaving any evidence of their having possessed any structure-forming power whatever. Increase in power seems to be associated with the most limited change in germinal matter, while rapid change—increased vital action—seems to be invariably connected with decadence in power. So that the formation of highly elaborate and complex tissues, organs, or organisms, is not in any way connected with, or due to the influence of, the ordinary forces associated with lifeless matter, but it must be attributed to the influence of some peculiar power capable of controlling and directing both matter and force, and therefore of a nature very different to ordinary force. The laws governing vital phenomena are not yet understood. It will naturally be suggested that the different substances and different structures produced by germinal matter at different periods of development may depend upon the different surrounding conditions present when the changes occur. This, however, is no explanation at all, for the surrounding conditions present, as well as the circumstances concerned in their production, are themselves complex. They are not simple external conditions, but are in part the result of external circumstances, and in part of a previous state of things in the establishment of which pre-existing vital powers associated with germinal matter played no unimportant part. Extending our inquiries still further back, we must at length discuss how the first formed material itself was produced, and it has been shown that this is due to the death of living matter under certain conditions, which is itself a highly complex phenomenon, and cannot be explained without supposing certain *internal* forces capable of causing the elements of the matter to arrange themselves in a certain definite manner, totally different to that in which the ordinary forces of matter would cause these elements to be arranged,—and certain *influences operating from without* (surrounding external conditions) tending to prevent the supposed internal forces from exerting their sway. The composition, structure, and properties of the matter produced must, in fact, be referred to the influence of very different and antagonistic forces acting upon matter from opposite directions.

Of the Changes in the Cell in Disease.—It has been shown that of the different constituents of the fully formed cell, the germinal matter is alone concerned in all active change. This is in fact the only portion of the cell which lives, while at an early period of development, the parts of the cell usually regarded as necessary to cell existence are altogether absent. The "cell" at this period is but a mass of living germinal matter, and in certain parts of the body at all periods of life are masses of germinal matter, destitute of any cell-wall, and exactly resembling those of which at an early period the embryo is entirely composed. White blood and lymph corpuscles, chyle corpuscles, many of the corpuscles in the spleen, thymus and thyroid, corpuscles in the solitary glands, in the villi, some of those upon the surface of mucous membranes, and minute corpuscles in many other localities, consist of living germinal matter. There is no structure through which these soft living particles may not make their way. The destruction of tissue may be very quickly effected by them, and there is no operation peculiar to living beings in which germinal or living matter does not take part. Any sketch of the structure of the cell would be incomplete without an account of some of the essential alterations which take place in disease, and it is therefore proposed to refer very briefly to the general nature of some of the most important morbid changes.

If the conditions under which cells ordinarily live be modified beyond a certain limit, a *morbid* change may result. For instance, if cells, which in their normal state grow slowly, be supplied with an excess of nutrient pabulum, and increase in number very quickly, a *morbid* state is produced. Or if, on the other hand, the rate at which multiplication takes place be reduced in consequence of an insufficient supply of nourishment, or from other causes, a diseased state may result. So that, in the great majority of cases, disease, or the morbid state, essentially differs from health, or the healthy state, in an increased or reduced rate of growth and multiplication of the germinal matter of a particular tissue or organ. In the process of inflammation, in the formation of inflammatory products, as lymph and pus, in the production of tubercle, and cancer, we see the results of increased multiplication of the germinal matter of the tissues or of that derived from the blood. In the shrinking, and hardening, and wasting, which occur in many tissues and organs in disease, we see the effects of the germinal matter of a texture being supplied with too little nutrient pabulum, in consequence sometimes of an alteration in the pabulum itself, sometimes of an undue thickening and condensation of the tissue which forms the permeable septum, intervening between the pabulum and the germinal matter.

The above observations may be illustrated by reference to what takes place when pus is formed from an epithelial cell, in which the nutrition of the germinal matter, and consequently its rate of growth, is much increased. And the changes which occur in the liver cell in cases of cirrhosis may be advanced in illustration of a disease which consists essentially in the occurrence of changes more slowly than in the normal condition, consequent upon less than the normal freedom of access of pabulum to the germinal matter.

The outer hardened formed material of an epithelial cell may be torn or ruptured mechanically, as in a scratch or prick by insects, or it may be rendered soft and more permeable to nutrient pabulum by the action of certain fluids which bathe it. In either case it is clear that *the access of pabulum to the germinal matter is facilitated*, and the latter necessarily "*grows*"—that is, converts certain of the constituents of the pabulum that come into contact with it into matter like itself,—at an increased rate. The mass of germinal matter increases in size and soon begins to divide into smaller portions. Parts seem to move away from the general mass. These at length become detached, and thus several separate masses of germinal matter, which are embedded in the softened and altered formed material, result. These changes will be understood by reference to fig. 43, *a*, *b*, *c*, plate IV. In this way the so-called inflammatory product *pus* results. The abnormal pus-corpuscle may be produced from the *germinal or living matter of a normal epithelial cell, the germinal matter of which has been supplied with pabulum much more freely than in the normal state.*

It will be seen how easily the nature of the changes occurring in cells in inflammation can be explained if the artificial nomenclature of cell-wall, cell-contents, nucleus, be given up. In all acute internal inflammations a much larger quantity of inanimate pabulum is taken up by certain cells and converted into living matter than in the normal state. Hence there is increase in bulk. Cells of particular organs, which live very slowly in health, live very fast in certain forms of disease. More pabulum reaches them, and they grow more rapidly in consequence.

In cells which have been growing very rapidly and are returning to their normal condition, *in which the access of nutrient pabulum is more restricted than in the abnormal state*, as is the case in normal cells passing from the embryonic to the fully-formed state, the outer part of the germinal matter undergoes conversion into formed material, and this last increases as the supply of pabulum becomes reduced.

We will now enquire what alterations can be observed in cells, the "*formed material*" of which, under *normal conditions*, becomes *quickly* resolved into other soluble constituents if these cells be placed under circumstances which caused the formed material to become harder and less permeable to nutrient matter than in health. The formed material which enters into the formation of the liver "cell" is soft, moist, and readily permeable to certain nutrient matters. There is no cell-wall, but the outer part of the formed material is gradually resolved into soluble biliary matters, which pass down the ducts, and into amyloid and saccharine matters, which permeate the walls of the vessels and enter the blood. To make up for the disintegration of the outer part of the formed material, new formed material is produced in the interior of the cell from the germinal matter, and the germinal matter which undergoes this change is replaced by new germinal matter produced from the pabulum that is absorbed. If such cells and their descendants are bathed with improper pabulum, and especially with substances which render albuminous matters insoluble, or possess the property of hardening them, they necessarily diminish in size, in consequence of the formed material becoming less permeable, less nutrient matter is taken up; and of course, as the formed material becomes hardened, less disintegration takes place, the quantity of secretion, which really consists of the products resulting from disintegration, is much diminished, and the amount of work performed by the cell is reduced. Under the supposed conditions the cells shrink in size and become more firm in texture. Many gradually waste, and not a few die, and at length disappear. These seem to be the essential changes which slowly take place in the liver cells in *Cirrhosis*, and to these changes in the cells, the striking shrinking and condensation of the whole liver, so characteristic of this disease are due.

From these observations it follows that disease may result in two ways—either from the cells of an organ growing and multiplying faster than in the normal state, or more slowly. In the one case, *the normal restrictions under which growth takes place are diminished; in the other, the restrictions are greatly increased. Pneumonia*, or inflammation of the lung, may be adduced as a striking example of the first condition, for in this disease millions of cells are very rapidly produced in the air cells of the lung, and nutrient constituents are diverted from other parts of the body to this focus of morbid activity. Contraction and condensation of the liver, kidney, and other glands, hardening, shrinking, and wasting the muscular, nervous, and other tissues, are good examples of the second. The amount of change becomes less and less as the morbid state advances, the whole organ wastes, and the secreting structure shrinks, and at last inactive connective tissue alone marks the seat where most active and energetic changes once occurred. It is easy to see how such a substance as alcohol must tend to restrict the rapid multiplication of the cells if the process is too active, and how it would tend to promote the advance of disease in organs in which rapid change in the cells characterises the normal state.

We shall necessarily be led by these considerations to the conclusion that the rate of growth of cells in disease may be accelerated or retarded by an alteration in the character of the pabulum which is transmitted to them, and we shall be led to search for remedies which have the property of rendering tissues more or less permeable to nutrient fluids, or which alter the character of the fluid itself. Such considerations are of interest not to the physiologist only, but they have a very important bearing upon the practical treatment of disease.

It has been sought in this chapter to establish the fact that all formed matter results from changes in the germinal matter, and that the action of the cell consists really in a change from the living to the lifeless state of the matter of which it is composed. This change takes place in the same definite direction in all cases. The changes in the germinal or living matter must be attributed to the influence of a supposed vital force or power by which the matter is temporarily affected. The products formed by the cell do not depend upon any metabolic action exerted by the cell-wall or nucleus upon pabulum, nor are they simply separated from, or deposited by, the blood. The matter has passed through the living state, and by ceasing to live under certain conditions, the lifeless formed materials in question have resulted. The view here advanced leads us to look upon the 'living cell' as a minute body, consisting partly of living matter influenced by vital force, partly of lifeless matter resulting from the death of the first, in which chemical and physical changes occur, and these may be modified by the influence of surrounding substances and external forces.

CHAPTER II.

OF COMPOSITION.—CHEMICAL COMPOSITION OF GERMINAL MATTER AND FORMED MATERIAL.—SKETCH OF THE CHEMICAL CHANGES OCCURRING IN THE SIMPLE LIVING CELL.—CHEMICAL CHANGES IN THE ORGANISM AT DIFFERENT PERIODS OF DEVELOPMENT.—OF THE BLOOD.—OF THE CHANGES RESULTING FROM OXIDATION.—OF THE FORMATION OF VARIOUS COMPOUNDS IN DIFFERENT TISSUES AND ORGANS OF THE BODY.—THE CONVERSION OF PABULUM INTO BLOOD.

ANIMAL bodies are composed of solids, liquids, and gases, the last being held in solution in the liquids.

Solids and Liquids.—The solid textures contain only about one-fourth of solid matter, the rest is water. The great shrinking which they experience when dried, shows how much of their bulk they owe to this combination; and parts thus shrunken swell out again, and assume their natural condition on the addition of water. Nor does this swelling out after shrinking occur in water alone. The most soft and delicate tissues will regain their former volume, even if placed in very viscid fluids as syrup or glycerin, of much higher specific gravity than the tissues immersed. This seems to be due to the inherent elastic property in the tissue itself, in virtue of which its anatomical elements tend to assume the position and form they originally held in the natural state of the texture. The quantity of water existing, even in the hardest tissues, is far greater than would be supposed. The mummy of a large man is of very trifling weight. Blumenbach possessed the entire *perfectly dry* mummy of a Guanche, or aboriginal inhabitant of Teneriffe, presented to him by Sir Joseph Banks, which, with all its muscles and viscera, weighed only seven pounds and a half.

Water is one of the most important constituents of animal bodies. It forms four-fifths of their nutrient fluid, the blood; and it gives more or less of flexibility and softness to the various solid textures. The loss of it in great quantity speedily puts a stop to *vital*, as well as chemical and physical, action. Germinal matter is itself semi-fluid, and the very active movements of the portions of which it consists, which seem essential to the living state of matter, could not take place unless every portion of a living mass were free to move in fluid, or contained so much fluid as to be readily moveable, not only around, but through other portions. Water is a solvent of many organic and inorganic matters; it is, therefore, a valuable medium for conveying these substances to and from the several textures and organs. Moreover, it dissolves various gases. Oxygen is thus carried in solution to various parts of the body, where it acts upon certain of the insoluble solids, which are thereby oxidized and rendered soluble. The substances thus formed are carried away in solution. Water plays a most important part in the various chemical operations of the body; and by its addition to or subtraction from a particular compound, an alteration in its properties may be induced.

The various methods at our disposal for separating from one another the different compounds formed by living beings, and of resolving these into their ultimate elements, belong respectively to the departments of *proximate* and *ultimate analysis*. (See page 5.)

Organic and Inorganic Matters.—The solid textures and the soluble substances held in solution in the fluids of the body, consist of two classes of compounds, spoken of as *organic* and *inorganic*. But many of the so-called organic substances have been prepared artificially in the laboratory, and they cannot therefore be considered as peculiar to living beings. The organic matters are decomposed by a red heat, while the inorganic or mineral substances are not destroyed by incineration.

Organic compounds are composed of certain of the non-metallic elements, and principally of oxygen, hydrogen, nitrogen, and carbon. These elements, in the living body, are combined so as to form complex but often unstable compounds, and, under certain conditions, by hydration or by the appropriation of oxygen and other substances, these organic compounds may be afterwards split up, as it were, into much simpler but more stable bodies.

The organic compounds which enter so largely into the composition of the various solids and liquids of living beings, differ from one another, in composition and properties, in the most remarkable manner. Many have been placed by chemists in certain artificial groups, but hitherto it has not been found possible to arrange more than a very few in a naturally connected chemical series. The corresponding substances in different animals exhibit differences of properties and composition; and in disease, the characters and composition of the chemical components of the tissues and fluids undergo remarkable variations. Nor has any definite relation been proved to exist between the chemical composition, form, structure, and properties of organic, any more than inorganic bodies.

Of the different Constitution of the Corresponding Substances in different Animals.—There are many modified forms of albumen, fibrin, and casein, several different varieties of starch, sugar, fat, &c., numerous different forms of hæmato-crystallin, biliary acids, &c., and the difference is not explained by the varying conditions under which these substances have been produced, but must be ascribed partly to these and partly to the different properties and powers of the germinal or living matter taking part in their production. We have already observed that the tissues which precisely correspond to one another in different animals exhibit minute, but still very appreciable, differences in their *structure*, and we should, therefore, be led to anticipate that differences in the arrangement of their elements, and in their chemical properties, would also exist. Nor are these differences in chemical constitution confined to allied organic compounds, they are found to obtain also in the case of many inorganic salts.

Chemical Substances composing the Tissues, not found in the Blood. The chemical compounds entering into the formation of the solid tissues and liquid secretions have not for the most part been detected in the blood or nutrient pabulum, and there is reason to think that they have resulted, not from chemical changes taking place while the solutions traversed vessels or permeated membranes, but that they are the consequence of changes occurring in the temporary or living state, through which, as has been already shown, the various elements of the food must pass before they form a constituent part of the tissues or nutrient fluids of living beings. The germinal or living matter is alone concerned in this process, and different kinds of germinal matter, although, as far as we can tell, having the same composition, and certainly nourished by the same pabulum, may give rise to the formation of very different compounds. It may, indeed, be regarded as certain, that from a nutrient fluid common to them all, the masses of germinal matter of different textures take certain constituents which become converted into the tissues, or the constituents peculiar to the different secretions. The idea that these very substances existed in a modified form in the blood, and were merely *separated* from it by a sort of attractive force existing in the cells, will probably soon give place to the doctrine now supported by so many facts, that, from the same chemical constituents, different kinds of living matter may prepare or produce compounds very different in composition and properties from one another. For the crude notion that the formation of tissues was akin to the process of crystallisation, we must substitute the conclusion that the real cause of the peculiar composition and properties of the substances formed, is to be sought for in the living matter itself. And as the evidence that the wonderful changes occurring in this matter are due to the influence of some peculiar force or power, becomes stronger, it is to be hoped that comparisons between living things, and crystals laboratories or steam-engines, will no longer be insisted upon.

OF THE CHEMICAL CHANGES OCCURRING IN THE CELL.

Before we can hope to form a correct idea of the complex chemical phenomena occurring in man and the higher animals at any period of existence, we must have a knowledge of the general chemical changes occurring in the cell. Regarding the "cell" as consisting of—1. Germinal or living matter. 2. Formed matter; and 3. Formed matter undergoing disintegration, the consideration of the chemistry of the cell naturally falls under three heads;—*The Chemistry of the germinal matter, the Chemistry of the formed material, and the Chemistry of the substances resulting from the oxidation of, or other changes in the formed material.* This will, therefore, be discussed in the first place, and then we shall have to consider the more complex chemical phenomena occurring in man and the higher animals at different periods of existence.

The Chemical Characters of the Living Germinal Matter.—Just as the various tissues of living beings result from changes occurring in a perfectly transparent, structureless, germinal or *living* matter, so the numerous chemical compounds characteristic of different living organisms, and different tissues and organs, result from changes taking place in this same transparent material. Few substances which enter the organism of a living being pass through unchanged, without having their elements completely rearranged. There is reason to believe, that even the elements of many mineral substances become separated from one another, and recombined in the body.

It is remarkable that the germinal matter from the most dissimilar living beings presents the same characters, so that it is not possible to premise, from any microscopical or chemical examination, what will be the nature of the substances formed from any given mass of germinal matter. The general characters of germinal matter have been already referred to, and the student will readily form a notion of its simple transparent, jelly-like appearance, if he examines, under a high magnifying power, a white blood corpuscle, or the transparent moving matter forming the substance (sarcode) of a common *amœba*, specimens of which can always be obtained from water, in which a little dead animal tissue has been placed, left to stand for some days in a light part of the room.

