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NATURAL HISTORY OF ORGANIZED BODIES.

FROM THE COURSE OF LECTURES OF M. MAREY AT THE COLLEGE OF FRANCE.

Translated by C. A. ALEXANDER *for the Smithsonian Institution.*

I.—HISTORICAL EVOLUTION OF THE SCIENCES.

The course of instruction in the College of France is not limited to a simple exposition of the state of science at each epoch, but, as a school of discovery, extends its views to the actual tendencies of the human mind. It aims to signalize the new horizons which are opening for science, and which hold out to us the promise of further acquisitions. In order, however, to judge of the direction to be pursued, it is necessary, from time to time, to cast our glance backward, to consider the space which has been traversed, to recall the windings, the hazards, the difficulties of the route. Such a recurrence to the past is one of the most useful preparations for a new departure, and will enable us to attain our end much more promptly and certainly than it was possible for our predecessors to do. It is by availing ourselves of their experience that the march of improvement has been constantly accelerated, until, in our day, more discoveries are produced in ten years than formerly in an age.

The history of the natural sciences has, not long since, been retraced in this chair by the professor whom I have the honor of replacing. M. Flourens here passed in review the life and labors of the learned naturalists of the XVIth, XVIIth, XVIIIth, and XIXth centuries, having devoted to this subject several years of his instruction. I shall not undertake to unfold anew this historic tablet, however instructive may be its lessons. Permit me merely to retrace, with a rapid glance, the principal phases of the evolution of science. We shall thus see more clearly the tendency of scientific inquiry and the direction in which we should look for its further advancement.

The natural history of organized beings comprises zoology and botany. If we open the most ancient treatises on these subjects, we perceive that the engrossing occupation was to make an enumeration of the objects of nature. Science might be said to have been then engaged in taking possession of its domain; in making the inventory of its treasures. Each object received a name which might distinguish it, by recalling, as far as possible, its exterior characters. The "embarrassment of riches" soon gave rise to the necessity of a methodical arrangement. The first step was to separate animals from plants, and thus were formed the two great *kingdoms* of the natural world. Afterwards, in each kingdom, were created new divisions; first, *branches*, each of which was distributed into *classes*, and these again, by successive divisions, into *orders*, *families*, *tribes*, *genera*, and *species*. To be useful, these classifications should combine in the same group the beings analogous to one another, so that, by knowing to what family an animal or a plant belongs, a preliminary idea may be formed of its principal characters. It is for the attainment of this end that classifications have been so often modified, tending constantly to become more *natural*—that is to say, to

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establish the affinity or the separation of beings on the most important characters.

Anatomy, in the mean time, came in aid and revealed the interior structure of animals and plants. It showed that certain organs seem, from their constant occurrence in the series of beings, to have on that account a predominant importance, while others which are frequently modified, and sometimes wholly wanting, appear to be but accessories, and of a secondary utility. Hence it that the presence of a vertebral canal containing the spinal marrow has furnished the distinctive character of a whole branch of the animal kingdom, that, namely, of the *vertebrata*. In this second phase of the evolution of the natural sciences man no longer confined himself to the rôle of a spectator of nature. He scrutinized and compared; he essayed to form an idea of the general plan of the organization of beings. The dry nomenclature had thus given place to a methodical classification.

When Cuvier appeared, comparative anatomy was doubtless already founded. Antiquity itself had learned it from Aristotle; modern times had witnessed its advancement by Cl. Perrault and Vicq d'Azyr; but much remained to be done in order to complete the classifying of animals according to their anatomical constitution. The branch of the *invertebrata* comprised a multitude of incongruous orders, among which new divisions were of course necessary. The invertebrates were divided by Cuvier into three new branches, the *Mollusks*, the *Articulata*, and the *Zoophytes*. This natural classification, based on comparative anatomy, borrowed the distinctive characters from the arrangement of the most important organs in the animal: from that of the nervous system.

It was now that, combining in a comprehensive synthesis particular facts in order to derive from them general ideas, Cuvier was enabled to throw light on some of the laws which govern the organized world. Such, for example, is the law of *subordination of organs*, which teaches us that such or such an organ when it is present in an animal, implies the presence of other organs which are associated with it after a necessary manner. Natural history had thus become a veritable science, agreeably to the definition of Bacon: "Sciences are only facts generalized." Now, generalization had conducted Cuvier to the expression of laws. These, in turn, led him to a remarkable consequence—to the creation of paleontology. It was in conformity with his law of the correlation of forms that he reconstructed the entire skeleton of a fossil animal when possessed of but a few of its remains, and restored for science generations of beings which had long disappeared from the surface of the globe.

By the side of Cuvier another grand historical figure presents itself in Geoffroy Saint Hilaire, his cotemporary and friend, more recently his scientific adversary. Prepossessed by his labors in the natural classification of beings, Cuvier had bent his whole force to the discovery of the differences which separated them. The genius of Geoffroy disposed him rather to comparison; resemblances attracted him more strongly than differences, and enabled him to detect, in the zoological series, the unity of plan amidst the diversity of details. History will preserve the remembrance of the memorable conflicts of these illustrious adversaries, conflicts which powerfully developed two great conceptions in which, at last, there is nothing irreconcilable. From this epoch dates the rise of *anatomical philosophy*.

While zoology was establishing itself on foundations really scientific, botany had been pursuing a parallel career. As early as the XVIIth century, Pierre Magnol attempted to substitute for the ancient nomenclatures a natural classification. He sought, in 1689, to distinguish plants according to their principal organs—the roots, the stems, the flowers, the seeds. But vegetable anatomy was too little advanced to permit a classification based on the constitution of the most important organs of plants. Botany had still to pass through the artificial classifications of Tournefort and Linnæus before arriving at the more perfec form which it received from the Jussieus. It was Antoine Laurent de Jussieu, in effect, who first clearly apprehended and distinctly defined the principle of subordination of characters. He based his classification of plants on the anatomy of the most important apparatus in the vegetable kingdom—the apparatus of reproduction. Hence the number of the lobes of the vegetable embryo, that is to say, of the *cotyledons*, the insertion of the *stamens* in the flower, became the characters on which is still based the classification of plants.

Since Cuvier and the Jussieus, zoological and botanical classifications have continued to improve; but naturalists have, on the whole, respected the plan which has been handed down to them. Rectifications have been made, and certain beings have been transferred from one family to another, with which they are more closely allied by essential characters; at other times it has been found necessary to enlarge the zoological and botanical outline for the admission of newly discovered individuals, but these partial modifications constitute but a development of the fundamental idea which has remained unchanged: the necessity, namely, of keeping constantly in view the classification of beings according to the most important characters of their organization.

Anatomy, which had produced these reforms, has itself advanced to new conquests. Up to our present century it had remained purely descriptive—that is to say, it was limited to indicating the form of the organs considered each in its own mass. Thus it determined the form of the bones, of the muscles, of the vessels, of the nerves, &c., whether in man or a lower species, or else it compared the arrangement of these organs in a succession of individuals of the zoological series. It was Bichat who impressed on anatomy a new character. He created *general anatomy*, in the sense that he studied the *tissues* which enter into the composition of the organism. The extended employment of the microscope gave a vigorous impulsion to these studies. This instrument conferred the power of discerning distinct and well-defined elements in those tissues which had till then appeared homogeneous. The globules of the blood, the animalcules of the sperm, the cellules of the epithelium, the tubes of the nerves, the acini of the glands, have been all revealed to us by the microscope. The knowledge pertaining to these subjects constitutes *histology*, henceforth inseparable from general anatomy. Transferred to the domain of comparative anatomy, histology acquires a new interest; it shows us that certain elements of the tissues undergo, like the organs themselves, very decided modifications when we follow them up in animals or plants of different families.

The microscope further conducts us to a discovery of great importance, that of the development of the germs in animals and plants. Animal *embryogeny* constitutes a new branch of science, with which are connected illustrious names, almost all being those of cotemporaries: Von Baer, Graaf, Purkinje, Coste. Nor is vegetable embryogeny less curious; the intimate phenomena of reproduction in the two kingdoms resemble one another in a striking manner. The surprised observer hesitates in pronouncing whether he has not under his eyes an animal organism, when he sees the antherozoid of certain vegetables agitated as with spontaneous motion, seeking with persistence the orifice through which it is destined to pass, or disengaging itself with apparent effort from the impediments which obstruct it. The two kingdoms thus appear to be confounded in the elements of their origin, while they deviate so widely one from the other when we contemplate them only as complete beings.

This collective view of organized nature, important as it is, still exhibits it to us only under one of its aspects. It makes us acquainted with existencies as regards their form and structure, abstraction being made of what is most essential in them; namely, life. We seem to have been traversing an immense gallery of mechanisms of greatly varied combinations, some in appearance very simple, others of an extreme complication; these of enormous mass, those of an infinite delicacy. But everything here was mysterious in its immobility; the imagination is lost in conjectures on the function proper to each. It is now necessary to see these things in action, each executing the work for which it is adapted. The catalogue has been drawn up with sufficient exactness for present needs. To-day the current no longer tends to classification, it is directed to the study of the functions of life; that is to say, the play of the organs which anatomy has disclosed to us. This study of the phenomena which take place in living beings is ordinarily called *physiology*, or, more correctly, *biology*.

All organized beings live; animals or plants all accomplish a series of acts from their origin to their dissolution; but life is interpreted in them by manifestations as varied as their organization itself.

It may be said that biology is the offspring of anatomy, for it was from the form of the organs that man was first inspired with the comprehension of the function of each of them. This influence of anatomy gave to biology in the first instance a deductive character from which, even in our day, it finds difficulty in disengaging itself. It is true that when we see the arrangement of the articulating surfaces which unite the different parts of the skeleton, we readily comprehend the function of those organs; we see how each bone moves upon its contiguous bone, and this in itself explains the varied positions which certain portions of the body may assume. But the action of the muscles was much more difficult to be comprehended. Aristotle himself knew it not. The representative of ancient science, the founder of comparative anatomy, must have constantly observed the extreme variety of muscular development in different species of animals, and yet this anatomical principle conveyed to him no idea of the function of the muscle. It was reserved for Erasistratus, grandson of Aristotle, to discover first the elementary fact, that a muscle contracts in order to produce motion. The rôle of the other organs was still more obscure; but in regard to these, not satisfied with ignorance, inquirers accumulated in the name of science the most foolish suppositions. The viscera, in particular, were endowed with singular functions; each of them lodged one of the properties of the soul. In the head resided reason, in the heart courage and choler, in the liver concupiscence, and so with different organs. Such ideas, of course, could never have been inspired by anatomy, and they had, in effect, another source. Philosophers have by no means been insensible to the attractions of the mysterious and incomprehensible; psychology is more ancient than the sciences, and Aristotle had received from Plato a whole system ready made. It was thought indispensably necessary to lodge three souls in the human body, and each of these had several properties which could not be left without a habitat. Thus it is that mystical tradition has imposed even on those who have conscientiously sought to place themselves in direct relations with nature.

I would have willingly passed in silence these singular tendencies of the human mind to depart from the domain of real facts and to yield to the caprices of imagination; but the question relates not to a passing error to which time has already rendered justice. The ideas of Plato have a hundred times changed their form, but they have been transmitted from age to age; they prevail at this day under the form of *vitalism;* that is to say, the doctrine which pretends to have explained every phenomenon of life when it has pronounced such or such a phenomenon to be the effect of a particular *property* of the living being. This doctrine I shall not stop to combat; quite enough has been vainly said in attempting to confute those who do not choose to be convinced. It is safe to assume, however, that the vitalistic school is at present condemned for its sterility; that it loses ground every day, while the number of those is daily increasing who demand from the rigorous observation of facts and from experiment the solution of the problems of biology.

It would be more interesting to follow through its successive stages the development of the school of experimenters. To find its origin, we must go back to remote periods. Surprising it is, that the two opposite tendencies which have so long contended for mastery come to us from the same source. Aristotle, who encumbered science with entities uselessly imagined, has bequeathed to us many exact ideas on the nature, whether voluntary or involuntary, of movement, on the development of the fœtus, &c. Erasistratus, who represented vital spirits as circulating in the arteries, recognized the true nature of the action of the muscles. Galen, so much prepossessed with humorism, with the four elements, with the forces which preside over the functions, was not the less a great experimentalist. He alone made more discoveries than all his predecessors; he showed that it is with blood that the arteries and the heart are filled; he pointed out the influence of the nerves on the movement of the muscles; he recognized the paralysis produced by a lesion of the spinal marrow. He realized, in fine, one of the most striking experiments of physiology, by showing that the section of the recurrent nerves paralyzes the larynx and extinguishes the voice.

Soon afterwards all progress is arrested before the invasion of the barbarians, and science remains torpid for 14 centuries. On its revival, the two parties reappear more opposed than ever; with an antagonism more precisely defined, and each boasting its proper representatives. While Stahl revives the *immaterial principles* of Plato, Hoffman vindicates the supremacy of physical laws in the phenomena of life. Establishing themselves on the grand discovery of Harvey, the organicians proceed to demonstrate the potency of the experimental method. Finally, Haller appears, and, reassembling the materials of physiology, makes of it a well-defined science, and impels it onward in the path of experiment.

Since this epoch discoveries have rapidly succeeded one another; with each of them the name of some experimentalist is associated: J. Hunter, Bichat, Magendie, Ch. Bell, J. Müller, savants whose work has been so ably continued by our cotemporaries. Animal physiology has reached a very advanced stage, and one of great interest. Having emerged from that unsatisfactory phase in which the sciences, while in a state of formation, are engaged in accumulating isolated facts, and too often in seeking to connect those facts by premature hypothesis, we are able not only to realize the principal conditions under which certain functions are performed, but to obtain a view of their relations and reciprocal influences. In the collective functions of the organism, we discover, in effect, a subordination such as Cuvier has pointed out in the organs themselves. The nervous system, the most constant apparatus in animals, presides over sensibility and movement, the two prominent functions in the animal economy. But it governs also the functions of organic life—respiration and circulation, which in turn react upon the nervous system, so that the knowledge of one function would not be complete if we did not know at the same time its influence upon the others.

Vegetable physiology is unfortunately much less advanced; it can scarcely be said to consist of more than certain rather vague ideas. Not only is it true that we do not at present understand the general harmony of the functions of plants; we have but a very incomplete knowledge of each of those functions in itself. The *phytologists* have attempted to model themselves upon the procedure of the zoologists, but without deriving much benefit from the imitation.

The functions of the vegetable have been classed nearly in conformity with the functions of the animal, but this assimilation may itself have operated as a shackle on the progress of the science. All that has been said of the circulation in plants was plainly suggested by ideas borrowed from the circulation in animals. The double current of liquid supposed to ascend by the tubes of the lignum and to descend again by those of the latex, would seem, according to modern authors, but a false analogy established between the physiology of animals and that of plants. Vegetable respiration is however better known. The experiments of Bonnet, Priestley, Senebier, and Th. de Saussure have established the important fact, that the green parts of vegetables exhale oxygen under the influence of solar radiation, while, in darkness, these same parts disengage carbonic acid.

As to other phenomena of vegetable physiology, they remain to a great extent unexplained. Inquiry is, in a considerable measure, still confined to the verification of facts, of which the interpretation has not yet been furnished. Such for instance is the property possessed by the root and the stalk of vegetables, the one of directing itself in accordance with the terrestrial attraction, the other of rearing itself in the inverse direction of that attraction. Ingenious experiments were instituted by J. Hunter and Knight with a view to arrive at the solution of this problem, but the results obtained by these experimentalists have proved insufficient to explain the facts. The action also which the light exerts upon plants in curving their branches, the tendency which certain plants manifest to twine themselves always in the same direction, to the right in the case of some, to the left in the case of others, are facts ascertained but not explained. In a word, vegetable physiology is a science which is in process of formation, but is far from having attained the degree of development presented at this day by animal physiology.

In this rapid review, I have attempted to indicate the principal phases of the evolution of the natural sciences; their succession must doubtless take place in an order which may be pronounced necessary, each phase preparing the way for another, and rendering possible and productive researches which would previously have been premature. At the same time, the facts would certainly be strained did we pretend to exhibit a succession of well-defined epochs, each exclusively devoted to the elaboration of one of the links of this long chain. It is not the less true however, that the human mind, in the evolution of the natural sciences, has pursued in general the course above indicated, a course which we can trace in the advancement of all the sciences which depend upon observation and experiment.