There is no living or germinal matter which does not contain oxygen, hydrogen, nitrogen and carbon; and although some of the other elements are often present and are, undoubtedly, of great importance in special cases, the above are constantly found and seem essential to the very existence of vital changes. It is comparatively easy to ascertain what elements exist in the living matter, but it is not possible to demonstrate how these are combined, or if they are combined at all. Of the relation which these elements bear to one another in the living matter, we know indeed nothing; but since every kind of living matter exhibits the same characters, it seems probable that during this temporary living state, the elements do not exist in a state of ordinary chemical combination at all. Their ordinary attractions or affinities seem to be suspended for the time. That the matter is in a state of active molecular change, or vibration, is certain, but it is doubtful if chemical combination is possible as long as the matter *lives*. No chemical compound or elementary substance, as far as is yet known, exhibits life, or posesses vital properties or endowments. It is perhaps as impossible to conceive a *living chemical compound* as it is to conceive a *living elementary atom.* And the chemist who supposes that he can analyse *living* matter is in error, for he examines not the matter which is alive, but simply lifeless compounds resulting from its death. When the living or germinal matter is converted into formed matter, combination of its elements takes place, free oxygen being in some cases absorbed at the moment, and compounds of such complex nature result that the efforts of chemists to ascertain the chemical relations or the exact composition of many of them have not hitherto met with success. And it often happens that the chemical compound undergoes further change after it has been formed, so that the substance which we submit to examination in our laboratories, is not of the same chemical composition as when it was first produced by the cell.

Of the Production of Chemical Compounds (formed material) from Germinal Matter.—It is remarkable that the elements of every kind of germinal matter, when its life is *suddenly* destroyed, should combine to form compounds closely allied to one another in chemical composition and properties, and that an *acid* reaction should be always developed. From every kind of germinal matter a material which *coagulates spontaneously*, and one which is *coagulated by heat and nitric acid* may be obtained. The first of these is *fibrin*, and the second is *albumen.* Fibrin, albumen, water and certain salts, may be obtained from every kind of germinal matter. All kinds of germinal matter also yield fatty matters, and these continue to increase in quantity for some time after death has occurred. As is well known, the "nuclei" (germinal matter) of all organisms and tissues which have been kept for some time in preservative fluids become granular, and usually distinct globules are to be seen. These granules and globules are due to the formation of fatty matter from the germinal matter itself, or from the albumen, fibrin, and other substances immediately resulting from its death. It is very remarkable that the general characters, if not the chemical composition, of this fatty matter, should be the same in the case of every kind of germinal matter in both vegetable and animal tissues (see page 110). It would appear that the elements of every kind of germinal matter are so disposed or arranged during the living state, that they may combine to form water, albuminous matters including fibrin, fatty matters, and salts.

Although water may be obtained from every kind of living matter it is doubtful if water in its ordinary condition exists while the matter is alive, for this living matter may be exposed to a temperature considerably below the freezing point of water without becoming solid, and it is probable that death must occur before the actual congelation of the germinal matter, or of the water it contains, can take place.

The formation of all chemical compounds seems to be connected with the *death* of the germinal matter, and different substances will result according as the death is sudden or gradual, that is, according as the germinal matter dies suddenly *en masse* or more slowly, particle by particle. And it is probable that in the comparatively slow molecular death, a certain amount of oxygen is taken up at the moment of combination, and this alone would give rise to very different combinations to those which occur when the living matter is suddenly destroyed, little or no oxygen being present. An alteration in the conditions under which death takes place will be associated with a difference in composition of the materials produced; but it must not be supposed that external conditions alone determine either the form, composition or properties of the resulting substances.

When germinal matter becomes resolved into formed material, other compounds are produced besides the special ones which characterise that particular kind of germinal matter; and a product which largely predominates under certain circumstances may be produced in mere traces under other conditions. For instance, the germinal matter of the liver cell of some animals becomes resolved into amyloid matters and biliary matters with mere traces of fat. In others, fat which accumulates seems to form the main portion of the formed material produced. In man, under some circumstances, bile and amyloid appear to be produced; under others, fat seems to be the main product as in the fish. And various secondary morbid changes are brought about according as the formation of fatty, amyloid or saccharine matter predominates. The nature of the pabulum doubtless affects the composition of the formed materials produced by the cell, but this is only one of the many circumstances influencing the result. The products resulting from the changes of germinal matter seem to be almost infinitely varied, and those substances which exactly correspond in different animals do not exhibit the same composition. Even in the case of animals very closely allied zoologically, great differences are noticed. The bile, blood, milk, fat, &c., exhibit great difference in composition, although they possess many characters in common, and perform the same offices in the different animals respectively. There appears to be a resemblance generically, associated with striking specific differences.

The germinal or living matter of all living beings, vegetable as well as animal, contains nitrogen, and the broad difference between the changes in the animal and vegetable kingdoms seems to be that in the first a large proportion of the nitrogen entering into the composition of the germinal matter, enters into combination with other elements in the resulting formed substance; while in the latter, as a rule, the nitrogen although necessary to the germinal matter, does not enter into combination, so that while the animal requires a large quantity of nitrogen in its food to supply that which has been converted into various chemical compounds formed by the germinal matter, the plant needs but a very small proportion, because so little enters into the composition of the formed material produced. The tissues of fungi, however, contain a considerable proportion of nitrogen.

Certain saline or inorganic substances form constant and very important constituents of the animal body. Although it is possible that vital changes may continue to go on in the absence of saline substances, it is certain that the tissues, upon the integrity of which the duration of life depends, could not be produced or nourished without them. *Chloride of sodium* is one of the most important. This salt is always present in large proportion in all embryonic tissues, and it is probable that it is intimately concerned in some of the active changes taking place in the germinal matter itself. Whenever germinal matter is growing and multiplying very rapidly in the human organism, chloride of sodium is present, and it is probable that in the lower organisms and plants, other saline substances are of equal importance in corresponding processes.

Of the Chemical Changes taking place in the Formed Material after its production.—Most important alterations may occur in the formed material after it has been produced. In some cases it undergoes condensation, during which process structural peculiarities manifest themselves. Gradually, the formed material may become dry, after which, little alteration takes place. But in the soft, moist formed material, produced by many of the cells in the internal organs of the body, the most important changes occur. In some cases the formed material is perfectly fluid, and splits up into soluble or gaseous substances as soon as it is produced. In many instances, the elements of the formed material, although themselves insoluble, gradually undergo conversion into soluble compounds, in consequence of the action of oxygen, which combines with certain of the elements. If, in any case, the supply of oxygen be insufficient to convert the whole of the matter present into fully oxidised and completely soluble compounds, its elements may combine to form less soluble substances, which accumulate, and in many tissues give rise to morbid change. Hence it is of the utmost importance that the disintegrating processes in the internal organs of the higher animals should be in a state of due activity, for unless the formed material be constantly traversed by fluids rich in oxygen, the products necessarily resulting from disintegration are not fully oxidised and quickly removed in a very soluble form, but remain in the tissue in other states of combination, interfering with its function or even causing suspension of its action altogether. For instance, by the imperfect oxidation of the elements resulting from the disintegration of muscular and other tissues, fatty matters result, and if the conditions giving rise to their production continue, these accumulate, leading to various morbid conditions. Insufficient oxidation seems to be the main cause of the accumulation of uric acid, oxalates and fatty matters in the blood. Leucine, tyrosine, sugar and many other substances result from the ordinary chemical changes being interfered with. Their formation is perhaps due to the existence of conditions which interfere with the combination of the due proportion of oxygen with the elements of the compounds which unites with them under ordinary circumstances.

Sketch of the Chemical Changes occurring in the simple Cell.—Carrying out our inquiry according to the plan adopted in the chapter devoted to the consideration of structure, we may now consider the chemical changes which occur during the life of a simple cell, and we propose to select, for the purposes of inquiry, one of the lower microscopic fungi—the yeast plant.

If a minute germ of this vegetable organism be placed in a solution containing a trace of albuminous matter, a small quantity of phosphatic salts, and sugar in the proportion of about 4 parts of sugar to 20 of water, and the whole be exposed to the air, at a temperature of about 80°, growth will take place. The germ will give rise, in a short time, to many bodies like itself, and the sugar will be gradually appropriated by the plant, which will increase in size, divide and subdivide, until the greater part of the sugar has been removed. Now, in this process, as the sugar disappears, and the yeast corpuscles multiply, while oxygen and albuminous matter are taken up, carbonic acid and alcohol are evolved in considerable quantity. This is the process known as *alcoholic fermentation*, and there is no doubt that the formation of the alcohol and carbonic acid is intimately connected with the growth and multiplication of the yeast cells, but the precise manner in which the decomposition of the sugar is effected is still unknown. Many chemists, following Liebig, probably regard the change as too purely chemical. Because putrefying blood, white of egg, &c., caused the fermentation of sugar, Liebig came to the conclusion that yeast was a sort of vegetable fibrin, albumen, or caseine in a state of decomposition. We now know that putrefying substances themselves cause fermentation, only because they contain living organisms. It was supposed that the yeast cells effected the decomposition of the sugar without necessarily coming into actual contact with every portion of sugar, by virtue of some action, the nature of which was not explained, but which was spoken of as metabolic action. Mitscherlich proved, however, that for the change to occur, the living cells of the yeast plant must come into actual contact with every particle of syrup to be decomposed.

We may now consider this question from a somewhat different point of view. The germinal matter of yeast, like other kinds of germinal matter, contains nitrogen and exhibits an acid reaction. An albuminous substance may be obtained from it, as well as from all other kinds of germinal matter. The formed material of yeast—the envelope or cell-wall produced from the germinal matter (see page 77), consists, according to Mülder, of a substance closely allied to cellulose in composition. It is, then, a fact, that by the growth and multiplication of the germinal matter of the yeast cell, cellulose, carbonic acid, alcohol, a little lactic acid, and some other substances of less importance result; but the precise manner in which all these substances are produced, has not been determined. From what has been already stated, in chapter 1, it would appear probable that the nutrition and growth of the yeast plant occur somewhat as follows:—the cell takes up a certain quantity of sugar, with a trace of albuminous matter salts and perhaps oxygen, and these undergo conversion into germinal matter. At the same time the germinal matter already produced upon the surface undergoes conversion into formed material (see page 77), and this formed matter immediately becomes resolved into *cellulose*, which is precipitated, and *carbonic acid* and *alcohol*, which are soluble. All these substances probably result from the death of the germinal matter of yeast. The cellulose forms the insoluble capsule, envelope, or cell-wall, which is permeable to fluids in both directions. The carbonic acid and alcohol being soluble, pass into the surrounding water, and at length escape. Under certain conditions, the proportion of carbonic acid and alcohol formed is great, and the amount of cellulose small, while other conditions seem more favourable to the production of cellulose matter.

The germinal matter of some vegetable cells gives rise to cellulose upon the surface, while within starchy matter is deposited. In other cases chlorophyl and other colouring matters result from changes occurring in the germinal matter (primordial utricle) in the interior of the cell, after the formation of the cellulose wall upon its surface. In all these cases the formation of the peculiar and characteristic substance which accumulates, is accompanied by the formation of soluble and gaseous matters which escape. The germinal matter of the cells of the leaves and flowers of plants becomes resolved into peculiar coloured compounds, and these are often diffused through the germinal matter, but sometimes collect upon its surface. The germinal matter itself is never coloured, for the soluble coloured matter may be separated from the colourless germinal matter. The formation of chlorophyl from germinal matter may be studied in many of the lower plants, and its separation from the germinal matter effected. In like manner coloured matter may be separated from the colourless germinal matter of many of the young red blood corpuscles of mammalian animals which consist principally of germinal matter.

It is probable that in animal cells also, the formation of several chemical compounds from the germinal matter at the same moment occurs. In the liver cell, for instance, four distinct classes of solid matters seem to be produced by the re-arrangement of the elements of the germinal matter—resinous biliary acids, fatty matter, albuminous matter and amyloid substance. The relative proportion of these different substances produced seems to vary according to different circumstances. Sometimes the quantity of fatty matter is enormous, while in other instances only a mere trace is produced, and the same remark applies to the other constituents.

If, according to the view generally entertained, the different substances entering into the composition of a complex secretion, are separated from the blood and afterwards altered in composition by some unexplained action of the cell, or its nucleus, how are we to account for the fact of distinct classes of substances being separated, or separated and altered, by the agency of one and the same cell or nucleus? The oily, saccharine, and albuminous constituents (butter, sugar, caseine) of milk, have not been discovered in the blood, and there is only one kind of cell to form these three classes of substances. Does the same cell-wall or nucleus separate from the blood at the same time oily, starchy or saccharine, and albuminous matters, and convert these into the particular constituents of milk, or are they separated one after the other? Upon either supposition it would be extremely difficult to account for the actual facts, while, if, as has been rendered probable by different arguments already advanced, the constituents, absorbed from the blood, become first converted into germinal matter, which at length becomes resolved into these three classes of substances, at least a more plausible theory, if not a complete explanation, of the process, is arrived at.

The study of the circumstances under which these different classes of substances are produced by a single cell, and more especially the careful investigation of the conditions which determine a variation in the relative proportion of the different constituents, will greatly contribute to advance our knowledge of many of the most important morbid conditions, and thus give to practical medicine a stronger title to be considered a science.

OF THE CHEMICAL CHANGES OCCURRING IN THE ORGANISM AT DIFFERENT PERIODS OF DEVELOPMENT.

Although we are quite unable to give even a very imperfect idea of the chemical phenomena occurring in man at different periods of his development, we shall make the attempt to employ the imperfect data we possess, and consider some of the most important chemical changes occurring in the organism from the point of view already indicated.

At the earliest period of its development, the simple mass or collection of masses of germinal matter of which the embryo is composed, exhibits a chemistry simple as compared with that of the organism when its development is more advanced. The formed material resulting from the germinal matter, seems to consist principally of albuminous and fatty materials, without any substance capable of yielding gelatin. Saline matters may be detected, and it is certain that amyloid matter soon makes its appearance among the chemical substances produced in the embryo. The *albuminous matter* is closely allied to ordinary albumen, and with it is associated a small quantity of a coagulable matter, probably identical with fibrin.

Fatty Matter.—Little is known concerning the actual chemical nature of the fatty matter developed at the earliest periods of embryonic life, but the compound substance known as myelin, makes its appearance very early. The oil globules so commonly seen in germinal matter of various kinds, especially at an early period of development, and which have been sometimes termed nucleoli, consist of this form of very peculiar fatty matter. I have already shown that cholesterin, one of its constant constituents, is present in the oil globules found in various cells in fatty degeneration, and more recent examinations, with the aid of the highest powers, have displayed the masses of myelin, exhibiting their characteristic refraction, their double contours, and twisted forms amongst the germinal matter of pus, cancer, epithelial and other cells (plate VIII, figs. 73, 74), and there can be little doubt from the fact, that Beneke has detected myelin in the young shoots and actively growing buds of the potato, asparagus, and many other plants, that myelin is the particular form of fatty matter which immediately results from changes occurring in germinal matter. The reaction and chemical characters of this substance are described in page 148.

The Saline Constituents consist principally of chlorides, but a small quantity of alkaline and earthy phosphates are also present. The chloride of sodium performs some important office in connection with cell multiplication, as we find this substance invariably present in considerable proportion at an early period of the development of all animal tissues, when the masses of germinal matter are growing and multiplying rapidly. It is possible that salt may be serviceable at the earliest periods of nutritive change, by its property of rendering albumen less viscid, more diffusible, and capable of being very readily appropriated by the growing germinal matter.

Amyloid Substance ($C_6H_{10}O_5$).—As the formed material exhibits firmer consistence and structural peculiarities, a gelatin-yielding substance is produced. But with this is developed much matter of an amyloid or starchy character, sometimes called *glycogen*. This has been particularly studied by Rouget, who detected it in cartilage at an early period of development, and also in fibrous and muscular tissues. The epidermic textures exhibit a considerable proportion, although not a trace can be detected in the same textures in their fully developed state. The same is true of the delicate texture which is at length to become hair, horn, or nail. Dr. McDonnell has shown that this amyloid matter exists in the lung tissue in very large proportion, increasing, as development advances, to nearly twenty per cent., while shortly before birth the quantity is so small that it can scarcely be estimated. It is found in muscular tissue generally, but not in that of the heart, in which, probably from its reaching a state of functional activity long before the muscles of the system generally, the proportion of amyloid is comparatively small. In the liver, the formation of amyloid slowly increases, and after birth, its formation seems almost restricted to this organ. Throughout life, large quantities of amyloid continue to be produced in the liver, and in certain morbid conditions it accumulates enormously. This production of amyloid is probably associated with rapid change in the germinal matter. If this substance were formed by the germinal matter of the tissues in the adult state, it would exist in such small quantity in proportion to the other matters produced, that we might not be able to detect it by the processes at present at our disposal. With reference to the part played by the amyloid matter in the tissues in early life, it would seem probable, from the researches of Dr. McDonnell, that it appropriates to itself nitrogen, and that in this manner a material is produced which afterwards takes part in tissue formation. The same observer has advanced many arguments in favour of the view, that the amyloid matter, as it slowly escapes from the liver cells in which it was formed, takes to itself nitrogen derived from the retrogressive metamorphosis of fibrin in the blood, and that thus a protein substance, allied to casein and globuline and the matter of which the white blood corpuscles are composed, results.—(*Proceed. Royal Soc.* 1863, vol. xii, p. 478.)

The production of these substances allied to starch and sugar, seems to be associated with limited oxidation. It is probable that the chemical elements which, in the embryo, combine to form starchy matters, would, at a later period of development, combine with oxygen to form carbonic acid and other substances, which would be excreted in a soluble form. This view is confirmed by the fact that, in the liver, in which amyloid matters are being formed throughout life, oxidation is very limited; while those morbid conditions in which the formation of the same substance occurs in connection with many adult tissues, especially the smaller arteries and the nervous tissues, are characterized by a reduction in the activity of this process. Amyloid matter (glycogen) has been detected in the substance of the round worm of the pig (ascaris lumbricoides), by Dr. Michael Forster (*Proceed. Royal Society*, vol. xiv, p. 543, 1865), and it has been found in many of the lower animals, which live under conditions incompatible with a highly active state of the oxidizing processes.

Gelatin-yielding Substance.—The tissues have assumed their permanent anatomical characters, and have commenced to perform their normal functions, when the substance which yields gelatin by boiling is produced. At an early period of development, although delicate transparent tissue may be detected, it does not yield gelatin. According to Hoppe, this substance cannot be detected until after the embryo has left the egg. The proportion of the fibrous texture, and gelatin-yielding tissues allied to it, increases as age advances. Gelatin does not exist preformed in the tissues, and can only be obtained by artificial means. If the cutis or true skin, tendon, or bone, be subjected to continued boiling, this substance is obtained in solution in the hot water, and, upon cooling, assumes the form of a solid jelly, which is the more solid as the quantity of water contained in it is less. The textures which yield gelatin are, the white fibrous tissue, areolar tissue, skin, serous membranes, and bone; glue, prepared from hides, &c., size from parchment, skin, &c., and isinglass from the swimming bladder of the sturgeon, are various forms of gelatin used in commerce.

Gelatin, obtained by boiling, is in combination with a considerable quantity of water; by a slow and gentle heat this may be driven off, and the gelatin obtained in a dry state. Dry gelatin is hard, transparent, colourless, without smell or taste; of neutral reaction; in cold water, it softens and swells up, and dissolves in warm water. It is insoluble in alcohol and ether, but very soluble in the dilute acids and alkalies. When tannin, or the tincture or infusion of galls, is added to its solution in water, a brownish precipitate is thrown down—the tanno-gelatin, which may be precipitated from a solution of gelatin in 5,000 times its weight of water. Gelatin contains in 100 parts C 50·4 H 7·1 N 18·1 O 23·8 S 0·6.

The process of tanning leather, depends upon the affinity of gelatin for tannin. The skins of the animals, having been first freed from cuticle and hairs by soaking in lime-water, are tanned by submitting them to the action of infusion of oak-bark, the strength of which is gradually increased, until a complete combination has taken place. An insoluble compound is thus formed, capable of resisting putrefaction.

If a solution of gelatin, in concentrated sulphuric acid, be diluted with water and boiled for some time, glycocoll may be obtained from it on saturating with chalk. Again, by boiling gelatin in a concentrated solution of caustic alkali, it is separated into *leucine*, $C_6H_{13}NO_2$, and *glycin* or *glycocoll*, $C_2H_5NO_2$. The latter product crystallises in pretty large rhomboidal prisms, is colourless and inodorous.

Chondrin is a substance in many respects similar to gelatin. It is obtained in a state of solution, by boiling water, from the permanent cartilages and from the cornea; also from the temporary cartilages prior to ossification; it gelatinizes on cooling and when dry assumes the appearance of glue. It differs from gelatine, in not being precipitated by tannin, and in yielding precipitates to acetic acid, alum, acetate of lead, and the protosulphate of iron, which do not disturb a solution of gelatin. Chondrin contains in 100 parts C 49·9 H 6·6 N 14·5 O 28·6 S 0·4. Like fibrin and albumen, it contains a minute quantity of sulphur. The interesting researches of Dr. Roudneff, of St. Petersburg (*Archives of Medicine*, vol. iv, p. 304), seem to show that chondrin undergoes conversion into gelatin by oxidation. Prior to the formation of vessels in the temporary cartilage of the embryo, that substance yields chondrin, while, after this, gelatin is obtained from it. Chondrin, obtained from permanent cartilages, was subjected to the action of oxidizing agents, and the resulting mass it is stated gave the reactions of gelatin.

The chemistry of early life differs from that of the embryonic state enormously in the greater activity of the process of oxidation. The functions of Respiration and Circulation are more actively performed, and the quantity of material disintegrated is considerably increased. During the early periods of development there is comparatively slight demand for oxygen. The amount of germinal matter produced is very great, and tissue is being formed and accumulates, but there is no active discharge of function, and the amount of formed material oxidized and destroyed, is very small. Little *work* is performed at this period of life, for *work* results from the disintegration of materials which have been already formed. It is interesting to note how intimately an active condition of the oxidising process is connected with a healthy state and a full working condition of the various organs of the body, and how many morbid conditions of tissues and organs, which necessarily terminate in death, are due essentially to diminished oxidation.

OF THE BLOOD.

As the tissues and organs advance towards maturity, the blood becomes of vast importance, and it is not possible to discuss even cursorily the general chemical changes in the organism without referring to the composition of the blood and the phenomena which are taking place in it during every moment of existence. Although the chemical components of the blood and the blood corpuscles are more particularly considered under *circulation*, it will be necessary to refer briefly to them in this place.

Of the fluids of the body, the blood alone yields the various materials required for the formation of the tissues and organs, and for maintaining them in a state of integrity after their formation is complete; and, through its agency, all the substances resulting from the disintegration of textures which have already performed their work are carried to the different parts of the body at which their removal is effected. The blood must therefore be considered as the medium, by which, at the same time, nutrient matters are carried to every tissue of the body, and products resulting from decay brought to the points at which they can be discharged. The consideration of the chemical changes taking place in the blood will comprise some of the most important chemical phenomena occurring in man and the higher animals during all, except the very earliest periods of existence. The fluid which is concerned in distributing nutrient matter to the tissues of the lower animals, like the blood of man and the higher animals at an early period of development, is perfectly transparent and colourless. It contains some spherical colourless granular masses of germinal matter, which, when at rest, exhibit vital movements. These are the most important and the only constant corpuscles of the blood. The fluid, or *liquor sanguinis*, in which these are suspended, besides water, salts, and fatty matters, contains two very important substances. Of these, one, the *fibrin*, coagulates spontaneously when the fluid is removed from the living organism and brought into contact with any foreign matter. The other, *albumen*, is dissolved in the water, but on the application of heat, or upon the addition of a mineral acid, it passes into an insoluble condition, forming a white clot or coagulum. It is also precipitated by solution of tannin and by many metallic salts. White or colourless blood corpuscles, fibrin and albumen, which are included in the class of proximate principles (see p. 8), and water, are important constituents of the blood at every period of its existence.

The *white blood corpuscles*, or masses of living germinal matter of the blood, are the direct descendants of the germinal matter of the cells which took part in the first development of vessels. The white blood corpuscle in fact corresponds to the germinal matter in the interior of a 'cell.' There can be little doubt that, at least in those instances in which the nutrient fluid contains no red corpuscles, these colourless corpuscles are the agents concerned in the production of the albumen and fibrin, and there is every reason to believe that the red blood corpuscles, specially characteristic of the blood of vertebrate animals, are formed from these bodies.

It has been already stated that all forms of living germinal matter yield a spontaneously coagulable substance closely allied to the fibrin of the blood, though perhaps not identical with it, and a soluble albuminous material which is precipitated by heat and nitric acid. It is probable that the pabulum required for the nutrition of the higher tissues is prepared and formed through the agency of germinal matter of less special endowments, such as that found in connection with the capillary vessels; and that the free germinal matter in the blood, representing that in the interior of the fully formed cell, itself in its turn grows at the expense of materials formed from other kinds of germinal matter, especially that in connection with the intestinal mucous membrane.

Albumen is so called from the white colour it possesses in its solid coagulated state; 'white' of egg is largely composed of it. Besides forming more than 30 per cent. of the solid matter of the blood, albumen, more or less modified, enters into the composition of many of the tissues of the body. It exists in two states; fluid—being dissolved in the serum of the blood, and in some of the secretions; and solid—forming a large proportion of certain of the tissues; for example, $\frac{7}{12}$ of the dry cerebral substance, which are for this reason called albuminous tissues. These are, the brain, spinal cord and nerves. It also enters into the composition of the muscles, and traces are found in the aqueous and vitreous humours of the eye. It is present in the various kinds of serum and in pus, poured out under various circumstances, and formed in the course of disease. Albumen contains in 100 parts C 53·5 H 7·0 N 15·5 O 22·4 S 1·6. It exhibits no tendency to assume spontaneously the solid form, except by the loss of the water which is combined with it. By evaporating white of eggs, at a temperature not exceeding 120°, its water is driven off, and solid albumen, in the form of a yellowish transparent brittle mass, is obtained, with all its properties unimpaired. If a solution of albumen, in water, be exposed to a heat between 140° and 150°, it coagulates, and then becomes insoluble in water. Albuminous solutions are alkaline, and it is probable that at least a portion of the alkali is chemically combined.

The mineral acids have the property of coagulating albumen. Of these, the nitric is most used in medical practice. A few drops of this acid will enable us to detect a small quantity of albumen dissolved in a clear fluid, by rendering it more or less opaque. Alcohol also has this property; and hence any albuminous textures submitted to its influence, become hardened and condensed. Bichloride of mercury exercises a similar influence, and is a delicate test for albumen. It was Orfila who first employed this proximate principle as an antidote to the poisonous effects of the bichloride, which combines with the albumen, forming with it an innocuous compound. According to Peschier, the white of one egg is sufficient to render four grains of the poison harmless. Another delicate test for albumen is the ferrocyanide of potassium, which will precipitate it from solution, provided a little acetic acid have been previously added, in order to neutralize the soda in combination with it. Albumen is also precipitated from solution by tannin. It coagulates at the negative pole of the galvanic battery, or at both poles, when a strong battery is employed. Many other reagents will coagulate this principle, but enough have been mentioned for all practical purposes. Albumen is soluble in caustic alkalies. By prolonged boiling in hydrochloric acid albumen is resolved into a substance allied to chondrin. The existence of sulphur as a constituent of albumen, is shown by the blackening of silver that has remained long in contact with it, or by boiling a little albumen in a solution of oxide of lead in potash.

In disease it often happens that albumen is carried off from the system in large quantities in the urine. By any of the means above mentioned, its presence in that fluid may be detected. When heat is used it will always be advisable to ascertain previously whether the urine be acid or alkaline; for the presence of alkali prevents the coagulation of albumen by heat. Hence it is a good rule in testing for this substance to employ both heat and nitric acid. If, however, only one or two drops of nitric acid be added the albumen will be precipitated and then quickly re-dissolved by agitation. This acidulated solution, it must be remembered, is not coagulated by heat. The practitioner should, therefore, be careful never to test albuminous urine in a dirty test tube, which may contain a little nitric acid.* Gigon states that there exists even in healthy urine a substance allied to albumen, and according to Dr. George Harley, the albuminous matter resembles that form of albumen which has been dissolved by gastric juice; for, like this, it is not coagulable by heat or nitric acid.

Paralbumen and Metalbumen are modifications of albumen discovered by Scherer in the fluid of ovarian dropsy and in an albuminous fluid removed by paracentesis. The first is very slightly coagulated by boiling. Alcohol precipitates flocculi, which are re-dissolved by water. The latter is coagulated neither by hydrochloric acid nor by ferrocyanide of potassium. Pancreatin from the pancreatic fluid is closely allied to albumen.

In mammalia it is certain that many different cells can produce a substance which possesses all the chemical characters of albumen. From the cells of cuticle and many other structures a solution can be obtained which contains albumen. The cells of the follicles of the lacteal glands give rise to it, and those which occupy the Graaffian follicles also produce it, and in ovarian dropsy, when these follicles are enormously enlarged, there can be no doubt that the albumen is actually formed in the interior of the cyst, for, as above stated, it differs from the albumen of ordinary serum. Moreover, albumen is found in almost all animals, and in certain of the fluids of plants.

The facts above enumerated render it probable that the

* For the methods of testing albuminous urine, see "Urine, Urinary Deposits and Calculi."

albumen of the blood results from changes occurring in the blood corpuscles. In many cases albumen results directly from changes in germinal matter, but it seems probable that in man and the higher animals, part, at any rate, of the albumen of the blood is formed from the red corpuscles which are themselves formed material resulting from changes occurring in the white blood corpuscles. Albumen is one of the substances which forms the pabulum of cells, and there can be no doubt that from it many very different materials may be produced by the agency of the living or germinal matter of the various textures.

Fibrin exists, in a state of solution, in the blood, forming, with the serum of that fluid, the *liquor sanguinis* of Dr. Babington, in the lymph and in the chyle. It is a constituent of the exudation (coagulable lymph) which forms on certain surfaces, as the result of the inflammatory process, and it sometimes occurs in dropsical fluids.

Fibrin is distinguished from the other substances allied to it by its remarkable property of *spontaneous coagulation*. When blood or fluid containing much fibrin is drawn from a vessel and allowed to rest, it speedily separates into a solid portion, the *crassamentum* or clot, and a fluid portion, the *serum*. The clot of blood consists of fibrin, with the *white* and *red* blood corpuscles entangled in it during its coagulation. It sometimes happens that owing to an unusual aggregation of the red particles together, and to their more speedy subsidence, a portion of fibrin on the surface coagulates without enclosing the colouring matter. A yellowish white layer forms the upper stratum of the crassamentum, and this is called the *buffy coat* or *inflammatory crust*. It is an example of nearly colourless fibrin, but like other forms of this substance, contains also the white corpuscles.

We may obtain fibrin in a state of considerable purity, by cutting the crassamentum into slices, and washing them in clean water so as to dissolve out the colouring matter; or by briskly stirring with a bundle of twigs, blood as it flows from a vessel: the fibrin coagulates upon the twigs in small portions, which being washed, afford good specimens of colourless fibrin; by digesting afterwards, in alcohol and ether, the fatty matters are got rid of. Another mode of obtaining this substance in a state of purity is that suggested by Joh. Müller. This consists in adding to frog's blood a little syrup (one part of sugar to two hundred parts of water) which retards the process of coagulation for a sufficient time to enable us to filter it. The frog's red particles being too large to permeate the pores of the filter, the liquor sanguinis passes through in a colourless state, and its fibrin coagulates free from colouring matter. Sometimes we obtain masses of fibrin, great part of which is colourless, from the cavities of the heart, and from the large arteries after death. It is also accumulated and disposed in a peculiar lamellar form, in the sacs of old aneurisms.

Pure fibrin is white, tasteless and inodorous; it tears into thin laminæ. Under the microscope it is seen to consist of *a*, fibres crossing one another at every possible angle and interlacing in all directions; and *b*, very numerous white blood corpuscles. It is not yet possible to obtain the fibrinous material in a perfectly pure state and free from the corpuscles. It contracts for some time after its first precipitation, and retains remarkable elasticity, even after it has been for years immersed in preservative fluids. If fibrin be dried it becomes yellow, hard, and brittle, and loses three-fourths of its weight, but imbibes water again when moistened; it is insoluble in both hot and cold water, in alcohol, and in ether. By long-continued boiling in water its composition is changed, and it becomes resolved into a soluble and an insoluble substance, the first of which has been termed the *teroxide* and the second the *binoxide* of protein. Strong acetic acid converts it into a jelly-like mass which is sparingly soluble in water. A solution of nitrate of potash in the proportion of 1 part to 5 of water, readily dissolves fibrin. It is also to some extent soluble in solutions of some other alkaline salts. All the alkalies dissolve fibrin. Any of these solvents of fibrin will prevent the coagulation of blood which has been allowed to drop into it as it flows from the blood-vessels. Fibrin is dissolved by cold concentrated hydrochloric acid, and if kept at a cool temperature for twenty-four hours, the solution acquires an indigo blue colour. Albumen similarly treated assumes a violet colour. Caustic potash, common salt, carbonate of potash and many neutral salts, when mixed in certain quantities with the blood, have the property of retarding or preventing the coagulation of its fibrin. There still exists much difference of opinion concerning the mode of formation, origin, and uses of this substance.

Dr. Richardson supposed that the fibrin was held in solution by the ammonia present in living blood, but although there is no doubt that this substance will prevent the coagulation of blood, there are many facts opposed to Dr. Richardson's view, and some observers have not succeeded in detecting even traces of free ammonia in fluids in which fibrin existed in its uncoagulated state.