Auguste Comte, a philosopher whose doctrines have given rise, of late years, to so much discussion, has established a fact on which almost all parties are in accord. It is this: that the sciences which may be considered as having reached an advanced stage of maturity have passed through three successive phases; one *theological*, another *metaphysical*, the last *positive*. By this it is meant that man, in presence of the phenomena of nature, has been led in the first instance to suppose the influence of some divinity as the permanent cause of what he witnessed; that still later certain hidden forces or properties were imagined as governing matter in all its manifestations of activity; that subsequently, having become wise enough to resist the allurements of imagination, the authority of the ancients and the influence of routine, inquirers have taken the part of accepting nothing as true but what appeared susceptible of being demonstrated; of renouncing the search for first causes, and of directing their attention exclusively to the verification of facts and the deduction of laws under the control of experience.

I advance no pretensions to modify this formula so ingeniously propounded by Auguste Comte, still less would I venture to substitute another. But placing myself at the more restricted point of view of the sciences which have for their object the facts of nature, I think it competent still further to subdivide and specify the phases of their evolution, and to say that in all these sciences we may distinguish a certain number of periods, each corresponding to a certain stage in their development. We should thus have, first the period of nomenclature; next that of the natural classification of beings; still later the analytic study of natural characters would be developed, to be followed by the study of phenomena, leading finally to the establishment of general laws.

To show that the human mind has always proceeded by these steps, I shall not multiply examples, but will take the most general of all. I borrow it from the science which, in virtue of its comprehensiveness, takes precedence of all others, the science of the universe or cosmos, of the great *whole*.

We see the immensity of space peopled with objects each of which is an orb or heavenly body, and the first impulse of mankind was the desire to enumerate them. Artificial groups or constellations were first established, constituting a true nomenclature of the stars. Afterwards the effort was to classify them, and the stars which appear fixed were distinguished from those which exhibit movement; among these last again, the planets, the comets, and the asteroids were to be distinguished before the immutable laws of the planetary movements could be discovered. In this classification the terrestrial globe became an individual pertaining to the *genus* planet and a member of that class called the *solar system*. It will be seen further, that the earth, considered individually, was submitted to the same analysis as the individuals which pertain to the organized world. Thus the earth has its *descriptive anatomy;* it is the physical geography which teaches us the general arrangement of the planet, its double polar oblateness, the configuration of the land and seas, the altitude of the ground and depth of the waters in different places, the course of the rivers which traverse the terrestrial surface like the veins in our organs. The earth has also its *anatomy of structure*. This is represented by geology, properly so called, which, according to the composition or arrangement of the formations, refers them to different types, as is done with regard to the living tissues. The geologist, like the anatomist, does not confine himself to the exterior appearance, but subjects each part to chemical analysis, explores the densities and cohesions, observes with the microscope the details of structure, &c. *Embryogeny* itself finds its analogue in the science which is occupied with the evolution of our globe and the genesis of the different terrestrial strata. On one part and the other, we have the same method, the same induction from what is passing under our eyes to what must have passed at an epoch inaccessible to our observation.

Thus we observe, in regard to the material study of our planet, a striking similitude between the methods employed and those to which naturalists have recourse for the study of organized beings. Without forcing the comparison, it may be carried even further. The earth has functions; there are phenomena which take place in it that bear an analogy to actual life. As the moon has been called the *cadaver of a planet*, it may be said that the earth is a living planet. Under this point of view, we shall see that it has also its *physiology*.

It is *meteorology* which reveals to us the functions of our planet. In the ingenious treatise lately published on this subject by M. Marié—Davy, there may be found a particularly vivid picture of that perpetual circulation of the waters which, quitting the sea under the form of vapor, rise into the atmosphere only to be condensed in clouds, and, falling again upon the earth, are borne by the brooks and rivers to the sea from which they were separated. The atmosphere is the seat of an analogous aerial circulation; the equatorial zone is the common goal of the lower trade-winds, as it is the point of departure of the winds of an opposite direction, the upper trade-winds, which flow thence to the polar regions, whence they will again return towards the equator. The distribution of terrestrial heat presents a perfect resemblance to that of animal heat; the same tendency on either part to the refrigeration of the points remote from the central region; the same transference of caloric by the circulation of heated liquids. Could we enter here upon the study of the distribution of the animal temperature, it would be seen that the analogies are still more striking than the present occasion permits us to demonstrate.

If I have dwelt at some length on this retrospective survey of the progress of the sciences, it is because I have thought that much instruction might be found therein for those who are seeking to advance them; and should I have succeeded in showing that the methods followed are always nearly the same, the history of the progress achieved may enlighten us as to the value of each of those methods. Thus, as I said in commencing, the experience acquired by our predecessors will serve to conduct us in the new route which we shall have to traverse. That route is plainly traced; it is easy to see that the tendency is no longer to classifications, which will, of themselves, become perfect under the influence of ulterior discoveries respecting the functions of animals and plants. Nor yet is the actual tendency, as it seems, to descriptive studies. At the point which anatomy has reached, what is rather to be apprehended is confusion, through the multiplicity of minute details. Our science is already encumbered with descriptions which the life of one man would not suffice to master.

To this it may be answered that it is precisely to remedy this obstruction that recourse is had to a division of labor; that, by virtue of this expedient, we may look with confidence to the indefinite increase of human science, each ramification of which will be developed by the assiduity of inquirers devoted exclusively to some speciality. But can it be necessary to show how much such a state of things is to be deprecated? The more thoroughly any point of science is investigated the more numerous and intimate are found to be its connections with all others. Need we recall the services which zoology and botany have rendered to geology, the utility of chemistry and physics to those who cultivate anatomy or physiology? So much for the *solidarity*, the inter-dependence of the sciences, in view of the means of study and the furtherance of one through the other; a like solidarity is found in regard to the laws which govern them.

Every law, when once known, throws light on a vast field, for it controls a great number of phenomena. The law of *proportionality to the squares* applies not only to the gravitation of the heavenly bodies, but to light, electricity, magnetic attraction, accelerated movement, &c. Chemical laws enable us to foresee a great number of phenomena which no one has yet attempted to realize.

If all the sciences allowed of our evolving, from this time forward, precise laws, it would be easy for us to combine in a grand assemblage all dispersed facts; a single mind might embrace in their generality all human cognitions; what the sages of antiquity could not realize by reason of the narrow extent of their knowledge, would be accomplished to-day on a field much more vast, thanks to the excellence and simplicity of method. This ideal, which however we shall never attain, should at least be the star which serves us for a guide; it is to the research of the laws of life that it behooves us henceforth to direct our earnest attention.

II.—OFFICE OF ANALYSIS IN THE SCIENCES.—POWER WHICH IT DERIVES FROM THE EMPLOYMENT OF GREATLY IMPROVED INSTRUMENTS.

I have endeavored to show that the human mind proceeds in all the sciences after nearly the same manner, so that, as regards each of them, progress is represented by an evolution strikingly similar. I hope to prove also that the sciences, in the process of their development, tend to an approximation towards one another, resulting in their reciprocal advancement, since each of them sheds light upon the other. Zoology and botany, it is obvious, have furnished to geology an inestimable element of progress, by disclosing one of the most indispensable characters for recognizing the relative age of different formations. This character is derived from the determination of fossil species, some of which characterize, so to speak, certain geological epochs.

Physics and chemistry have so many points of contact that it is almost superfluous to mention them; the time may be foreseen when these two sciences can be no longer separated, chemistry constituting, in effect, only molecular physics. But physics and chemistry exert on the other hand an ever-increasing influence on the natural sciences. Neither animal nor vegetable physiology can dispense with their aid; it may even be said that all that we know accurately in these two sciences is what is explained by means of the laws of physics and chemistry. Examples would present themselves in crowds were it requisite to furnish them. Thus the mechanical phenomena of respiration were unintelligible before atmospheric pressure had been discovered. Anatomists and physiologists were surprised to see the air rush into the pleura when the diaphragm or walls of the breast of an animal, alive or dead, were pierced; there is now nothing obscure in the nature of this effect. The same cause explains also many phenomena relating to the exchange incessantly produced between the gases of the blood and the atmospheric air, the action of respiration on the course of the blood, &c. Mechanics elucidates the muscular phenomena, and in general all the movements produced by animals. The circulation of the blood borrows from hydrodynamics the explanation of everything relating to the movement of the sanguineous fluid. Without chemistry, what ideas could we possess respecting the digestive functions, the offices of respiration, the function of the glands? Optics and acoustics are treated, in the works on physiology, in the same manner as in those on physics. Finally, the laws of electricity acquire every day more importance in the interpretation of the nervous phenomena.