It has been inferred by Mr. Lister that the chemical combination of globulin and fibrinogen, and the formation of fibrin was due to some mysterious and unexplained action of extraneous matters and ordinary solids, upon the previously soluble materials. Others consider that the blood possesses a "natural tendency" to coagulate, but that as long as it remains within the body, if the vessels be in a healthy state, coagulation is prevented. Neither of these views are entitled to be considered *explanations* of the process of coagulation.

Professor Andrew Buchanan, of Glasgow, observed long ago that the fluid of hydrocele yielded a coagulum, if blood serum, probably containing a few blood corpuscles, were allowed to fall into it, although it might be kept for any length of time without coagulation, if no blood serum were added. A. Schmidt, of Dorpat, apparantly ignorant of Buchanan's observations made twenty years before, has recently shown that for the formation of fibrin, a *fibrino-plastic substance* of the nature of globulin, must combine with another substance, which he terms *fibrinogen*. Either may be present without the occurrence of coagulation, but if the smallest proportion of the fibrino-plastic compound be added to fibrinogen, coagulation occurs. The fibrino plastic substance is globulin, and may be obtained from various sources, as saliva, synovia, the fluids of the eye, connective tissue, probably also from muscle, nerve, &c. This view concerning the formation of fibrin has been accepted by Mr. Lister.

According to some, the formation of fibrin is a purely chemical process, and results from the direct oxidation of the albumen. Von Gorup-Besanez has shown that ozonized air causes the formation of fibrin-like coagula in an albuminous solution, and that these coagula might be re-dissolved in the fluid. The researches of Mr. A. H. Smee (*Proceed. Royal Society*, 1863, vol. xii. p. 399), have proved that if oxygen be passed through a solution of albumen, for thirty-six hours, at a temperature varying between 95 and 100° Fah., the solution becomes of firmer consistence, and when examined microscopically, numerous lines indicative of fibres are seen. Mr. Smee infers that the substance thus produced is fibrin, and that it has been formed directly from the albumen by oxidation. He states that it cannot be distinguished from true fibrin by the microscope. But although the new material agrees in many of its characters with what we call fibrin, it is doubtful if it is identical with it. One very remarkable character of fibrin is to contract gradually after its formation, but Mr. Smee has not stated if his fibrin exhibits this property. While the fibrin-like material was being produced, carbonic acid was evolved and phosphoric acid was formed. By the oxidation of gluten, from wheat flour, Mr. Smee also obtained a substance which he could not distinguish from ordinary fibrin. He was unable to obtain fibrin by passing oxygen through urine which contained a large quantity of albumen.

The fact that the quantity of fibrin in blood is increased by oxidation, may be explained, as well by supposing that the oxygen acts upon the matter of the white blood corpuscles, as by inferring that albumen is oxidized; while its absence in certain cases of asphyxia, in hunted animals, and in sudden death by lightning, would be accounted for by the too sudden death of the white corpuscles ensuing in these cases, although it could hardly be attributed solely to deficient oxidation.

We may now consider what may be actually observed under the microscope when fibrin passes from the fluid to the solid state. Observations with the aid of the very high powers ($\frac{1}{25}$ and $\frac{1}{50}$) recently brought into use, have taught us many new and highly important facts which could not have been arrived at without their aid. If the phenomena of coagulation be carefully watched as it occurs under a power magnifying upwards of 2,000 diameters, the following points will be observed in favourable cases soon after the blood has been covered with the thin glass or mica. The first change noticed is, that a film-like appearance is developed in the liquor sanguinis, and this is especially observable in the wake of those red corpuscles, which are being slowly moved across the field by the currents in the fluid produced by the unequal pressure of the thin glass cover. The appearance may be compared to that seen in the fluid circulating in the cell of vallisneria, except that in this latter innumerable and excessively minute spherical, colourless particles can be discerned; while although many very transparent and scarcely visible corpuscles may be seen in the blood, the fluid does not appear to be almost entirely composed of minute spherical particles, moving about one another as in vallisneria. This film-like appearance is gradually succeeded by the formation of delicate threads, which are seen to cross one another at various angles, and apparently correspond to the lines which the blood corpuscles have traversed as they have moved about the field (plate V, fig. 44). The lines seem to acquire greater density and increase in refractive power for some time after they were first visible. I have never been able to demonstrate that the lines are formed by the actual coalescence and running together of minute particles. It seems to me more probable that the coagulable matter exists in the first instance as a highly diffused plasma, probably formed by the white blood corpuscles, and the smaller colourless corpuscles allied to them, which gradually separates from the serum with which it was originally united, and contracts until it acquires sufficient density and refractive power to be seen by us. During the process of coagulation many of the red corpuscles are seen to become stellate, and these refract more highly, are more dense and are of much less diameter than those which retain their smooth surface, and even, circular, outline. In this change, fluid, containing globulin (?), probably escapes.

That fibrin may be formed *directly from the white blood corpuscles* seems to be proved by the fact that if a white blood corpuscle, which has become attached to a little elevation or depression upon the surface of the glass, be caused to move in one direction away from its point of attachment, it will develop a narrow thread, which gradually increases in length and appears to be drawn out from the corpuscle. It becomes firmer, and more highly refracting. This thread exhibits all the characters of fibrin, and is probably composed of this substance (fig. 45). In many cases the white blood corpuscles throw out exceedingly thin, thread-like processes, which gradually assume the appearance of filaments of fibrin.*

White corpuscles, which, when first removed from the body, appear perfectly smooth and transparent, gradually become more or less granular, plate V, fig. 44, above *a*; and the granules increase in number and size for some time, until the movements exhibited by the perfectly transparent germinal matter cease, and the white corpuscle dies, and forms a coagulum. The fibrin in the blood of some rodents appears perfectly granular immediately after coagulation has occurred, and there is no indication of distinct fibres, plate V, fig. 48.

All recently formed fibrin is found to contain an immense number of the white blood corpuscles, as may be readily demonstrated in the beautifully transparent colourless coagula not unfrequently found in the cavities of the heart, plate V, fig. 47. The substance, therefore, which we know as fibrin, undoubtedly consists of the highly refracting, insoluble, and eminently elastic threads (fibrin); and the insoluble transparent matter resulting from changes in the living and eminently mobile material of the white blood corpuscle.

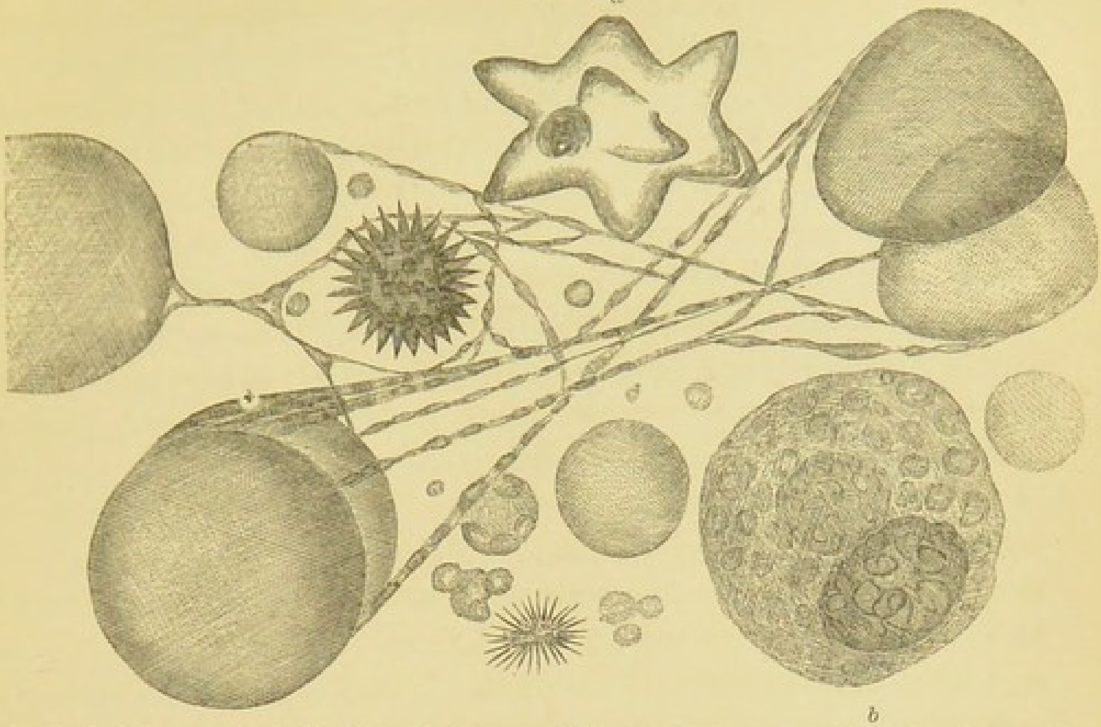
It seems probable that the threads are originally formed from a substance produced by the white blood corpuscle. The above observations are not opposed to the view of Buchanan and A. Schimdt,—for the fibrinogen, the material which is required in very large proportion, may be furnished by the white blood corpuscles and the minute corpuscles of the same nature; while from the red blood corpuscles the fibrino-plastic substance, of which a mere trace seems to be necessary, may escape. The spontaneously coagulable matter may, however, in certain cases, remain diffused for months after it has been formed, without coagulation taking place, and then an alteration in the external conditions, exposure to air, &c., may cause it to assume the solid form.

With reference to the uses of fibrin there can be no doubt that it performs an important service in limiting hæmorrhage when vessels are divided, and that it forms, when effused in internal parts, or on the surface of wounds, a temporary tissue,

* "On the germinal matter of the blood, with remarks upon the formation of fibrin."—Trans. Mic. Soc., December, 1863.

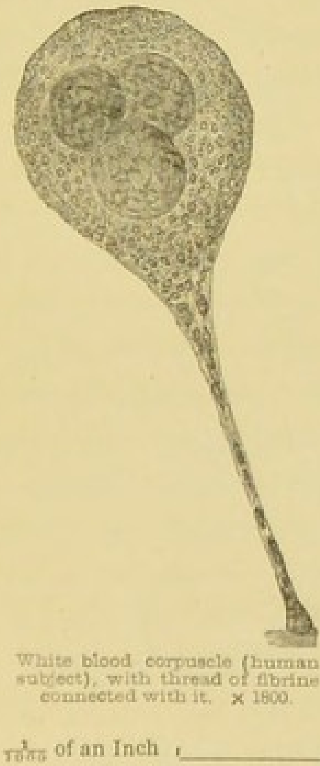
COAGULATION OF FIBRINE.

Fig. 44.



Red and white corpuscles in blood from the finger. × 2800 linear. The large smooth circular bodies are the red corpuscles. Three very small red corpuscles are less than the $\frac{1}{8000}$ of an inch in diameter. The smallest particles are composed of matter like that of which the white blood corpuscle (B) consists. Threads of fibrine undergoing coagulation are observed between the corpuscles in the upper and lower part of the field. A, red corpuscle, exhibiting angular projections. Below it, and to the left, is another, with still more pointed processes. September, 1863.

Fig. 45.

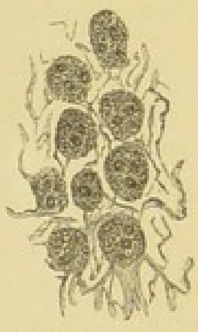


White blood corpuscle (human subject), with thread of fibrine connected with it. × 1800.

Fig. 46.

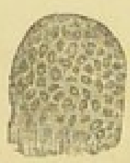
Capillary vessel from the mucous membrane of the epiglottis from a man aged 71. × 700.

Fig. 47.



From a pale clot in the heart of a patient who died of exhaustion, showing white corpuscles and fibres of fibrine. × 700.

Fig. 48.



Portion of a large mass of fibrine from Guinea pig's blood the instant coagulation had occurred. × 1800.

$\frac{1}{1000}$ of an Inch × 700.
" " × 1800.
$\frac{1}{10000}$
" " × 2,800.
$\frac{1}{10000}$

[To face p. 124.

a cementing or protecting substance, or bond of union, between separated parts, which serves as a nidus for the development of the masses of germinal matter which are to take part in the formation of a higher, more elaborate, and more slowly formed, but much more durable texture. It has been suggested that fibrin is required for the nutrition of a special class of textures, as the gelatin-yielding tissues, but we find fibrin in cases in which there are no such textures; and where these tissues do exist, they require such a small amount of nutrient matter, and undergo such slight change, that we should scarcely expect to find the proportion of fibrin, which exists when the formation of these tissues is complete, as great as it is. Nor is it probable that such highly important elements of the blood, as the white blood corpuscles, should take part in the nutrition of any one special tissue; and if upon other grounds than those advanced we were disposed to accept such a view, we should hardly be inclined to assign to such highly important and peculiar bodies the office of nourishing the lowest and simplest tissue in the body. Upon the whole, the facts known render it more likely, as has been before advanced, that the various masses of germinal matter of the several textures, form, from the same nutrient materials compounds different in structure, property, and composition; than that substances allied to the tissue to be formed, are simply selected, separated, and deposited from the nutrient plasma. There is indeed no evidence of the existence of many different substances in the blood of man and the higher animals, in which the number of different textures and secretions is very great.

Red Blood Corpuscles.—The blood of vertebrate animals contains numerous coloured corpuscles, which are known as the red blood corpuscles, and these contribute to the blood its most important characteristics. The red colour of blood is entirely due to these bodies, and the difference in colour between arterial and venous blood is caused by alterations occurring in the material of which the red corpuscle is composed.

These corpuscles are probably derived from the white ones, so that the younger red blood corpuscles contain germinal matter, a fact proved by the circumstance, that in some instances, under high magnifying powers, this germinal matter has been seen to move away from the coloured material already produced.* A the corpuscle advances in age, the whole of the germinal matter becomes converted into the coloured lifeless formed material which very readily assumes the crystalline form. The red corpuscle, in fact, seems to be composed of a small portion of soft matter, of a viscous consistence, very slightly soluble in fluid, but capable of undergoing solution in the serum under certain circumstances. In some animals the red matter retains its colloid semi-fluid state only while it is kept in active motion in the circulation. The red blood corpuscles of the Guinea-pig pass into a crystalline state within half-an-hour after they have been removed from the vessels, and without the addition of any reagent or solution whatever. It is certain, at least in this case, that there is no rupture of membrane and escape of contents. The small mass of viscid matter of which each single corpuscle is composed may be seen to form a single crystal, while if the corpuscles be slightly warmed, they break up into many small portions, each one of which assumes the tetrahedral form.* (See plate VI, fig. 49; plate VII, figs, 58 to 61.)

It appears probable that the coloured material of which the fully-formed red blood corpuscle is composed is a lifeless chemical substance, which, under the conditions to which it is exposed during the circulation, becomes resolved into certain compounds which are of great importance in nutrition, and others, which being readily soluble in fluid, with a high power of diffusion, or in a gaseous state, are readily removed from the organism altogether.

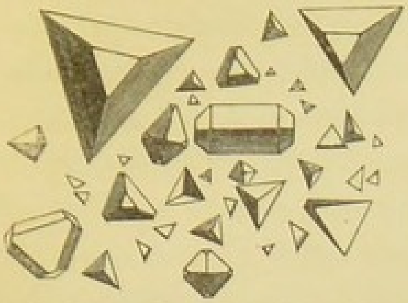
It was formerly considered that the matter which enters into the formation of the red blood-corpuscle consisted of two substances, hæmatin and globulin, but later researches rather tend to the conclusion, that in the natural condition there is one chemical substance which, however, is readily decomposed. This has been termed *Globulin*, *Hæmato-globulin*, *Hæmato-crystallin*, and *Hæmo-globulin*. It is the crystallisable material above referred to. Various forms of hæmato-crystallin, from the Guinea-pig, human subject, cat, and mouse, are represented in plate VII.

A solution of this substance, as well as of certain products of its decomposition, produces peculiar absorption-bands in the

* Observations on the Red Blood Corpuscle. Trans. Mic. Society, Dec. 1863.

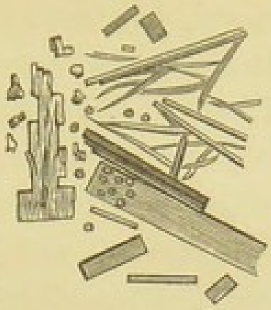
BLOOD CRYSTALS.

Fig. 49.



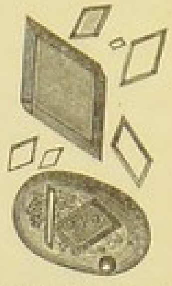
Blood crystals. Guinea Pig. × 215.

Fig. 50.



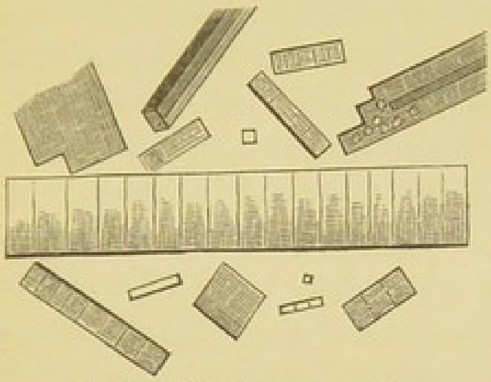
Human blood crystals. × 215.

Fig. 51.



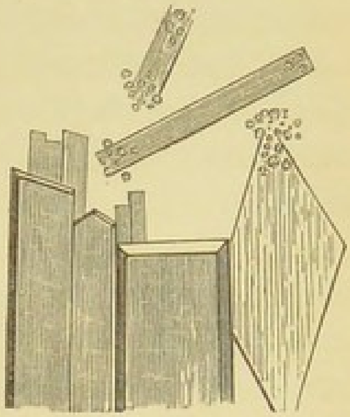
Crystals of hæmatoidin from human liver. × 215.

Fig. 52.



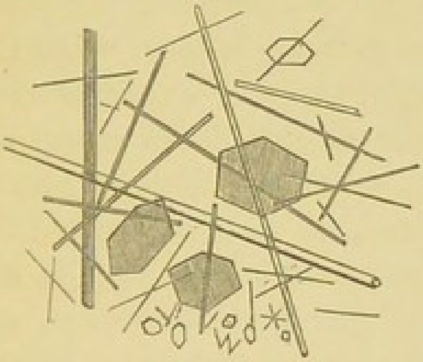
Blood crystals. Human. × 215.

Fig. 53.



Blood crystals. Cat. × 215.

Fig. 54.

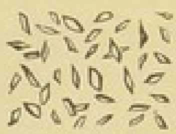


Blood crystals. Mouse

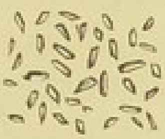
Fig. 55.

HÆMIN CRYSTALS.

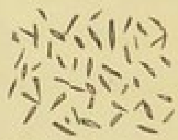
Human. × 215.



Pig. × 215.

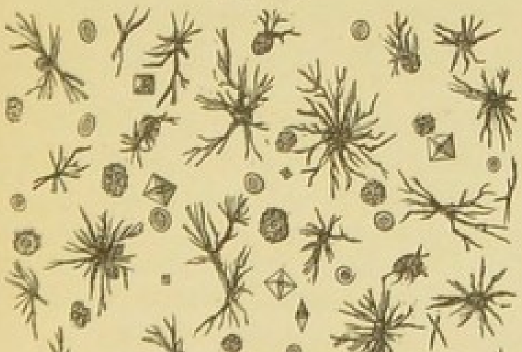


Toad. × 215.



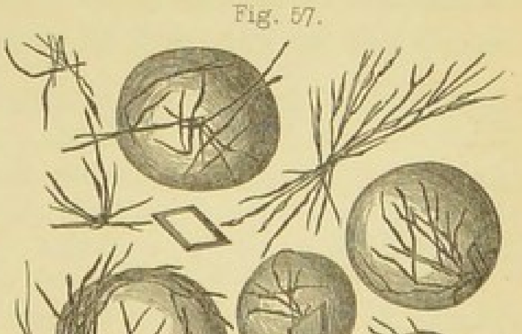
Goldfinch. × 215.

Fig. 56.



Feathery crystals of hæmatin, found in the urine a fortnight after slight rupture (?) of one kidney. Human subject. × 215.

Fig. 57.



Rhomboidal and feathery crystals of hæmatin, from a softened clot. Human × 215.

$\frac{1}{1000}$ of an Inch × 215.

L. S. B.]

[To face p. 126.

solar spectrum. Hoppe was the first to demonstrate this interesting fact, and found that a very dilute solution of blood was sufficient for the purpose. The same bands were produced by the blood of different animals. Stokes proved that this colouring matter was capable of existing in two states of oxidation, and that a very different spectrum was produced according as the substance which he termed *cruorine* was in its more or less oxidised condition.* Protosulphate of iron,† or protochloride of tin, causes the reduction of the colouring matter, and by exposure to air oxygen is reabsorbed, and the solution again exhibits the spectrum characteristic of the more oxidised state. In venous blood there is reason to believe that part of the cruorine exists in its purple or less oxidised condition, and that this, in passing through the lungs, is reoxidised and converted into the scarlet cruorine, plate VII, figs. 62 to 65.

The different substances obtained from the normal blood colouring matter produce different bands. Thus, *Hæmatin* gives rise to a band in the red of the spectrum between the lines C and D. *Hæmato-globulin* produces two bands, the second twice the breadth of the first in the yellow portion of the spectrum between the lines D and E. The absorption bands differ according to the strength of the solution employed, and the medium in which the blood salt is dissolved;‡ but an exceedingly minute proportion dissolved in water is sufficient to bring out very distinct bands, and in his new spectroscope Mr. Sorby is able to obtain the band from a single blood corpuscle.§

The most important chemical compounds obtained from the red blood corpuscles are the following:—*Hæmatin*, *Hæmatoidin*, and *Hæmin*.

Hæmatin may be obtained from *hæmato-globulin*. It occurs in old extravasations of blood, and may be detected in the fæces.

* "On the reduction and oxidation of the colouring matter of the blood," by G. G. Stokes.—Proceed. R. S., 1864, vol. xiii, p. 355.

† The solution is made as follows. To a solution of protosulphate of iron, enough tartaric acid is added to prevent precipitation by alkalies. A small quantity of this solution made slightly alkaline by ammonia, or carbonate of soda, is to be added to the weak solution of blood in water.

‡ On this subject the most recent observations will be found in F. Hoppe-Seyler's Handbook of Physiological and Pathological Chemistry. Hirchwald. Berlin, 1865. This work is a very valuable one.

§ "On the construction and use of the Spectrum Microscope," by H. C. Sorby, F.R.S.—Pop. Science Review, January, 1866.

It is not crystalline, and when dry it forms a brown powder, which contains nearly 9 per cent. of iron. A thin layer of a solution of hæmatin exhibits a greenish colour, while a thick one is dark red. Hoppe-Seyler names another substance allied to *Hæmatin*, *Methämo-globulin.* This may be a mixture of hæmatin and some albuminous substance.

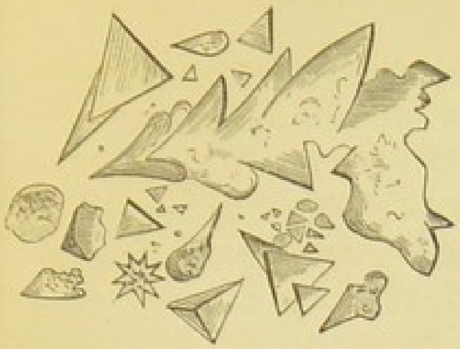
Hæmatoidin is a modified form of hæmatin. It is not easily decomposed, is insoluble in water, alcohol, ether, and acetic acid, but readily soluble in alkalies. This is the substance which is found in old clots and extravasations, and not unfrequently in the walls of some of the smaller vessels, perhaps marking the situation of old hæmorrhages. It crystallises in very beautifully defined rhombic crystals, plate VI, fig. 51. It also forms long filaments, and not unfrequently slightly curved elongated crystals collected into bundles, which sometimes take the form of oval or dumb-bell shaped masses, plate VI, figs. 56, 57. This substance seems closely allied to a yellow crystalline material obtained from the bile. It would indeed be very difficult to distinguish hæmatoidin crystals found in clots from some crystals which have been produced in biliary matters. Hæmatoidin may therefore be the same substance as that obtained from bile under the names Cholepyrrhin Biliphæin, Bilifulvin, and more recently Bilirubin. Zenker and Funke have shown that from the yellow crystals of bilifulvin red crystals of hæmatoidin may be obtained.

Hæmin is a substance which was discovered by Teichmann. It is obtained artificially from hæmatin and hæmato-crystallin. By the addition of a little glacial acetic acid to a small portion of clot of blood, the hæmin is produced and crystallises in rhombic scales. Hæmin crystals may be thus obtained from the red blood of man and the lower animals. Blood that has been kept for some time yields these crystals as well as fresh blood, and, with care, they may be obtained from the smallest blood spot on clothes, &c., hence this reaction is of value in medico-legal inquiries, but, as a test, it is less delicate than the spectrum analysis already referred to. Hæmin crystals from the human subject, pig, toad, and goldfinch are represented in fig 55.

Extractive Matters.—It is probable that the so-called extractive matter of blood consists of substances which result during

BLOOD CRYSTALS. CRUORINE. CAPILLARIES.

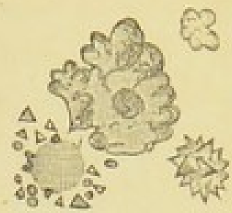
Fig. 58.



Blood crystals from the blood of the Guinea pig. × 700.

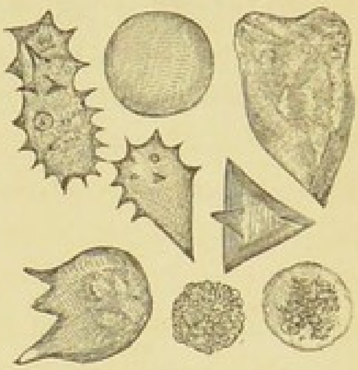
Fig. 59.

Fig. 60.



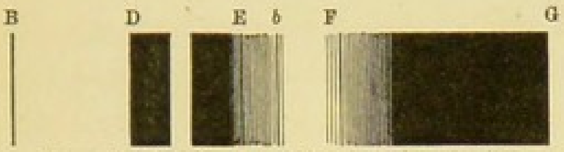
Disintegration of red blood corpuscles of Guinea pig's blood, and formation of crystals. After application of a gentle heat. × 700.

Fig. 61.



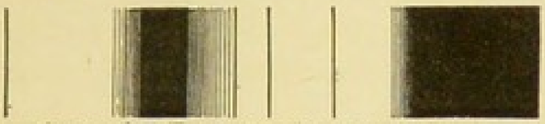
Formation of blood crystals from the red blood corpuscles of Guinea pig's blood, shortly after removal from the body. No reagent added or heat applied. × 1800.

Fig. 62.



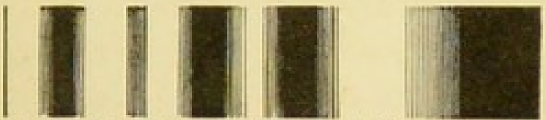
Absorption bands. Arterial and scarlet cruorine.

Fig. 63.



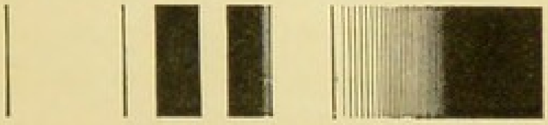
Absorption bands. Venous blood and purple cruorine.

Fig. 64.



Absorption bands. Blood treated with acetic acid.

Fig. 65.



Absorption bands. Solution of hæmatin. Copied from Stokes. Proc. R. S., 1864.

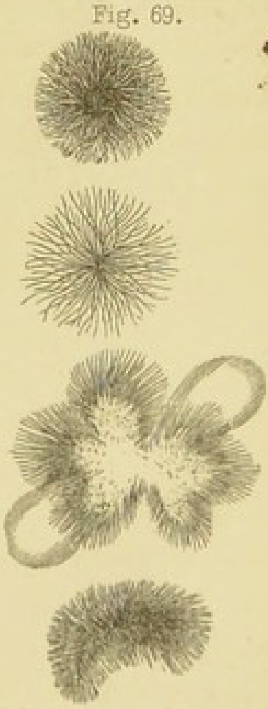
Fig. 66.

Chloride of sodium

Fig. 67.

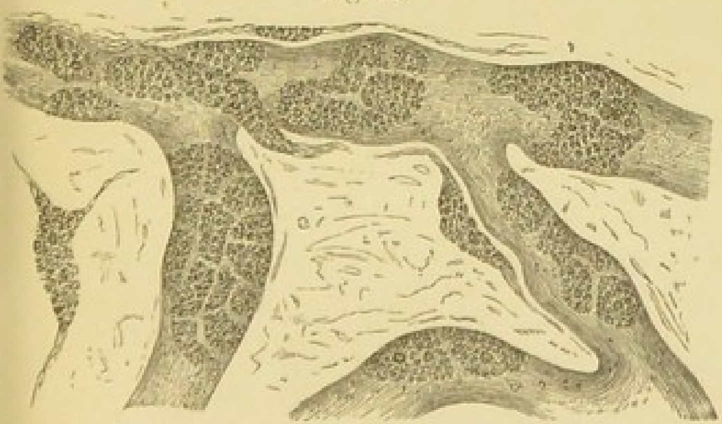
Capillary showing masses of germinal matter projecting into its interior. Areolar tissue Mouse. × 700.

Fig. 69.



Margarine crystallised spontaneously After Robin and Verdeil.

Fig. 68.



Capillary, connective tissue Cattle plague. The masses of germinal matter of the capillary are very much enlarged, and are dividing and subdividing to form new masses. × 700.

$\frac{1}{1000}$ of an Inch × 700.

" " × 1800.

$\frac{1}{10000}$

L. S. B.]

[To face p. 128.

the decay and disintegration of the blood corpuscles, and their resolution into various definite compounds. These indefinite extractive matters probably pass off in an altered form in the urine and other secretions almost as fast as they are produced, for the quantity of extractive matter in normal blood is very small, scarcely amounting to more than ·5 or ·6 per cent., but in certain morbid conditions a much larger proportion is found.

Of the *saline* constituents of the blood taking part directly in the nutrition of tissues, or subservient thereto, probably the chlorides and alkaline and earthy phosphates are the most important. The chlorides increase the fluidity of an albuminous fluid, and probably facilitate the access of the nutrient pabulum to the germinal matter of the cell. In all cases in which cell-development is going on actively a large quantity of common salt is present. During the development of the normal tissues in the embryo, and during the multiplication of the masses of germinal matter in disease, as in pneumonia, the formation of abscess, in cancer, and other morbid states, characterised by rapid cell growth, chloride of sodium is to be detected in considerable proportion. It is doubtful if the alkaline phosphates are devoted to nutrition, although there can be no doubt they are of service in giving to the serum an alkaline reaction, and are, perhaps, to some extent, concerned in the absorption of carbonic acid and other changes. The greater part of the phosphate in the blood is probably derived from the bread and meat taken in the food. The earthy phosphate of lime which forms 3·5 per cent. of the ash of blood is an important substance. *Iron* should also be enumerated among the saline constituents of the blood, of service in the nutritive process, but we are not yet acquainted with the exact part it plays in the chemistry of the body. The foregoing are probably the constituents of the blood which take part in the nutrition of the various textures, and from them the chemical compounds found in the tissues and entering into the composition of the various secretions, are alone formed.

There are many other substances in the blood, which probably result from the action of oxygen upon certain of the constituents of that fluid or of the tissues, and are poured into the blood prior to their further oxidation and ultimate removal from the organism by the agency of various excretory organs.

From an albuminous fluid of comparatively simple composition, but undergoing constant change by the action of oxygen upon certain of its constituents, textures and organs of very elaborate structure, capable of performing complex functions, are constructed, but, indirectly, through the agency of germinal matter.

The highly important part which the blood plays both in the nutrition and disintegration of the textures of man and the higher animals cannot be advantageously discussed, unless the general nature of the changes effected in it and in the textures, by the process of oxidation, is referred to in the first place. We may then allude to the operations occurring simultaneously in different parts of the organism under the two following heads:—the production of peculiar compounds in the tissues and organs, from certain constituents of the blood of a very different composition:—the manner in which new substances are added to the blood to take the place of those which have been removed from it and appropriated.

OF THE CHANGES EFFECTED BY OXIDATION.

By the direct or indirect action of oxygen upon certain constituents, soluble matters fit for appropriation by the germinal matter of the several tissues are prepared, while at the same time insoluble substances which are to be got rid of are converted into highly soluble compounds, which are easily removed from the body. It has been very generally concluded that oxygen is directly concerned in the processes of nutrition and growth. But many considerations render it probable that it is required in greater proportion for the conversion of products resulting from death and decay into chemical compounds which may be readily and quickly removed from the organism, by which the access of new pabulum to the germinal matter is facilitated, than for the direct nutrition and increase of the germinal matter itself. Oxygen is to be regarded as a destroyer of compounds already formed, not as a pabulum. It seems subservient to the process of disintegration rather than to that of construction. It has been observed that the activity of cell growth and multiplication is remarkable at an early period of development when the process of oxidation is far less active than in the fully developed state. The organs in which these processes are most active in the adult are remarkable rather for a very limited, than for a very free, supply of oxygenated blood. In the case of morbid growths, like cancer, which are remarkable for rapidity of growth, the supply of arterial blood is often very small. In acute inflammation of the lung, the air cells become rapidly filled with "lymph," the formation of which is dependant upon minute masses of germinal matter, and these have grown and multiplied under conditions which were quite incompatible with free oxidation. Lastly, we shall find that the anatomical distribution of the small arteries to certain secreting organs and their arrangement in the muscular and nervous tissues is such as to render it more probable that the arterial blood which they carry, takes part in the process of oxidation and disintegration of materials already formed, than that it is connected with nutritive operations.

Although there can be no question concerning the great importance of oxygen in the changes taking place in living beings, we are still in doubt as to the precise manner in which this oxygen acts, and the particular substances with which it combines. It is possible that the oxygen may be in some peculiar state of combination before it acts, for it is well known that many substances which are not affected by free oxygen, readily combine with this substance, if it be already in a state of combination.