All this proves the reciprocal dependence (*solidarity*) of the sciences; it shows that it is necessary to separate them as little as possible, that the tendency should be to their simplification, to the reduction into general laws in order to render them easily accessible to every one.

A very important point, for it is decisive of success or failure in scientific researches, is the choice of a good method. On this subject it is necessary to be guarded against a very common error. We become habituated generally by the usual processes of demonstration to pass from the simple to the composite, to start from a well established principle in order to arrive, from one deduction to another, at the demonstration of more complex propositions. It is in this way that the theorems of geometry are successfully demonstrated; but is it by this method that a science is established? Far otherwise; nor do those who make discoveries in the natural sciences proceed in this manner. They observe a great number of facts, compare them, place them side by side, seek the conditions which modify each phenomenon, and succeed only in the last place in finding a principle or a law which may guide the understanding in the midst of an embarrassing complexity.

Medicine, a science which touches us so nearly, since it deals with the troubles which occur in the functions of life, was long misled by that false method which generates *systems*. Starting from a principle supposed to be true, it proceeded with the most irreproachable logic to heap deductions upon deductions, till the moment when error became so obvious that the whole fabric collapsed at once, and the work was to be commenced anew. It was a pure metaphor that wrought the evil: "It was proposed to *construct* the science, and a corner-stone was to be sought to support the edifice." But by what right, among so many materials, was one stone to be taken for this purpose sooner than another? By what token was it to be recognized as the real base of the structure? Certainly, by none. If there must be a metaphor, I would prefer to compare the study of the natural sciences to the labor of the archeologists in deciphering inscriptions traced in an unknown language. They try, turn by turn, several senses for each sign; they seek assistance at the same time from the conditions under which each inscription has been found, and from the analogy it presents with inscriptions already known, and they arrive only in the last place at a knowledge of the principles by which they teach others to decipher the strange language.

In every science progress is only to be obtained by the employment of certain processes which act like powerful levers in the service of the human mind: *analysis*, which serves for research, and *synthesis*, which is employed to verify the results of analysis, or to set in a more simple light a truth already discovered. But everything is susceptible of improvement, even the means which are at our disposal for the realization of further progress. I propose, therefore, summarily to state the present resources of analysis and synthesis, instruments which are so constantly to be handled by the teachers as well as cultivators of science.

Analysis consists in reducing to its most simple elements a phenomenon too complex to be otherwise comprehended. If the multiplicity of simultaneous incidents perplexes our understanding, we endeavor to abstract one of these incidents, observe it as exactly as possible, then, passing to another, study it in the same manner. In thus overcoming successively the difficulties which present themselves, and which in combination exceed our efforts at comprehension, consists the function of analysis, and it is this which constitutes the source of its power.

But, in this conflict of details, difficulties of another order still present themselves. These arise from the insufficiency of our senses, baffled alike by objects too small or too large, too near or too remote, as well as by movements too slow or too rapid. Man has found the means of creating for himself more powerful senses in order to detect the truth which evades him. He has rendered his vision more penetrating by help of the telescope which sounds the immensity of space, and of the microscope which explores the infinitely little. Balance and compass in hand, he estimates with precision the weight and volume of bodies, which his touch indicated to him in only a rough manner. The more advanced the state of any science, the more it has need of instruments, for it has passed beyond the horizon embraced by the unassisted view of our predecessors. It has transcended the limits of the circle in which the human intellect was so long exercised, while exhausting itself in contemplating the surface of the same objects and consuming in sterile dialectics the power which to-day it employs in rigorous observation.

Instruments are the indispensable intermediaries between mind and matter; the physicist, the chemist, the astronomer can effect but little without their succor; the anatomist, the physiologist, the physician have recourse to them as indispensable to the progress of medical science. The invention of cadaveric injections and that of the microscope have inaugurated a new era for anatomy, which owes to the use of these expedients the comparative perfection which it has attained in our day. The same is the case with physiology; it is to the manometer, the thermometer, to electric machines of various construction, apparatus for registering, &c., that the physiologist is indebted for the power of substituting experimentation, in its proper sense, for observation, always slower and often powerless to discover the laws which govern life.

To show the progress already realized in the method of analysis, and to mark the multiplicity of resources of which it may avail itself, we take a few examples:

In chemistry, when the object is to recognize the nature of certain bodies which enter into a combination or mixture, we proceed, by *qualitative* analysis, to disengage each of these bodies and to isolate them successively. Then, by *quantitative* analysis, we determine in what quantity each substance existed in the mixture. In making this discrimination, the balance is at our service. This, we see, is an apparatus borrowed from physics which enables the chemist to arrive at exact determinations. But the helpful intervention of physics stops not there. In virtue of that solidarity of the sciences, of which I have before spoken, the chemist resorts to the physicist for the aid of still other instruments. If, for instance, we have the solution of a known salt whose degree of concentration we would ascertain, there is no need to destroy the mixture and extract the salt, in order afterwards to weigh it; we seek, by means of the *areometer*, the density of the mixture, and, knowing the density proper to the salt, it is easy to calculate the quantity contained in the solution. If in another solution substances exist which are crystallizable together with others which are not so, the use of the *dialyser* enables us to effect their separation. This again is an apparatus of physics placed at the service of chemistry. The *polarimeter* is also of great utility. It enables us to appreciate in an instant the existence of certain substances contained in a solution, and to determine their proportion with rigorous exactness. Lastly, the *spectroscope* contributes a new power to chemistry: it has extended the domain of chemical analysis beyond the world we inhabit, by enabling us, from the optical properties of the light of the stars, to determine their chemical composition, and to affirm, for example, that in the sun there must be iron, nitrogen, cobalt, &c.; in the star Aldebaran, sodium, magnesium, calcium, iron, mercury, hydrogen, &c. Thus science, by means of analysis, has realized wonders which the most daring imagination would have never ventured to conceive.

In physics, the functions of analysis are not less extensive. It is by employing different kinds of apparatus, each of which reveals certain properties of electricity, light, heat, &c., that we have succeeded in forming an idea of the manner in which these agents act in nature. The physicist renounces the idea of ascertaining their essence as we renounce a knowledge of the essence of life, and is content to describe each agent according to its manifestations. Electricity, which reveals itself to us in great meteorological effects, in the production of lightning and boreal auroras, for instance, everywhere else evades our perception, and yet it is demonstrable that everywhere in nature electricity exists. The *electroscope* discloses it in the atmosphere which surrounds us. The *galvanometer* shows us that electric currents are formed, so to say, wherever an act of a physical nature is accomplished: water which evaporates, a plant which vegetates, an animal which lives, give rise to electric phenomena which our senses cannot directly perceive, but which we render perceptible by means of instruments of analysis. Such expressions as *electric currents*, *electro-motive forces*, *intensity* and *tension* of electricity, are artifices of language which enable us to conceive more readily the conditions under which the phenomena called electrical are produced and modified. But in proportion as known facts become multiplied by analytic researches, science is seen to disengage itself from the ambiguities of language and to sacrifice the expressions which are no longer useful to it. It is thus that the hypothesis of two electric fluids, the one *positive*, the other *negative*, is tending at present to disappear.

What we know regarding *light* has been acquired by the same method: we have learned to decompose it by the *prism* into its different elements; some colored in different manners, others invisible, but endued with heat or chemical properties. The theory of light furnishes us with a good example of the disappearance of an hypothesis in the presence of contradictory facts. We know that the hypothesis of radiation has vanished before the phenomenon of interferences, and has given place to the theory of undulations, which alone explains all the phenomena actually known.

Thus physical agents become characterized every day in a more complete manner, and are more and more accurately determined by the characters which their analysis discloses. I shall not attempt to follow the progress realized by the analytic method in the knowledge of magnetism, heat, mechanical force, &c. I confine myself to the statement already made that the solidarity of the sciences constantly augments in proportion to the progress realized. For the different branches of physics the fusion is evidently taking place in our own day. It is interpreted to us by the profound conception of the *equivalence of forces* and of the transformation of mechanical labor into heat or into electricity.