The absence of red blood corpuscles from the blood of many invertebrate animals proves conclusively that these bodies are not essential to the process of oxidation. All the nutrient juices which permeate the various tissues hold oxygen and carbonic acid gases in solution, and it is certain that in some cases the action of oxygen is brought about solely by its aqueous solution. While on the other hand, it has been conclusively shown that oxygen is directly absorbed and carbonic acid evolved by the tissues as well as by the blood; and the experiments of G. Liebig have proved that frogs' muscles continue to absorb oxygen and give off carbonic acid even after their removal from the body. It is therefore certain that neither for the absorption of oxygen nor for the production of carbonic acid, are the red blood corpuscles essential, but that chemical combination takes place between the oxygen and certain elements of the tissues. It is not possible, however, to state confidently whether combination actually occurs in the tissue itself or is effected only through the agency of the masses of germinal matter so abundant in every tissue, and found in connection with the capillary wall. With regard to muscle it must not be forgotten that upon the surface of each elementary muscular fibre are numerous delicate nerve-fibres, having many masses of germinal matter connected with them, and it is therefore at least possible that the process of oxidation may be taking place in connection with this tissue instead of in the interior of the contractile material, as is generally supposed. If the oxygen combines with or decomposes substances entering into the formation of the tissues, or immediately resulting from their disintegration, the process is merely a chemical one, and might, one would think, be imitated out of the body, but if only with matters resulting from the immediate disintegration of germinal matter, it cannot be so easily explained, and the change may perhaps be due to the elements coming into contact with the oxygen in some very peculiar state.

If the fluids distributed to the tissues in which active changes are taking place are only imperfectly charged with oxygen, or if, although fully saturated, there be some impediment to their free circulation through the tissue, imperfectly instead of fully oxidised substances result, which, from being insoluble or only slightly soluble, cannot be readily removed from the seat of their formation, and if these conditions interfering with free oxidation, persist, such insoluble compounds accumulate. Not only do such substances impair the action of the tissue in which they are deposited, but they interfere, to some extent, with the equable distribution of fresh nutrient material. In the process known as *fatty degeneration* the substances resulting from the disintegration of the tissue under the influence of a too limited supply of oxygen, accumulate in its texture and seriously impair its action. In many cases not only is the existing tissue rendered soft and rotten, and prone to give way, but the process of formation of new tissue to take its place is partly or entirely suspended.

The activity of the process of oxidation seems to be increased by the presence of alkali, as is well known to be the case with the oxidation of organic matters out of the body. In cases in which the quantity of alkali in the blood is less than normal, various substances in that fluid are not fully oxidised, and the so-called extractive matters, together with uric and oxalic acids, and allied compounds, result, instead of the more soluble highly oxidised substances, such as urea and carbonic acid, which are so readily removed from the system in the excretions. The value of alkalies and of their salts with the vegetable acids, in all those conditions which are characterized by the formation and accumulation in the blood, or tissues, of imperfectly oxidised substances, is well known to all practical physicians. The blood and the fluids which bathe the tissues in health exhibit an alkaline reaction, due to the presence of soda in combination with albumen, and with carbonic and phosphoric acids. It is probable that substances resulting from the biliary matters exert an influence similar to that of alkalies, and perhaps perform a very important office in facilitating that intimate contact between elements having a strong chemical attraction for one another, which immediately precedes chemical action.

It has been sometimes imagined that oxygen at once combines with the carbon of certain constituents dissolved in the blood or fluids, or even entering into the composition of the solids of the tissues, but it is very unlikely that this should be the case. Although the present state of chemical knowledge has led chemists to infer that in the body highly oxidised products result from the combination of successive portions of oxygen with the same substance, so that portions of hydrogen and carbon are successively removed, until a highly complex organic compound is reduced to one of a comparatively simple composition, and finally into the raw materials of organic life, carbonic acid and water, it is extremely doubtful if chemical changes occur in this manner in the organism. A process of the kind has indeed been performed in the laboratory;* for

* An example of this degrading oxidation is afforded by the action of oxidising agents upon glycol (a chemical analogue of alcohol).

Glycol	$C_2H_6O_2$
Glycolic acid	$C_2H_4O_3$
Glyoxal	$C_2H_2O_2$
Glyoxalic acid	$C_2H_2O_3$
Oxalic acid	$C_2H_2O_4$
Formic acid	$C\ H_2O_2$
Carbonic acid	$C\ \ O_2$
Water	H_2O

These substances, with the exception of glycol, are also formed by the decomposition of nitrous ether ($C_2H_5NO_2$) in contact with water.—[Note from Prof. Bloxam.]

example, by subjecting certain complex chemical substances to oxidising agents, bodies are obtained "in which the number of the constituent atoms of hydrogen and carbon becomes progressively less and less, until we arrive at bodies containing only two, and finally at bodies containing only one carbon atom."

By oxidising stearic acid $C_{18}H_{36}O_2$ with nitric acid of moderate strength, the following bodies are obtained:*

	Oxidation Products.	
Rutic acid	$C_{10}H_{20}O_2$	
Suberic		$C_8 H_{14}O_4$
Œnanthic	$C_7 H_{14}O_2$	
Pimelic		$C_7 H_{12}O_4$
Caproic	$C_6 H_{12}O_2$	
Adipic		$C_6 H_{10}O_4$
Butyric	$C_4 H_8 O_2$	
Succinic		$C_4 H_6 O_4$

It must however be borne in mind that no evidence has yet been adduced of the occurrence of this successive modifying action of oxygen in the animal body. The chemist observes in the laboratory that a substance under the influence of oxidising agents gradually descends in the scale of complexity as the oxygen successively burns off portions of its hydrogen and carbon; but it seems much more probable that the formation of the chemical substance in the animal body is due to the action of oxygen upon germinal matter, and that, so far from there being a series of changes, a highly, moderately, or slightly oxidised substance results, according to the conditions present when the change occurs. The facts of the case render the chemical view of successive oxidations untenable. There is no good reason for believing that starch as starch, sugar as sugar, or fat as fat, unites with oxygen in the body. The theory that several chemical compounds must be produced between the starch, sugar, or fat on the one hand, and the carbonic acid on the other, is merely a chemical hypothesis, for which as yet no very good grounds exist, since no one has produced these intermediate bodies by causing oxygen to unite directly with any of the above substances, and such intermediate products have not been satisfac-

* Odling's Lectures on Animal Chemistry. 1866. P. 48.

torily traced in the animal body; while anatomical facts render it more probable that in the disintegration and removal of *all* textures germinal matter is intimately concerned, and that instead of oxygen acting directly upon the materials of the texture these are first taken up by germinal matter which in its turn is destroyed, giving rise to the substances which are usually considered to result directly from the disintegration of *tissue.*

Of the carrying of Oxygen to all parts of the Body.—The red blood corpuscles of vertebrate animals are the agents principally concerned in carrying the oxygen introduced into the organism by respiration, to different parts of the body. They also take up carbonic acid from the tissues and deliver it at the pulmonary surface where they receive the oxygen in exchange. The material of which the red blood corpuscles are composed possesses in a remarkable degree, as has been already stated (page 126), the property of absorbing and parting with oxygen and carbonic acid gases. Fernet (Comptes rendus, August 2nd, 1858) showed that blood corpuscles absorbed twenty-five times as much oxygen as the same quantity of water, and that the oxygen could be again expelled in vacuo at 98° F. This temporary fixation of gases by the material of the red blood corpuscles is interesting, and, as is well known, other substances behave in a similar manner towards gaseous bodies; for instance, ferrous sulphate will take up nitric oxide, which it again gives up in vacuo. Cuprous chloride takes up carbonic oxide, which may be disengaged from it by boiling. One per cent. of common phosphate of soda enables water to absorb twice the normal proportion of carbonic acid, which may be expelled by agitation with air. And many other examples of bodies possessing similar properties might be adduced.

It is probable that some of the constituents of the red blood corpuscles undergo oxidation, and, perhaps, in this way a certain proportion of urea, carbonic acid, and other substances may be *formed;* while in cases where the oxidation is imperfect, uric, oxalic, lactic, and perhaps other incompletely oxidised bodies may result. The property exerted by the blood corpuscles of absorbing gases is, however, greatly influenced by various agents, and there can be little doubt that the deleterious effects of many poisons are due to the influence they exert upon the absorption and removal of carbonic acid. The experiments of Dr. George Harley have shown that *snake poison*, *uric acid*, and some other substances accelerate the absorption of oxygen and the exhalation of carbonic acid; while *sugar*, *hydrocyanic acid*, *nicotine*, *morphine*, *chloroform*, and *alcohol* exhibit a contrary effect, and diminish the property which the constituents of the red blood corpuscles exhibit to unite with oxygen and give off carbonic acid.* The action of oxygen on *cruorine* has been referred to in page 127.

Besides the property of acting as carriers of ordinary oxygen, it is possible that the red blood corpuscles may be very efficient carriers of *ozone*. This opinion has been adopted by His and other observers, who state that they readily take up and give off this peculiar form of oxygen which possibly is instrumental in combining with certain products resulting from the decay of animal substances, and thus preventing their deleterious action in the organism; but, at the same time, it should be remarked that at present we know very little of a positive nature concerning ozone or its actions.†

Relation of Oxidation to the heat producing process.—Not only has the development of heat in the animal body been attributed to the combination of oxygen with carbon and hydrogen of some of the constituents of the blood and tissues, but it has been concluded that in all cases in which the temperature of the body rises above the normal standard the activity of the oxidising process must be necessarily augmented; and this notwithstanding the fact well and widely known, that certain states of disease, remarkable for an elevated temperature, are associated with conditions seriously interfering with the free introduction and distribution of oxygen. The fact that the temperature of the body has been known to rise several degrees after death, in diseases in which for some time previously the introduction of oxygen into the blood had been seriously

* Proceedings of the Royal Society, 1864.

† Much difference of opinion still exists concerning the nature of ozone. Schönbein considers that oxygen exists in three different allotropic conditions, of which, two are active and opposed to each other; these are *ozone* and *antozone*, equal quantities of which neutralize each other and form inactive or *neutral oxygen*, which may be separated one-half into ozone and one-half into antozone. Neither ozone nor antozone, have however, yet been isolated in a state of purity, but are always mixed with neutral oxygen. It appears that Brodie discovered the polar condition of oxygen, and his views were applied to ozone by Schönbein about ten years afterwards.—(See Proc. Roy. Soc., vol. xi. p. 442.)

interfered with, would seem to be fatal to this view, although it is still widely accepted and taught.

In all those conditions of system which are accompanied by an elevation of the temperature there is an increased production of germinal matter of the tissues of the body generally, while in cases in which there is a local increase of germinal matter, as in the formation of a common abscess, there is invariably a rapid evolution of heat. In both conditions the activity of the oxidising process is far below the healthy standard, while the temperature is many degrees above the normal range, and it is therefore impossible to resist the inference that the elevation of temperature is due rather to changes accompanying the increase of this germinal matter than to increased oxidation. The elevation of temperature is, in fact, associated with suboxidation, and therefore cannot, as has been affirmed, be dependent upon per-oxidation. We must not omit to notice that it has been recently shown by Berthelot that, by the hydration and dehydration of organic substances heat results.* Thus, sugar, starch, and fatty matter, by decomposition give rise to increased development of heat; and when albuminoid matters are hydrated and decomposed, or dehydrated and caused to enter into combination, heat is set free altogether independently of the process of oxidation. And, lastly, it has been demonstrated by MM. Estor and St. Pierre (Mémoires de la Société de Biologie, 1865) that the venous blood returning from an inflamed part is of a brighter tint than ordinary venous blood, and contains sometimes more than twice as much oxygen. So that, although the temperature is several degrees higher than in the normal state, these observations prove that less oxygen is consumed.

Many facts would indeed justify the inference that the red blood corpuscles are more intimately concerned in the carrying away and distribution of heat, and thus in equalising the temperature in various parts of the body, than in the actual production of heat. Supposing heat to be set free during the increase of the germinal matter of the capillary walls, which is associated with its increase in adjacent tissues, as in an ordinary case of inflammation, the effect of the corpuscles coming into contact one after the other with the enlarged masses of germinal matter, as they traverse the capillaries, would be to carry

* Mémoires de la Société de Biologie, 1865.

away the increased amount of heat and diffuse it over the system. In this way a plausible explanation is afforded of the great importance of keeping up the heart's action in diseases characterised by a considerable elevation of temperature, the beneficial effects of which have been demonstrated by observation and abundantly confirmed by experience.

Of the substances resulting from the action of Oxygen upon constituents of the Organism.—It is proposed to refer in this place very briefly to a few only of the many compounds which are formed in the organism by oxidation. Many others will be alluded to when the various liquid secretions in which they are found come under consideration.

The *action* of organs is in great part dependent upon oxidation, and the amount of texture destroyed; and the quantity of oxygen required for the formation of oxidised products varies according to the intensity of the action. In many cases the degree of activity, or the actual amount of *work* performed within a given time, can, in fact, be measured by estimating the amount of oxidised substances produced. By the artificial oxidation of certain albuminous matters, oxidised products similar to those found in the body may be formed. Van Deen states that, by the action of nascent oxygen developed from water by a constant current of electricity, he succeeded in obtaining urea, uric acid and allantoin from *albumen*, and the two first from *gelatin*; sugar and lactic acid from glycerine and from inosite; and urea and allantoin from uric acid. Many of these bodies, he says, may also be obtained by the action of ozone upon the same substance, and it is probable that the electrolytic ozone is the real agent in the above experiment.

It has been stated that a great number of the substances found in living beings have been produced in the laboratory, and that there is reason to think that eventually every one may be artificially built up. When, however, the various instances which have been adduced are carefully investigated, it is surprising how the number usually advanced becomes reduced, and it is indeed difficult to point out a single product proved to result immediately from direct tissue oxidation, which can be formed synthetically from substances taken exclusively from the inorganic kingdom,* and the least consideration will satisfy

* Berthelot's synthesis of formic acid from carbonic oxide derived from carbonate

any one that so far from the conditions under which compounds are formed in living things resembling those present when similar substances are produced in the laboratory, they are totally different. There is not indeed, as far as is yet known, the slightest real analogy between the chemical operations in the laboratory and those taking place in living germinal matter.*

Urea (CH_4N_2O). Among the substances probably resulting from the oxidation of compounds allied to albumen, one of the most important is urea. This is a crystalline excrementitious substance, very soluble in water, and readily diffusible. In health it is separated from the blood as it passes through the vessels of the kidney so fast that only mere traces can be detected, even if a large quantity of healthy blood be operated upon. But if the action of the kidneys is impaired by disease, or if the organs are extirpated, or if a ligature be passed round the artery, so as to prevent the blood from passing through the kidney, urea may accumulate in the blood in sufficient quantity to be detected in the serum without difficulty. Urea is not found in the muscles, although it can be obtained by the decomposition of kreatine and other substances found in muscular tissue. Recent researches have rendered it probable that much of the urea which is excreted is not *formed* in the tissues or in the blood, and merely separated and eliminated by the kidney, as was formerly supposed, but that a considerable proportion is actually produced in the kidney itself. It seems probable that the oxygen dissolved in the water which filters away from the arterial blood as it slowly traverses the capillaries of the Malpighian tuft, oxidizes certain constituents of the cells which line the uriniferous tubes, and that urea is one of the substances resulting from this action. It would appear that for the formation of urea in quantity a large proportion of fluid is necessary, and in the case of animals living under conditions which interfere with the introduction into and passage through the system of large quantities of water, uric acid, and other less soluble substances seem to be substituted for urea. Crystals of urea are represented in plate VIII, fig. 70.

of baryta by the action of iron at a high temperature, does seem to be entirely independent of organic life.

* See papers in the Medical Times and Gazette, especially April 7th and 14th, 1866.

Uric Acid ($C_5H_4N_4O_3$), plate VIII, fig. 71, is a substance less highly oxidised than urea, and there are reasons for believing that the latter is formed from it by oxidation. The proportion of uric acid increases under various conditions, in which the oxidising operations are interfered with, or imperfectly performed. It has been detected by Dr. Garrod in the blood and other fluids of gouty patients, in decided quantity, and it may be regarded as one of the products of incomplete oxidation. In birds and certain reptiles the renal secretion consists principally of salts of uric acid. By the formation of urate of ammonia a considerable proportion of the waste carbon is removed by the kidneys of birds, instead of nearly the whole being exhaled by the pulmonary surface. Dr. Odling remarks that the lungs of birds are required to discharge only $\frac{3}{4}$ instead of $\frac{7}{8}$ of the carbon resulting from the metamorphosis of nitrogenous tissue, as in animals. "On this view, the comparatively large kidneys of birds and insects will have reference not only to the absolute amount of tissue metamorphosed, but also to the relative increase in the proportion of carbon excreted by their kidneys to that excreted by their lungs."

Hippuric Acid ($C_9H_9NO_3$) is found in large quantity in the urine of the horse and many graminivorous animals, and seems to be formed under the conditions which, in carnivora, lead to the production of uric acid. Hippuric acid is formed in the human organism, and is always present in the urine. According to Weismann and Hallwachs, nearly thirty-five grains are excreted by a healthy man in twenty-four hours. The researches of Kühne and Hallwachs render it probable that hippuric acid is produced from the glycocine formed in the liver. Crystals of hippuric acid are figured in plate VIII, fig. 72.

Leucine ($C_6H_{13}NO_2$) and *Tyrosine* ($C_9H_{11}NO_3$). Among the substances resulting from the oxidation and decomposition of albuminous matters in the body, and capable of being formed in the laboratory artificially, are two bodies, leucine and tyrosine, which are of great interest. They may be obtained from all substances allied to albumen or gelatine by prolonged boiling with mineral acids or alkalies. Dr. Odling has well remarked that these two apparently opposite processes are the same in principle. "In each case the acid, or alkali, merely enables the protein or gelatinoid substance to react with water whereby one portion of it becomes oxidised into leucine, tyrosine, &c., while another portion is hydrogenised into divers products." Leucine and tyrosine cannot be built up synthetically from inorganic matter. They have been found in the normal tissues and secretions in small quantity ; but in diseases in which certain physiological processes are seriously deranged they are found in comparatively large proportion. This is particularly the case in certain diseases of the liver, as was shown by Frerichs. Not only may both substances be detected in the liver after death from acute yellow atrophy of that organ, and some other affections, but large quantities are often excreted in the urine during the patient's life.

Leucine has been detected in the saliva, pancreatic fluid, bile and urine. It is present in the intestinal glands and in the spleen pulp, and it has been obtained from the thymus, thyroid and lymphatic glands. Bœdeker states that leucine is an ordinary constituent of pus. In most cases, tyrosine is associated with the leucine. Both substances have been obtained from the tissues of many of the lower animals; and from the cochineal insect tyrosine may be obtained in quantity, as was first proved by De la Rue. And there can be no doubt that they are much more widely distributed than was formerly supposed. They have not yet been detected in muscular or nervous tissue. Leucine crystals are seen in plate VIII, fig. 76.

The various substances resulting from the oxidation of starchy and saccharine substances and fatty matters will be considered in the proper place. Among these, perhaps water (H_2O), oxalic acid ($C_2H_2O_4$), acetic acid ($C_2H_4O_2$), mucic acid ($C_6H_{10}O_8$), butyric acid ($C_4H_8O_2$), and succinic acid ($C_4H_6O_4$), are the most important. It is probable that when the process of oxidation is fully performed, carbonic acid is produced in place of these less highly oxidised organic acids.

OF THE FORMATION OF VARIOUS COMPOUNDS IN THE TISSUES AND ORGANS, FROM THE BLOOD.

The special changes produced in the blood as it circulates through the capillaries of the different organs will be referred to in their proper place, but it is desirable to consider at once the general phenomena of the process of nutrition as it occurs in the elementary tissues of the body.

Before any tissue can be nourished, certain of the soluble substances formed in the blood and held in solution in the serum, must permeate the walls of the vessels, and traverse the texture. The nutrient fluid having perhaps undergone some change in its course, reaches the masses of germinal matter of the several textures, by which it, or certain of its nutrient constituents are taken up. Thus the germinal matter increases by the formation of new germinal matter; and the loss of that which has already undergone conversion into tissue is to some extent, completely, or in certain cases more than, compensated for. These processes in the healthy condition occur at a definite rate, but if the capillary walls be unusually thin, or be stretched, they necessarily become more permeable to the fluids passing from the blood; or if the soluble nutrient matters be formed in the blood in undue proportion, a greater amount of pabulum must pass to the tissues than is sufficient to compensate for the waste occurring. Consequently, under such circumstances, the masses of germinal matter increase in size. If this excessive proportion of soluble pabulum were not very soon taken up by the living germinal matter it would, at the temperature of the body, soon undergo decomposition, and the resulting products would, probably, very soon destroy all the living germinal matter in the neighbourhood, as well as the existing tissue. At the same time that the masses of germinal matter increase in size and number from increased access of pabulum, the tissue or formed material becomes softened and altered in consequence of being too freely permeated by the fluid.

Changes affecting the quantity and quality of the soluble nutrient substances in the blood, and their distribution to the tissues, frequently form the starting point of many morbid processes which, after proceeding for a certain time, may cease, or be caused to stop, or they may be compensated for by actions of a different nature being excited in other parts; or, running on to a certain degree, the entire destruction of a tissue which cannot be renovated or replaced, may result. If a considerable extent of the tissue of some highly important organ as brain, lung, liver or kidney is affected, the patient's death may occur long before the changes have reached the degree to which they often attain when confined to a small circumscribed portion of comparatively unimportant tissue as skin, bone or connective tissue.

There can be little doubt that from the same pabulum different kinds of germinal matter produce substances having a very different chemical composition. Nor are we able to explain why one form of germinal matter should produce muscle, another fibrous tissue, another nerve, and so on. On the one hand there can be no doubt that all these different kinds of germinal matter have descended from one, and on the other it is probable that from them all a common form of germinal matter (pus) might result; while the germinal matter of muscle or nerve may cease to produce these higher kinds of formed material, and give rise to fibrous tissue alone. It would seem as if, by virtue of some original power, the germinal matter of the embryo evolved in due order the several kinds of germinal matter which, under conditions brought about at the proper time, give rise to the formation of their respective tissues, but that if, from altered conditions, the production of the series were interfered with, the formation of the special compounds and tissues became impossible in that particular organism. The changes would go on in order until the perfect organism was produced; but any interference or derangement of these would render the ultimate attainment of the perfect form in that particular case impossible.

The great importance of the nuclei, or masses of germinal matter of the tissues, in connection with each special formative process has been already indicated, and the conclusions arrived at render it very improbable that those which are constantly, and in such great number, met with in connection with the capillary vessels are unimportant, or are connected only with the development of the vessel as has been supposed. These masses of germinal matter, varying in size and number in different capillaries, and in the same vessels under varying circumstances, often project into the cavity of the vessel, and on the other hand extend beyond the line of its external wall. In inflammations and fevers these masses sometimes increase to four or five times their normal size.* Moreover, it is well known that fatty degeneration of these capillary nuclei, and

* Microscopical Researches on the Cattle Plague, a Report to Her Majesty's Commissioners, by Lionel S. Beale, M.B., F.R.S., &c. May, 1866. See also plate V, fig. 46, and plate VII, figs. 67 and 68.

other morbid changes, are associated with most important alterations in the character of the blood, and serious derangement in nutrition as well as in the actions of the tissues. It is, therefore, almost certain that these bodies are intimately concerned in the changes taking place in the blood and in the tissues in health. It seems not improbable that the masses of living or germinal matter under consideration are concerned in the selection and distribution of materials to the tissues as well as in the removal of substances from them and their introduction into the blood. When they project considerably into the interior of the vessel, the red blood corpuscles must, one after the other, come into contact with them, and probably part with some of the oxygen with which they are charged. This may combine with some of the elements just set free by changes in the living matter, and many of those chemical compounds which are obtained from the blood result. Under ordinary circumstances these bodies may take up nutrient matter from the blood into which they project, while on the side directed towards the tissues, the germinal matter may become resolved into substances fitted for the nutrition of the various textures.

Milk.—Some of the most important substances formed by the agency of special germinal matter from the fluid constituents of the blood are those which enter into the composition of milk. This secretion contains, without doubt, all the materials necessary for nutrition and tissue-formation—*albuminous, saccharine matters* and *earthy salts*, dissolved; and *fatty matters in a state of extremely minute subdivision*, suspended in fluid. All these different classes of substances are undoubtedly formed by the secreting cells of the mammary gland, and the pabulum of those secreting cells must be derived from the blood. The arrangement of the vessels, the disposition of their nuclei, and their relation to the secreting cells, differ in no essential respect from what is observed in other secreting organs, and there can be little doubt that the material distributed to the cells of the lacteal gland is a simple serous fluid, the elements of which are rearranged by the germinal matter, and caused at last to combine to form the peculiar substances characteristic of milk.

Casein.—This principle has many properties in common with albumen and fibrin. It is found abundantly in milk. Its occurrence in other fluids has not been positively determined.

The curd which is formed by heating milk in which a free acid existed, consists of a combination of casein with the acid. Heat alone will not effect the precipitation; but the addition of a little acid of any kind will occasion it. When dilute sulphuric acid is added to skimmed milk a precipitate occurs which is sulphate of casein. By digesting the clot thus formed with water and carbonate of lime, the acid combines with the lime, and the casein, which is set free, though not in a pure state, dissolves in the water and may be obtained by evaporation. It exists in the proportion of 3 to 4 per cent. in women's milk and in cow's milk, and 2 per cent. in asses' milk.

Casein is coagulated very perfectly by the action of rennet (the fourth or true digesting stomach of the calf) aided by heat. This property of coagulating casein is not to be attributed to the acid of the calf's stomach, but to the organic principle (pepsin) resident in it; for the power remains after all evidence of acid reaction has been removed. Rennet is one of the most powerful agents in causing the coagulation of casein, and it has been employed in domestic economy for the manufacture of cheese, which consists of the curd mixed with butter, compressed and dried. So perfect is its coagulating power that not a particle of casein in milk submitted to its action, will remain uncoagulated.

Casein comports itself with reagents in a manner very similar to albumen. In the coagulated state, it is insoluble in water, but soluble in *liquor potassæ*. It is not precipitated by heat alone, in which respect it differs from albumen. Casein, unlike albumen, is precipitated both by acetic and lactic acids.

The fatty matters present in milk, amount to about 4 parts in 100. They occur in the form of separate globules, each of which is protected by an envelope of casein, which prevents them from running together. Chevreul obtained from butter of cow's milk, the glyceride of stearic, palmitic, oleic, capric, caprylic, caproic, and butyric acids, but it is doubtful if these bodies exist in this state in the fresh secretion.

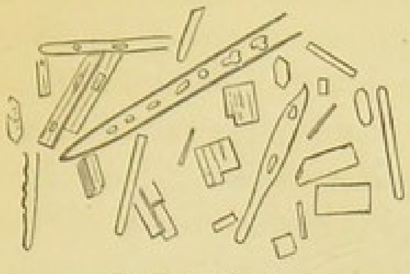
Sugar of milk ($C_{12}H_{24}O_{12}$) is a crystallisable substance existing in the proportion of about 4 parts in 100 of milk. In women's milk, the sugar varies from 3 to 6 per cent. In asses' milk it amounts to 4·5, and in mare's milk to 8·7 per cent. It is formed only in the secreting portion, and probably by the cells, of the lacteal gland and does not exist in the blood. If cane sugar or grape sugar be injected into the blood of animals while suckling their young, these forms of sugar do not find their way into the milk, but milk sugar is formed as usual; while, if this latter substance be injected into the blood of an animal, it becomes converted into grape sugar, and is excreted as such in the urine.

The saline matters present in milk, consist of alkaline chlorides and phosphates, with potash and soda in combination with the casein, and phosphates of lime and magnesia, which are dissolved in company with this substance. The proportion of the different constituents of milk varies much under different circumstances and in certain acute diseases.

Fatty matters,—are to be obtained in greater or less proportion from almost all the fluids and solids of the animal body. They exist in three different states in animal bodies—1, *dissolved;* 2, in the form of *minute granules,* as in the chyle; and 3, in quantity, forming *large* or *small globules.* Pl. I, figs. 1 and 2. The production of fatty matter from germinal matter has been already alluded to (p. 103), and minute examination of the elementary parts of the various tissues seems to show that fatty matters may be formed under certain circumstances from any of them. It may be regarded as certain, that a perfectly transparent albuminous material may give rise to the formation of fat; it is well known that fatty acids are found among the products of decomposition of albuminous substances. Not only may germinal matter, which at one time was perfectly clear and transparent, develop oil globules, but fatty matter may be seen to appear in perfectly transparent and structureless germinal matter *after it has* been removed from *the body.* Careful microscopical observation will convince any one that the fatty matter of ordinary adipose tissue results from changes occurring in its germinal matter. Pl. III, fig. 33*a*, *b*, *c*. While, when the fat already formed is to be re-absorbed, it is probable that it is again taken up by the germinal matter, and its elements transferred to the germinal matter of the blood. In the case of adipose tissue which undergoes absorption rapidly, as the fat bodies of the abdominal cavity of the frog and newt, the masses of germinal matter of the fat vesicles and of the capillaries are large, and those of the latter numerous.

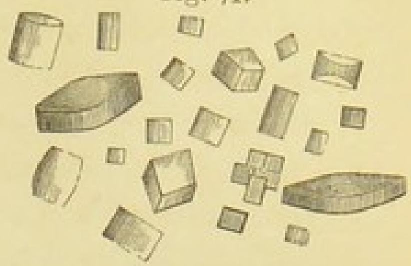
CRYSTALS. UREA. URIC ACID, &c.

Fig. 70.



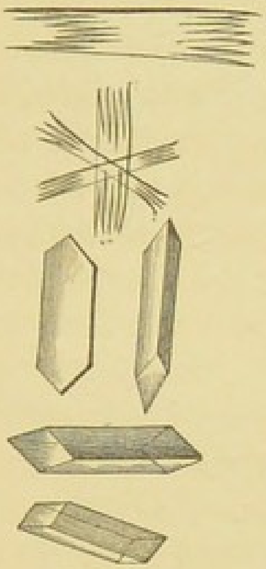
Crystals of urea.

Fig. 71.



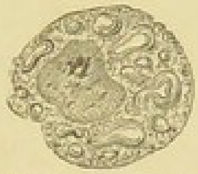
Crystals of uric acid.

Fig. 72.



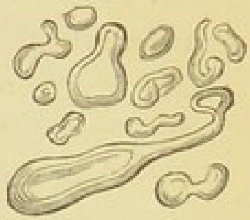
Hippuric acid,

Fig. 73.



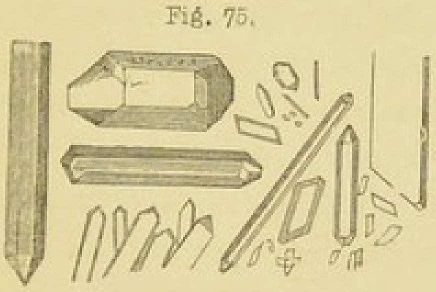
Epithelial cell. Air-cell of lung. Cattle plague. Myelin particles in outer part. × 1800.

Fig. 74.



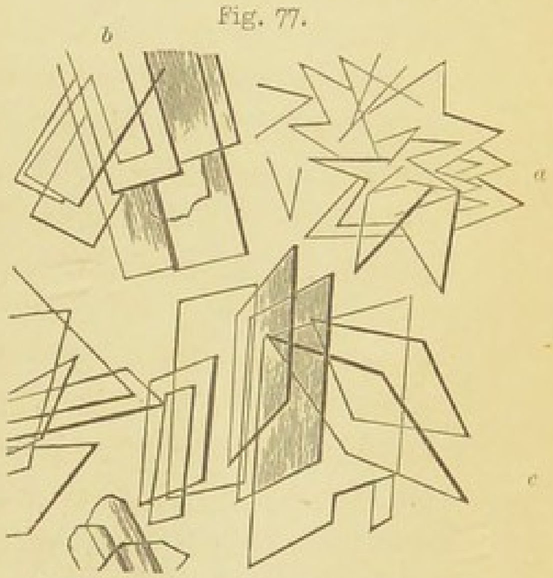
Myelin particles from the external portion of cells in air-cells of the lungs. Cattle Plague. × 2800

Fig. 75.



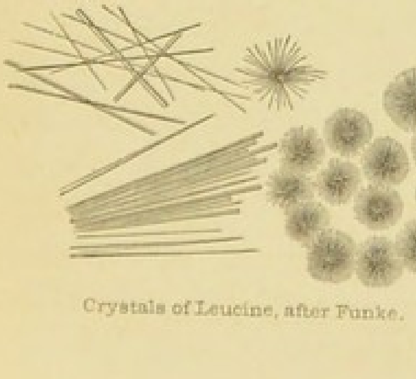
Taurin, after Funke.

Fig. 77.



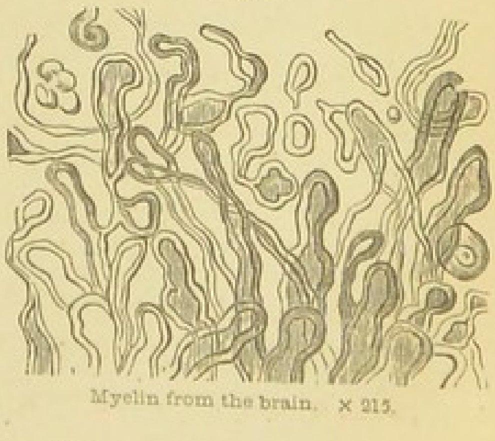
Cholestrine. *a*, from pneumonic lung. *b*, from fluid round an hydatid cyst. *c*, from the brain. × 215.

Fig. 76.



Crystals of Leucine, after Funke.

Fig. 78.



Myelin from the brain. × 215.

$\frac{1}{1000}$ of an Inch ⌐____¬ × 215.