The naturalist who is not content with observing the forms, however varied, of organization in animals and plants, must proceed like the physicist and chemist, if he desires to discover the conditions of life. His first means for the analysis of phenomena is *vivisection*. It is through this that he becomes a witness of the accomplishment of functions; all that is visible and palpable in the play of the organs is revealed to him by this *anatomia animata*, as it was called by Haller. On this head I could say nothing which will not be found more competently stated in the valuable treatise of M. Cl. Bernard *(Introduction à la Médicine expérimentale.)* In this work may be seen everything relative to physiological experiment, while excellent advice is given regarding the disposition of mind which it is necessary to bring to the study of biology.

But, of itself alone, vivisection is insufficient for this pursuit; it can do no more, so to say, than lay bare the phenomenon simultaneously with the organ which is the seat of it; it reveals to our senses only what they are capable of perceiving. Now, we have seen that in physics our senses teach us very little, and that it is necessary, at every step, to have recourse to apparatus for analyzing the more delicate phenomena. The same is the case in biology. The electrical phenomena which take place in animals are, in certain cases, directly perceptible. The commotion produced by the torpedo and gymnotus have been known from antiquity, but the most sensitive galvanometers have been needed to detect those electric modifications, so weak and yet so important, which accompany the nervous and muscular actions. Du Bois-Reymond and his successors have made known to us an entire new phase of physiology, and one of the most interesting kind. Optical apparatus is indispensable for the exploration of the interior of the eye, as well as for the delicate measurement of the curvatures of each of the refractive mediums which compose it. Thus, while dissection teaches us certain details of the organization, it would nevertheless deceive us by destroying the normal disposition of the parts, had we not the means of studying the living apparatus *in situ*.

Anatomy shows us the organs with a definite form and volume; physiology, on the contrary, teaches us that most of the organs present, in the actions of life, changes both of form and volume, a few of which only can be easily perceived. We must resort to instrumental aid for the demonstration of changes too delicate for naked vision. Now, *micrometry*, as is well known, has attained an extraordinary precision in the determination of the diameters of objects extremely minute; it constitutes one of the principal resources at the disposal of histology, and enables it, in effect, to assign to each element its normal diameter, which is one of its important characteristics.

As there exists, then, a micrometry by which we can measure the slightest changes in the volume of the organs in living animals, I deem it the more important to indicate the apparatus destined for this purpose, since it is still but little employed, though possessing, in certain cases, very great utility. It will be remembered that discussions were heretofore maintained respecting the dilatation of the arteries under the afflux of the blood propelled into them by the contraction of the ventricle. Some writers contended that the arterial system makes room for the sanguineous wave by means of an elongation sustained by the vessels, while others thought that the arteries, in this act, dilate and lengthen at the same time.

To resolve this question, M. Flourens conceived the idea of encircling the artery of a living animal with an interrupted ring formed of an elastic spring, which would yield to the dilatation of the artery and manifest it by the separation of the two ends of the ring. This separation takes place, in effect, whenever a new discharge of blood is received from the heart. But the method is not wholly free from objection. If we suppose the pressure of the elastic ring to produce a slight constriction of the vessel, the latter may simply recover its normal dimension, and in this way, without undergoing dilatation, would separate the ends of the ring which compressed it. M. Poiseuille employed a more rigorous method, which consists in placing the artery which we propose to examine in a small box with rigid walls, pierced on one side and the other by a suitable hole. In this box the artery is maintained at such a degree of tension as to preclude any liability to elongation through pressure of the blood. The box is filled with liquid, and is furnished at some point in its walls with a capillary tube in which the liquid ascends to a determinate level. If the blood-vessel thus enclosed undergoes the slightest augmentation of diameter, it necessarily displaces the liquid of the box, and the level in the capillary tube is seen to rise or descend, according as the diameter of the vessel is increased or diminished. This method is susceptible of a great number of applications; it enables us to show that all the vascular organs undergo, at each sanguineous discharge from the heart, a distension followed by contraction, similar to that presented, in a higher degree, by the erectile tissues. But this mode of examination is not new; there may be seen in the works of Swammerdam the description of an apparatus very analogous to the one in question, and destined to determine whether a muscle in contracting undergoes a change of volume.

Of all the phenomena which characterize life, movement is the most important; it may be said, indeed, that in general it is movement which gives their distinctive character to all the functions; now, it is under this aspect that the phenomena of animal life can be analyzed at present with the most admirable precision in the three correlative elements of *duration*, *extent*, and *force*. We are but little capable of appreciating duration with exactness, especially that which is very short, and we generally consider as instantaneous such phenomena as occupy a space of time shorter than the half or quarter of a second. For the same reason we assume the synchronism of two acts which follow one another at a short interval. But *chronometry* has made so much progress of late that we can now measure the shortest durations, thanks to the apparatus employed by the physicists. The velocity of projectiles, of light, of electricity, is readily reduced to measurement, and nothing prevents the application in general of the same methods to the still shorter durations of physiological acts. The *extent* of a movement is susceptible of very exact appreciation, provided the movement furnishes a trace which may be afterwards submitted to the estimates of micrometry. The idea of *force* has recently undergone an important modification; it has been reduced to that of *labor accomplished*, and is referable henceforth to a determinate standard, the *kilogrammetre* and its divisions. We find ourselves therefore in possession of accurate terms of comparison, and should eliminate in future every vague expression relative to movement. We should characterize it in every case according to its duration referred to the second of time, its extent in terms of the metre or its fraction, its force as expressed in kilogrammetres. Perhaps a still more complete conception is that which further characterizes a movement by its *form*; that is to say, which takes account of the different phases of the movement, and no longer only of its commencement and end, its maximum and minimum, but which determines all the intermediate states. Such is the result obtained by the *graphic method*, to which I shall have occasion elsewhere to call attention, as furnishing of itself the solution of a great number of problems of the highest importance.

Movement, before being executed, is, so to say, potentially contained in certain causes which produce it: *weight*, *elasticity*, the *pressure* of a liquid, the *tension* of a gas. We now know how to appreciate these forces, which may be called virtual. It is *statics* which measures them, and introduces into their measurement that rigorous exactness which tends at present to become general. The application of the *manometer* to the valuation of the pressure of the blood, of the thoracic aspiration, of the force with which the glandular reservoirs contract, is a further step in the progress of our epoch.

If I have here given but a rapid and incomplete enumeration of all these exact processes and their appropriate apparatus, it is because the occasion will hereafter present itself, in my collegiate course, of describing them more completely, and of more fully exemplifying their value. I have aimed to show in the first place the resources which we have at our disposal, and to prove especially that it is by drawing more closely its relations with the other sciences, that biology has become progressive and will continue to progress. Now that we are provided with new means for attempting the solution of the problems of life, we may resume the researches in which our predecessors have been foiled. A subject which might be supposed to be exhausted becomes once more a fertile field for study, if we acquire new processes with which to explore it. It is chiefly when we recur to ancient experiments that we are struck with the progress which has been realized. We might almost be disposed to condemn the narrowness of view of the old experimenters, if we did not revert in thought to the epoch when they lived, and to the exiguity of the means of analysis of which they could avail themselves.

Still another reason necessitates the employment of apparatus in physiology. Even in the cases in which vivisection reveals to us important facts, it induces such extreme perturbations in the functions of life as greatly to modify them and to convey a false idea, if the normal expression of the function be assumed to be exhibited in any phenomenon which we may thus witness. To take an example, the case may be cited when the section of the spinal marrow is performed on an animal, and artificial respiration is practiced in order to maintain organic life as long as possible. Under these conditions the phenomena of circulation undergo so profound a modification that we should be on our guard against the false ideas which may be drawn from the experiment. The rapidity of the current of the blood becomes excessive, the pulsations of the heart are accelerated, the central temperature is lowered, while the peripheral temperature rises. The physiologist should, therefore, endeavor to inflict on the animal which he is examining as little mutilation as possible, if he would obtain an exact idea of the normal conditions of the circulation of the blood and the animal temperature. We know, moreover, that the secretion of the glands, under normal conditions, differs much from that which we collect by artificial means. Thus the pancreatic juice derived from an animal in which an opening has been effected differs chemically from that which the gland discharges normally into the duodenum. It would not be difficult to multiply examples showing how necessary it is to leave the animal in its normal condition if we would not have the function interfered with; but this is only attainable by means of the different and delicate apparatus of which some portions are above enumerated.

Another cause often obliges us to renounce vivisection, and to substitute the use of apparatus: it is the necessity of directly studying the human physiology. Of all the beings whose organization and functions science has essayed to investigate, man has been the most frequent object of study. It is the human physiology which serves, so to speak, as a type for that of the whole animal kingdom.

Nevertheless, if it is true that our own organism and functions seem to present the most complete model of animal organization, it is not less true that certain organs, as well as certain functions, are, in us, less sharply characterized than in the lower order of beings. Hence it is of the greatest importance to follow, by analysis, each of the phenomena of life in the whole series of living beings, or at least in the principal types, with a view to ascertaining what are the different processes which nature employs in order to arrive at her end, the life of the individual and of the species. Hence the origin and object of *comparative physiology*.

It is to the human being, however, his organs and his functions, that the greater number of investigations is at the present day directed. And, as all resources are to be laid under contribution in the prosecution of our object, we may sometimes borrow aid from the science of *medicine*, which finds in the study of maladies certain conditions not always to be realized by experiment. It is not to be forgotten, however, that medicine is not the basis of biology, though, in an utilitarian point of view, it may be its end. In such inquiries as we are now pursuing, it is but one means the more of analyzing the conditions which modify the functions of life, and of arriving at a better determination of the laws which regulate those functions. In order to give an idea of the influence which medicine has had on the knowledge of the organism, I need but recall that it was in a case where a perforation of the thoracic walls had occurred that Harvey observed the beatings of the heart; and in another, where a gastric fistula had been formed, that Beaumont conducted his memorable studies on digestion. The vices of congenital conformation furnish us with numerous indications, not only on the subject of *embryogeny*, but also in relation to certain functions, such as those of the nervous system, respiration, and circulation, which produce the movements of the cephalorachidian liquid, &c.

The above is but a summary statement of the means of analysis at our disposal at the present time. Our resources, it will be seen, are great, and furnish a guarantee of success in researches yet to be undertaken. I would repeat, in conclusion, what I have before said, that progress is visibly taking place through the fusion of the sciences, and for us, naturalists and biologists, resolves itself into the facilities which we every day derive from physics and chemistry. The time will come, no doubt, when we shall be able in our turn to furnish to those sciences new elements of progress. But, for the moment, we are their debtors, for the reason that the physical and chemical sciences, more simple than ours, and long disengaged from the bad methods by which we have been misled, are to-day more advanced than biology, in the sense that they arrive more readily at exact ideas of the phenomena which they study. It is only after having fruitlessly employed in the study of the phenomena of life the methods supplied by physics and chemistry that we shall have any right to invoke the intervention of extra-physical causes for the explanation of the vital phenomena; and it is not difficult to see how far we are from having exhausted the resources which physical and chemical analysis now places at our disposal.

III.—EXPERIMENTAL SYNTHESIS IN THE NATURAL SCIENCES.

In speaking of the processes which the human mind employs in scientific researches, I have mentioned analysis and synthesis. We have thus far treated of analysis; we have considered it in its progressive improvements, and know, in a general manner, the immense resources which it has at its command.

It remains to inquire the meaning of synthesis and the services which it is capable of rendering. It has already been seen that it is not a method of research; that a science which should propose to found itself upon synthesis, by setting out upon principles established *à priori*, would incur the peril of going widely astray. But nothing of this sort is to be apprehended when analysis has finished its work and has put us in possession of a large number of facts, well established. It is then that the office of synthesis commences. *Synthesis* is the opposite of analysis; it reconstructs what has been decomposed. This is the most general definition of the method. But to give a more complete idea of it, it is well to follow it in its different applications. We will first examine experimental synthesis, in so far as it serves to control the results of analysis by reproducing a phenomenon through a reassemblage of the conditions of its existence. Afterwards we shall pass to synthesis properly so called, being such as it is defined by *scholastics*, and which collects particular facts into general laws.

Experimental synthesis recompounds that which has been decomposed into its different elements. The chemist, for instance, when he has decomposed water by means of analysis and has separated it into oxygen and hydrogen, can recombine those two gases. He has effected the synthesis of water. In this second experiment, then, is found the most satisfactory demonstration of the exactness of the first. Synthesis has served for the proof of analysis.

In organic chemistry the introduction of synthesis is altogether recent, but it has effected in this branch of science a real revolution. In the last century, chemists believed that organic matter was formed in animals and plants by virtue of forces different from those which govern unorganized matter. Buffon even recognized an animated organic matter, destined to furnish unceasingly the material of beings endowed with organization. As late as 1849, Berzelius still admitted of special chemical laws in organized nature.

It belonged to Berthelot to overthrow these erroneous opinions, and to show that the same laws prevail in organic chemistry and mineral chemistry; to prove that by employing the inorganic elements disclosed by analysis, it is practicable to reproduce by synthesis a great number of the substances found in vegetables. It was thus that, by means of carbon and hydrogen, our learned chemist formed acetylene, C^4H^2; this body, treated with nascent hydrogen, gave him olefiant gas, C^4H^4.

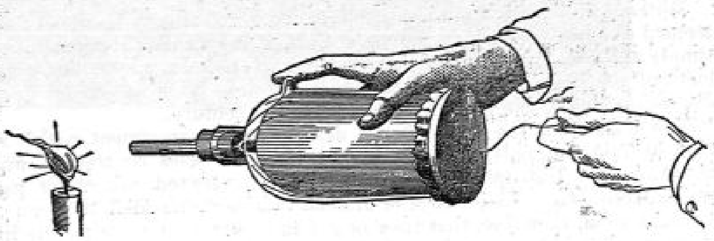
By the employment of water and carbonic acid, Berthelot formed the oxide of carbon, C^2O^2. This again, by the fixation of the elements of the water, yielded formic acid, $C^2H^2O^4$, whence was obtained the gas of the marshes, C^2H^4. From the gas of the marshes, in turn, are derived, by successive condensation of the elements, acetylene, propylene, benzine, and naphtaline. The ternary bodies spring from the preceding by the addition of oxygen. Thus are produced the alcohols: the methylic alcohol, $C^2H^4O^2$, by the oxydation of the gas of the marshes; common alcohol, $C^4H^6O^2$, by the hydratation of the olefiant gas. By removing the hydrogen from the alcohols, we obtain the aldehydes; by oxydizing the alcohols, we form the organic acids. By the fixation of the nitrogen in these new products, whether by means of ammonia or by the action of nitrous acid, we obtain the quaternary compounds. So that it may be foreseen that a resort to synthesis will enable us to reproduce artificially those important substances which are called the alcaloids of vegetables.

The physicist also makes extensive use of synthesis. Thus, when he wishes to produce with great intensity a phenomenon of which analysis has revealed to him the conditions of existence, he constructs an apparatus in which he assembles those conditions, and evokes the phenomenon with a degree of evidence which leaves no longer any doubt. Knowing, for instance, the electric phenomena which occur between two different metals, both submitted to a chemical action, physicists have constructed batteries which produce currents of dynamic electricity of a surprising intensity. In general, what is called an instrument of demonstration is constructed in virtue of a synthetic idea.

In biology, synthesis is generally too little employed, and yet it would appear, in certain cases, eminently useful, whether for controlling the results obtained by analysis or for furnishing a clear and striking demonstration of the phenomena. This means of control and demonstration should certainly not be neglected. It is often proper that experiments should be made with the view of reproducing a phenomenon, and demonstrating that it takes place in certain determined conditions. In this case, the experimentation is synthetic. One of the principal applications of this method consists in reproducing, outside of the living being, certain phenomena which take place in the interior of the organism. Thus, in order to demonstrate the action which the air exerts on the blood through the walls of the pulmonary cellules, we make it appear that venous blood can be arterialized by the action of the air taking effect through an organic membrane. To prove the action of the acids of the stomach as well as that of heat in digestion, it is usual to show that, in a matras, the addition of an acid to a mixture of gastric juice and food excites an artificial digestion which would take place but very incompletely without the presence of the acid. The action of heat in digestion may at the same time be shown, for the temperature must be somewhat elevated for that phenomenon to be produced with rapidity.