L. S. B.]

[To face p. 146.

The saponifiable fats occurring in the organism of man are *Olein*, *Margarin*, or perhaps more correctly, *Palmitin*, and *Stearin*. Margarin is probably not a simple substance. Pl. VII, fig. 69. Margaric acid consists, according to Heintz, of a mere mixture of stearic and palmitic acids. The fatty acids are *Oleic acid* ($C_{18}H_{34}O_2$), *Stearic acid* ($C_{18}H_{36}O_2$), and *Palmitic acid* ($C_{16}H_{32}O_2$).

Cholesterin ($C_{26}H_{44}O$), Pl. VIII, fig. 77, and *Serolin*, are the only non-saponifiable fats found in the organism. They are very widely distributed and exist in large quantity in connection with all parts of the nervous system. They are also present in the bile; and cholesterin is not unfrequently met with almost pure in certain kinds of gall-stones. These non-saponifiable fats increase as the textures in which they are found advance in age. In young textures the proportion is much smaller than in the adult, and at an early period of development mere traces are to be detected in nerve tissues, which in their fully developed state yield a considerable proportion. Moreover, in many tissues in which at an early period, and even in a fully formed state, no cholesterin can be detected, this substance exists in considerable proportion in old age; and in certain diseases in which morbid changes induce, at a comparatively early period of life, alterations resembling those which occur under ordinary circumstances in advanced age, cholesterin is one of the substances resulting from the altered chemical changes.

Myelin.—It has been recently shown, by some very interesting researches of Beneke's, that the peculiar fatty matter termed myelin may be obtained from all the tissues of the body. In the liver it exists in large quantity; it is found in all parts of the nervous system; and much may be obtained from the yolk of egg. It is yielded even by albuminous matters and fibrin.

Myelin was first described by Virchow, who showed that it was not an ordinary fatty matter, as it swells up and is soluble in water. Its peculiar characters are well known. It is colourless, glistening, semifluid, prone to form drops, and capable of being drawn out into long threads, which curve and twist into the most peculiar forms. The masses often exhibit double contours, and not unfrequently many lines may be discerned equidistant from one another, but varying in their apparent thickness and intensity. Myelin is soluble in hot alcohol, ether, and turpentine. It contains both nitrogen and phosphorus, like Fremy's cerebric and oleophosphoric acids. It yields the reaction characteristic of the biliary acids, with Pettenkofer's test.* Beneke obtained the reaction with the alcoholic extracts of almost all the tissues. Cholesterin is a necessary component of all forms of myelin, and it seems to be rendered soluble by the other constituent of this substance; indeed, Beneke has shown that myelin is in fact a mechanical mixture of *cholesterin* and *cholate* of *lipyl*. It would seem not improbable that, as Beneke suggests, the oxide of lipyl (the hypothetical body which yields glycerine on hydration) separated from the fatty acids by the action of the pancreatic juice, is presented in a nascent state to the biliary acids which then combine with it, forming a cholate of lipyl. This then becoming mechanically mixed with the cholesterin, myelin results. Myelin is represented in plate VIII, figs. 73, 74, and 78.

Muscle.—The germinal matter of both striped and unstriped (voluntary and involuntary) muscle produces contractile material, which consists principally of a substance termed syn-

* The following are Pettenkofer's directions: Pour a portion of the suspected fluid into a test tube and add English sulphuric acid, guttatim, to about $\frac{2}{3}$ the volume of the fluid, whereby the temperature is considerably raised. The addition must be made so gradually that the temperature shall at no time exceed 145° F., as otherwise the choleic acid is too much changed; then add 2—5 drops of ordinary cane sugar solution containing 1 part sugar to 4—5 parts of water, and shake the whole. If choleic acid be present, a more or less deep violet red colour will be produced according to the amount of bile in solution.

Neukomm (ueber die Nachweisung der Gallensäuren, &c., 1860,) proposes the following modification: "A single drop of a $\frac{1}{20}$ per cent. solution of choleic or glycocholic acid will yield a splendid purple violet colour if it is brought in contact with a drop of dilute sulphuric acid (4 water, 1 sulphuric acid) and a trace of sugar solution in a porcelain cup, and then gently warmed over a spirit lamp; as 1 cubic centimetre equals about 8 drops, it is thus possible to demonstrate $\frac{6}{100}$ milligr. of biliary acid with complete accuracy." As a further test he suggests "the biliary acid or salt is to be sprinkled with a small quantity of concentrated sulphuric acid moderately warmed and then water added. The resinous flocculi that subside are to be separated from the acid, washed with water, but not so as to remove all the sulphuric acid, and then again gently heated in a porcelain cup till coloration ensues. If the residue be taken up in a small quantity of alcohol, and the green solution be evaporated, the interior of the cup will be coated with a deep indigo blue film, even when but little acid has been used. If the biliary acids have been impure, or the sulphuric acid or the temperature react too long, the pigment film will be green." See the abstract of Beneke's Memoir "On the Occurrence, Diffusion, and Action of the constituents of the Bile in the Animal and Vegetable Organism," by Dr. Duffin, Archives of Medicine, vol. iv, p. 192, 1865.

tonin, or muscle fibrin. The contractile material is associated with a small quantity of delicate passive texture, moistened with fluid holding several different substances in solution. Syntonin, from σύντονος, contains in 100 parts, C 54·06, H 7·28, N 16·05, O 21·5, S 1·11. It resembles fibrin in many of its properties, but unlike this substance it is insoluble in a 6 per cent. solution of nitrate of potash. Kühne has obtained syntonin in a fluid state from striped muscle, and considers that this is its condition as long as contractility lasts, but that stiffening of muscle after death, or *rigor mortis*, is due to the coagulation of this substance. It dissolves readily in water containing $\frac{1}{1000}$ of hydrochloric acid. When the acid solution is neutralised the syntonin forms a jelly. Soon after death a free acid is formed in the juice of the muscular tissue, probably from changes in the syntonin. Du Bois Raymond showed that no free acid was to be detected in the muscles in a state of rest. Indeed, as long as the muscle retains the property of contractility it appears not to exhibit an acid reaction, but after it has lost this property, acid is rapidly developed. The amount of acid to be obtained from the juice of muscles after death is remarkable, and Liebig has calculated that the voluntary muscles alone contain more than sufficient to destroy the alkalinity of the blood (Lehmann).

The colour of the muscular tissue of animals with red flesh is an organic colouring matter. It is probably allied to hæmatin, and the intensity of the colour is increased by oxygen.

Among the chemical substances obtained from muscle, and probably resulting from disintegration consequent upon action, are the following: *Kreatine*, *Inosite*, and *Phosphoric*, *Lactic*, *Butyric*, and *Inosic acids.*

Kreatine ($C_4H_9N_3O_2$, H_2O) is a crystallisable substance, existing in the proportion, according to Gregory, of about five grains in one pound of flesh. The muscles of birds, probably from their much greater activity, contain about three times as much kreatine as those of fishes. Kreatinine ($C_4H_7N_3O$) is also found in the juice of muscle.

Inosite ($C_6H_{12}O_6$, $2\,H_2O$), or muscle sugar, is soluble in alcohol, from which it may be obtained in crystals resembling those of gypsum. According to Scherer it is isomeric in its anhydrous state with anhydrous grape sugar. This substance hitherto has only been found in the muscular tissue of the heart in animals (Lehmann). Kidney-beans contain about 0·75 per cent., when unripe.

Inosic acid ($C_{10}H_{14}N_4O_{11}$?) is not crystalline, but forms crystallisable salts with the alkalies. *Phosphoric*, *Lactic*, and *Butyric acids*, obtained from the juice of flesh, have the same characters as those acids obtained from other animal fluids.

The *fatty matters* contain olein, palmitin and stearin, with oleo-phosphoric acid (Valenciennes and Frémy). The *ash of flesh* contains phosphate and sulphate of potash, chloride of potassium, earthy phosphates, and iron.

Nerve.—The nervous tissues consist principally of an albuminous substance combined with peculiar fatty materials, perhaps partially dissolved as soaps. The nerve cells contain more water and albuminous matter, but much less fatty matter, than the nerve fibres in connection with them, and at an early period of development the proportion of fatty matter present in the nervous system is very small. The tubular membrane, or nerve sheath, is composed of a substance nearly allied to elastic tissue in composition. It appears probable that the albumino-fatty material existing in such large proportion in the medullary sheath, or white substance of Schwann, accumulates as the nerve fibres advance towards their fully developed condition. This fatty substance seems to form a protective covering to the axis cylinder within, and probably acts as an insulator, by which currents passing along neighbouring axis cylinders are prevented from acting and reacting upon one another by induction. The fact that this fatty matter of the white substance is neither formed nor removed under the same circumstances as the fats of adipose tissue, would seem to show that its relation to the ordinary changes occurring in the body is of a very different kind from that of the ordinary fats. The axis cylinder of the nerve, which, like other textures, is formed from germinal matter, consists of a substance allied in its chemical properties to yellow elastic tissue. It seems a very passive kind of formed material, and at any rate in many instances resists the action of chemical reagents, which completely destroy many other tissues.

The nerve textures contain, besides ordinary albumen, modifications of albuminous matters, which are not precipitated from their solutions by boiling. Von Bibra states that the brain fats consist of cerebric acid, a number of different fatty acids, and cholesterin.

Cerebrin is of neutral reaction, and soluble in boiling alcohol and ether. According to W. Müller it contains in 100 parts C 68·35, H 11·30, N 4·69, O 15·66. It is also found in the yolk of egg and in pus, and probably in the fat of blood serum (Gorup-Besanez).

Oleo-phosphoric acid was discovered by Frémy, and has been found in the brain, spinal cord, kidneys and liver.

Olein, stearin, oleic and stearic acids, in part combined with soda, potash, or lime, and cholesterin, are also present in the nervous tissue. The substance known as *myelin*, which exists in connexion with the nerves in very large quantity, has already been referred to (p. 148).

The chemical substances obtained from white fibrous tissue, cartilage and bone, have been briefly referred to in page 113. Yellow elastic tissue yields a substance which is very insoluble, not altered by prolonged boiling in water, quite insoluble in cold strong acetic acid, and scarcely affected by potash and soda. By digestion in sulphuric acid, *elasticin* yields leucine, and by the action of nitric acid, xanthoproteic acid is formed. Donders has arrived at the conclusion that all fully formed cell membranes are composed of a substance closely allied to yellow elastic tissue, which might be termed animal cellulose. At an early period, however, of the process of cell formation, no such substance exists in any cells, and in some, no cell-wall can be demonstrated at any period.

The epithelial textures, as epithelium, epidermis, various kinds of nail, horn, and hair, wool, whalebone, feathers and tortoise-shell, consist of a substance allied to the protein compounds and containing from 1 to 5 per cent. of sulphur. Associated with the protein compound, at an early period of life, is a certain proportion of amyloid (see page 111). The colouring matter formed in connection with epithelial textures is produced at the same time as the soft, horny material. It is an organic colouring matter, which, like other natural organic colouring matters, results from changes occurring in a perfectly colourless germinal matter.

THE CONVERSION OF PABULUM INTO BLOOD.

The simplest organisms obtain their pabulum from the medium which surrounds them. This seems to be at once absorbed into the organism, taken up by the germinal matter, and converted into the peculiar constituents of the body. But in more complex structures, the pabulum derived from without, is not already adapted for the nutrition of the tissues generally. It is, in the first instance, taken up by certain special masses of germinal matter which grow and multiply at its expense. The substances resulting from the death of these particles, consisting of compounds not to be detected in the original pabulum, are afterwards taken up by the germinal matter of the various tissues. Thus the spongioles of the plant probably absorb the crude materials from the soil in a state of solution. These are converted by the living matter into new substances, which circulate in channels, and are taken up by the germinal matter entering into the formation of the cells of the various tissues of the plant. In like manner, it appears that nutrient materials in their crude state, cannot be directly appropriated by the tissues of man, but must pass through several stages of preparation, undergoing conversion entirely into new substances which did not exist before, and which are peculiar to his organism alone. Even substances closely allied in composition to the tissues to be nourished, and in a state of solution, are not directly appropriated by the tissues; nor, if injected into the blood, would they be rendered by that fluid fit for this purpose. They must be first modified by various preliminary operations, taken up successively by two or three series of cells (masses of germinal matter), of course in a totally altered form, and not until then are compounds produced, which are adapted for the nutrition of the tissues. If either of these successive processes be modified by an altered action of the cells the pabulum is not properly prepared and the textures suffer in nutrition.

The new constituents, whether albuminous, starchy, saccharine, or fatty, which are to be added in the blood, to supply the place of the materials which are being removed from it in the process of nutrition, are probably taken up from the intestinal surface in a soluble form, and appropriated by germinal matter,—

entering into the composition of the chyle corpuscles which grow and multiply in the lacteal vessels, as well as the white blood corpuscles, circulating in the capillaries. At the same time that these masses of germinal matter are increasing in size, and giving rise by division to new masses, a certain proportion of the mass probably becomes resolved into the various soluble substances which enter into the composition of the serous fluid. All the new pabulum must, therefore, pass into the blood in these two forms, as masses of living germinal matter, varying in size, which become the white, and at length the red blood corpuscles, and *serum* which consists of a solution of albumen in water, with the so-called extractive matters, traces of fatty matter, and various kinds of salts.

There is reason to infer that very few alimentary substances can be taken up directly by germinal matter of the intestinal surface. Most of the materials entering into the composition of our food require most important preparation and undergo great modifications before they can be appropriated by any living matter at all. Thus, starch is converted into a form of sugar by the saliva and pancreatic fluids—fatty matter is rendered capable of absorption by the action of the latter secretion and the bile. Insoluble albuminous matters are rendered very soluble by the action of the gastric juice, and most important changes, which are as yet very imperfectly understood, are doubtless effected in the contents of the alimentary canal by these and the other secretions poured into it in such enormous quantity. The substances so prepared are appropriated by the germinal matter, and this appropriation mainly constitutes what has been termed *primary assimilation.*

The germinal matter of the tissues, as has been already explained, undergoes conversion into the tissue itself. This tissue is often greatly modified after its *formation.* It may undergo condensation by the removal of water and the approximation of its particles, or it may be rendered firm and hard by the deposition of calcareous or other salts in its substance or in its interstices, and these may chemically combine with it, or be merely deposited. The organic matrix of bone, teeth, and some other tissues is first formed by germinal matter, and the earthy material to which its physical properties are entirely due, is subsequently deposited. The *formation* of the matrix itself is the result of a *vital* process, but the impregnation of this matter with saline matter is probably due to chemical changes alone.

We may, then, conclude that in the preparation of the substances required for the nutrition of the germinal matter of the different tissues, the lifeless pabulum, after being rendered soluble, is appropriated by the living matter of the cells of the villi. Portions of this germinal matter then die, and the products resulting from their death become taken up partly by the germinal matter in the lacteals, partly by that in the walls of the capillaries, and partly, perhaps, by the white blood corpuscles. These forms of germinal matter probably give rise to white blood corpuscles from which the red blood corpuscles are produced. By the action of oxygen upon these last, probably two series of compounds result; one which is capable of being appropriated by the germinal matter of the capillary walls and that of the tissues, while the other becomes resolved into carbonic acid, urea, and other compounds which are eliminated by particular organs of the body. From the nutrient matters so prepared the germinal matter of the various tissues derives the substances for its nutrition, and these, when taken up, become part of its substance, and take the place of that portion which has recently undergone conversion into tissue.

In the removal of old and worn out tissue and the introduction of its elements into the blood prior to their elimination by the various excreting organs, it is probable that similar operations occur, the old texture being taken up by germinal matter, this undergoing conversion into formed material, which is appropriated by the germinal matter of the vessels and the white blood corpuscles, until at last, by the disintegration of those substances which serve as pabulum to the secreting cells of various glands, imperfectly, or highly oxidised bodies, are prepared, which are at once carried off.

Alteration in composition of Formed Material in Disease.—The integrity of the formed material of many tissues is preserved, and the activity of its function maintained, by the continual passage of fluid through it. The disposition of the nuclei, or masses of living germinal matter in the healthy tissue, is such as to ensure the existence of currents through every part. If from a change in the composition of the fluid itself, or in consequence of an alteration occurring in the masses of germinal matter, the tissue is no longer permeated, or permeated irregularly, by these currents of fluid, most important changes soon result. The products of decay not being carried off as fast as they are formed, and not being converted into readily soluble substances, accumulate, and seriously interfere with the action of the tissue already formed. Such is, in part perhaps, the explanation of the changes which occur in the formed material of various cells and elementary parts, which are said to be affected by degeneration.

The formed material of tissues is also sometimes modified in consequence of being bathed with fluids of composition different to that in the healthy state, and this alteration in composition may be due, in part, to the composition of the pabulum, and partly to the conditions under which its preparation is performed, or as frequently happens, to the circumstance that certain excrementitious compounds, which ought to have been entirely eliminated, remain in the fluid.

The character of the formed material will also be influenced by the rate of its formation, and this will, to some extent, depend upon the amount of pabulum which reaches it, and which, of course, varies much.

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