The physical phenomena which occur in living beings are particularly susceptible of synthetic demonstration. The apparatus of demonstration or *schemas* are admirably adapted to give an idea of the mechanism of these functions; nor can anything more instructive be readily imagined than the employment of such expedients, which enable us to assist, as it were, in the production of all the details of the phenomena.

There are many, doubtless, who will recall the difficulties experienced, at the outset of physiological studies, in comprehending perfectly the mechanism of respiration; that *virtual* vacuum, as it is called, which exists in the cavity of the pleura, and into which the air tends to precipitate itself as soon as an opening is formed at any point of the thoracic structure. Now, this phenomenon can be counterfeited in a very simple manner. (*Fig.* 1.)



We take a bottle whose bottom has been removed and is replaced by a stretched membrane of caoutchouc: this bottle will represent the thoracic cavity, while the membrane corresponds to the diaphragm. In the interior of this apparatus we place an elastic bladder of caoutchouc, which represents the lungs. The neck of the bladder is luted to the neck of the bottle, so that there shall be but one orifice, that which enables the exterior air to communicate with the interior of the bladder of caoutchouc. A hole has been formed in one side of the wall of the bottle, and a cord is attached to the centre of the membrane which represents the diaphragm, for the purpose of communicating to this membrane movements which imitate the diaphragmatic action in respiration. We now proceed to place this apparatus in the same conditions with the thoracic cavity. We blow through the throat of the bottle into the bladder, so as to distend it until it fills the cavity of the bottle and expels the air contained therein. We have thus established a state of things analogous to that in which the thorax is filled by the expanded lungs. If we cease to blow, leaving the lateral hole free, the wind at once enters with a whistling sound through the hole in question, precisely as happens in the case of an animal whose breast has been suddenly pierced. But, if we close that hole after having finished the insufflation, the bladder will continue adhering to the walls of the bottle, although the throat of the latter be open. To imitate the movements of the diaphragm, we exert a traction on the membrane; the bladder follows all these movements just as the lungs would do, and a reciprocating motion is established between the exterior and interior air, through the throat of the bottle. If we desire to measure the energy with which the bladder-lung tends to collapse upon itself, a manometer is fitted to the hole in the side-wall; the mercury will now be seen to be drawn towards the apparatus with a force represented by the inspiration of a column of air a certain number of centimetres in height.

A rather curious phenomenon sometimes occurs in surgery, being a hernia of the lung through a wound of the breast. This hernia might seem inexplicable, in view of the tendency of the lung in such case to collapse upon itself. If we close the throat of our bottle, an act which corresponds to the occlusion of the glottis in an animal and prevents the escape of the air from the breast, the bladder will no longer have, as before, a strong tendency to retreat upon itself; for, to do that, it must become empty. At this juncture let the diaphragm be stretched, which will be equivalent to a strong effort at inhalation. The bladder will then be seen to form a hernia through the opening in the side of the bottle. The explanation of this fact is quite obvious: the air, compressed in the elastic pouch with a certain force, tends to escape outwards by driving back the thin membrane which confines it; this it effects at the sole point where the walls offer little resistance. Suppose, for an instant, that, in place of the thin membrane which now forms the hernia, there were a spongy but more consistent tissue, like that of the lungs; the hernia would become strangulated between the edges of the opening and be unable to re-enter spontaneously, even when the effort has ceased. Many other demonstrations might be made by means of this simple apparatus.

Without digressing from the subject, another fact may be noticed which long seemed obscure, but which is susceptible of a synthetic demonstration at once simple and convincing. Have the intercostal muscles any action on the movement of the ribs, and, if so, what is that action? This was the subject of much discussion among the physiologists of the last century.

The solution of the question was demanded of experiment, and it was found that, in living animals, the external intercostal muscles contract at every inspiration of air. But this result of observation presented something paradoxical and inexplicable. The external intercostals are extended between two ribs: it would seem, therefore, that they ought, in contracting, to bring the ribs nearer to one another. Now, at the moment of inhalation, the ribs separate and the intercostal spaces are enlarged.

P. Berard, in his courses of physiology at the Faculty of Medicine, was accustomed to recall the discussions in question, and removed any hesitation on the part of his auditory by tracing on a tablet a schematic figure which rendered the phenomenon easily intelligible. He would state, at the same time, that he had received from Dr. Hutchinson a small apparatus formed of pieces of wood in imitation of the arrangement of the ribs in relation to the vertebral column, and of elastic bandelets which represented the action of the external intercostal muscles. The whole, when the parts representing ribs were lowered so as to exert a traction upon the elastic bandelets, was calculated to take the position attending the act of inhalation in the animal frame. Annexed is an apparatus which I have constructed upon these indications and which aptly reproduces the phenomenon in question, (*Fig.* 2.)

The vertebral column is represented by a piece of vertical wood on which three transverse pieces are articulated: these represent the ribs. The direction of the intercostal muscles is indicated by that of the braces of caoutchouc fastened by pins on the crossbars of wood. When the ribs are horizontal, as in the figure, there is a considerable interval between them, but the insertions, A, B, of the brace of caoutchouc are not so widely separated as in the case when the rib-pieces, being lowered, approach and touch one another. In that case, the brace of caoutchouc corresponds to the diagonal of a very oblique parallelogram. Now, the position of the elastic brace is that which the external intercostals present in relation to the ribs. The contraction of these muscles serves, therefore, to raise the ribs, as the elasticity of the caoutchouc acts in the schema which we have been describing.

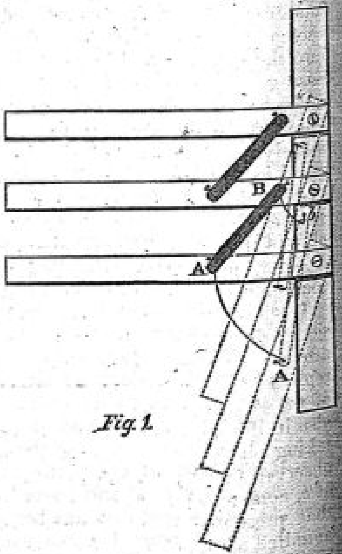
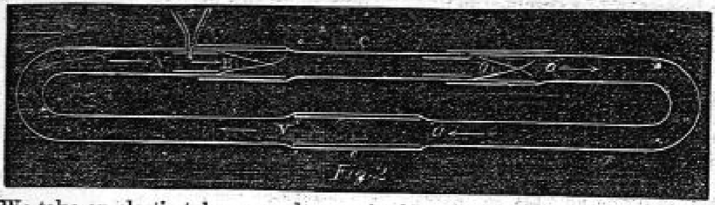


Fig. 1.

Among the mechanical phenomena of the circulation of the blood there are quite a number which may be imitated in a perfect manner. A schema, well known in Germany, is that of Weber: it shows how the circular movement of the blood is accomplished in that vast self-re-entering system represented by the heart and blood-vessels, (*fig.* 3.)



We take an elastic tube, curved upon itself, so as to form a complete circuit, which may be filled with a liquid by means of the funnel, *e*. At a point in this tube a part, marked *c*, is bounded by two valves, both of which open in the same direction. This portion of the circuit corresponds to the heart. At the point directly opposite the portion *c* is placed, at *c*, a tube of glass, in which a sponge is infixed tightly, forming, of course, an obstacle to the passage of the liquid, in regard to which it exerts a resistance like that opposed by the capillary vessels to the course of the blood. The apparatus being now filled with liquid is ready for operating. If intermitting pressures be exerted on the part *c* which represents the heart, the enclosed liquid is propelled and made to pass into the portion of the tube where the play of the valves permits its being introduced, namely, into *a*, *a'*. Under the influence of compressions frequently repeated, the portion into which the liquid flows becomes distended. Now, it is in this condition that the arterial system subsists in animals, since there the blood is continually pressed forward by the systolés of the left heart. Hence the liquid acquires in this part of the tube a considerable amount of pressure which imitates, with sufficient exactness, the pressure of the blood in the arteries. The sponge, *c*, allows the liquid to pass gradually from the arterial part of the tube into the venous part, that is to say, into the portion *v' v* of the apparatus. This passage of the liquid takes place in a continuous manner, notwithstanding the intermission of the impulses given to the liquid. Here, then, we realize an imitation of the phenomenon produced in the circulatory apparatus: the regularity, namely, of the course of the blood in the small vessels. In both cases this result is obtained through the effect of the elasticity of the conduits in which the liquid has circulated. Further, it is the same cause which produces in fire-engines the regularity of the jet, notwithstanding the successive checks in the play of the pump. In apparatus of the latter kind resort is had to a bell-shaped receiver, under which the liquid arrives on issuing from the pump, and which counteracts the irregularities of the motive force.

It should likewise be remarked, that, under the influence of successive impulsions given to the liquid by pressing on the part *c*, it will be found that the arterial and the venous portion of the circuit present opposite conditions of repletion: the arterial pressure constantly tending to distention at the expense of the venous portion which is at the same time partially depleted. It is thus also in the economy of the living animal, the repletion of the arterial system taking place at the expense of the contents of the veins. Finally, it will be observed that each impulsion given to the liquid, by the compression of the tube at *c*, communicates to the whole of the arterial column a pulsation analogous to that presented by the arteries of a living animal, and that this impulsion is annulled at the extremity of the arterial part, so as to fail entirely in the venous portion. On the whole, then, this schema of Weber's reproduces in a very simple way some of the principal phenomena of the circulation of the blood: 1st. The circuit and the continuous current through the whole system of tubes; with the understanding, however, that the apparatus is intended to represent only one of the two circuits which constitute the circulation in the higher animals—namely, the greater one. 2d. The formation of two unequal pressures, one rather high, being that of the blood in the arteries; the other lower, being the venous pressure. 3d. The continuity of the course of the blood in the capillary vessels under the influence of the elasticity of the arteries. 4th. The pulsation which is produced in all the arteries at each systole of the heart. It might be possible to imitate in a more perfect manner the hydraulic phenomena of the course of the blood, but the schema before us suffices for the moment as exhibiting a synthetic reproduction of an action taking place in living beings.

In studying the circulation, theoretical considerations had led me to conclude that the elasticity of the arteries produces on the course of the blood still other effects than those demonstrable by the apparatus of Weber, and that this elasticity itself favors the circulation by diminishing the obstacle which the heart encounters at each contraction; in other words, that the heart has less difficulty in emptying itself into elastic vessels than it would meet with if the arterial system were formed of rigid conduits. Now this effect of the arterial elasticity has been contested by the whole body of physiologists. Some of them have held, with Bichat, that the circulation would be effected quite as well in inert tubes as in elastic ones, the only difference being that in inert vessels no pulsation would be felt. Others, relying on experiment, asserted that two tubes, one elastic, the other inert, give passage to the same quantity of liquid if both have the same calibre; and this is perfectly true if the flow of the liquid takes place under a constant discharge, but ceases to be true if the afflux of the liquid occurs in an intermittent manner, as is the case with the circulation of the blood. Still other physiologists, struck with the regularity of the course of the blood in the small vessels, have considered the elasticity of the arteries as an additional force, which propels the blood in the arteries during the repose of the heart. But these also were in error, and we might refute their opinion by saying, with Berard, that the elastic force of the arteries is in reality only indirectly contributory, a *force d'emprunt*, and that the heart is the sole impulsive agent which exerts an active part in the circulation. Nevertheless, I maintain my proposition: the elasticity of the arteries is favorable to the course of the blood, but it does not act as an impulsive force. *It diminishes the resistance which the heart experiences when it propels the blood in the vessels.* The annexed schematic apparatus will enable me to demonstrate this proposition.

Fig. 3

A Mariotte vase V is raised on a support. From this vase proceeds a large tube furnished with a faucet R. This tube is bifurcated at the point T, and each of its branches is continued by a long conduit. One $b\,b'$ is elastic, being formed of thin caoutchouc; the other $a\,a'$ is of glass, and consequently rigid. A valve, placed at the origin of the elastic tube, permits the liquid to penetrate freely into its interior, but opposes all reflux in an inverse direction. The two tubes have the same capacity of discharge: of this we may convince ourselves by opening the faucet R and allowing a continuous current to be established. But if the faucet be opened and closed alternately, it will be seen that the efflux by the inert tube is intermittent, while that by the elastic tube is continuous; it will be also found that the discharge has become very unequal, and that much less of the liquid escapes by the inert than by the elastic tube. The proposition might be considered, then, as already proved, for it is evident that if the elastic tube has discharged more liquid than the other, this results from its having received more, and as the penetration of the liquid into the tubes takes place under a constant charge, and can only be effected at the time when the faucet is open, this clearly proves that at those instants the tube of glass was more permeable than the elastic tube.

But we may form a more exact conception of what occurs under these conditions by inquiring not what issues from the tubes, but what enters them. The Mariotte vase employed as a source of supply furnishes the means of knowing accurately what penetrates into each of the tubes at a given moment, for not the smallest quantity of liquid can issue from the vase without the indication of what portion of it is withdrawn by the entrance of a more or less considerable quantity of air. Now, if the liquid be permitted to flow by the elastic tube alone, or the glass tube alone, it will be seen that in the two cases the Mariotte vase indicates very different discharges. If the efflux be by the inert tube alone, bubbles of air are seen to enter the vase one by one, at regular intervals, until the suppression of the flow of liquid, when, by the same act, the entrance of the bubbles is arrested. If, on the other hand, the inert tube being closed, the efflux commences with the elastic tube alone, a mass of air is seen on the instant to rush into the vase, announcing the escape of a wave of the liquid at the first moment; the bubbles then become more rare and enter with the same slowness which was observed in the case of efflux by the inert tube. Let the faucet be closed at this instant, and it will plainly appear that the elastic tube has received a quantity of liquid greater than that received by the inert tube and corresponding to the access of the large volume of air at the commencement of the experiment. It is this excess of liquid which occasions a flow more or less durable after the closing of the faucet. This whole quantity of water accommodated by the distension of the tube constitutes the advantage of the elastic tube as regards the afflux. If this tube more readily admits the penetration of the water into its interior, it is because the liquid is not required, as in the case of the inert tube, to overcome the total friction and flow outwardly, but finds lodgment within the tube by reason of the extensibility of the latter. It is obvious that as often as these intermittent openings of the faucet are repeated a new advantage is created in favor of the elastic tube. Finally, theory teaches us that to render the efflux by the two tubes as unequal as possible, it is requisite that the faucet should be opened, each time for a very brief period, and that the intervals between the openings should be of some duration.

The demonstration of this effect of the elasticity of the arteries, though heretofore unknown, would seem to be of much importance; it has enabled me to draw new conclusions, and to establish, for example, that if the arteries lose their elasticity, as is normally the case with aged persons, the heart must experience an increase of resistance, and, according to the known laws of pathology, become hypertrophied. The researches which I have made with a view to the verification of this prevision have furnished a complete confirmation of the theory, but I shall not insist here on particulars which enter properly into the domain of medicine, and which would divert me from my subject.

In returning to the synthetic reproduction of the phenomena which accompany life, I shall present but one other example of synthesis. The uses of the natatory bladder of fishes have been very much controverted; most naturalists, however, have considered this organ as capable of modifying the volume of the fish, and consequently its density, so as to render it sometimes lighter than the water, thus causing it to ascend to the surface; and sometimes heavier, thereby enabling it to plunge to great depths. More recently, M. Moreau resumed the study of this subject, and pursued it much further than had previously been done. His attention was first arrested by the circumstance that a fish drawn at sea from a great depth swells and sometimes bursts when brought to the surface of the water, and in this condition floats helplessly, because it has become much less dense than the water. The elastic force of the air of the bladder, resisted under normal conditions by the weight of a column of water extremely high, brings on a great distension of the animal if the pressure is diminished, so that, having become lighter than the water, it floats on the surface. Hence it follows that a fish which lives normally at great depths in the sea cannot rise above a certain altitude, under penalty of being borne to the surface by the expansion of the gas of its air-bladder. And this theoretical deduction involves a converse one: that the fish cannot descend to a depth greater than that for which its natatory bladder is adapted. If it ventures to a greater depth the gases of its bladder will undergo greater compression, the density of the animal will be augmented, and it will be precipitated indefinitely, even to the bottom of the sea; whence it can rise no more, unless it could secrete within its bladder a quantity of gas sufficient to distend it notwithstanding the enormous pressure to which it is subjected.

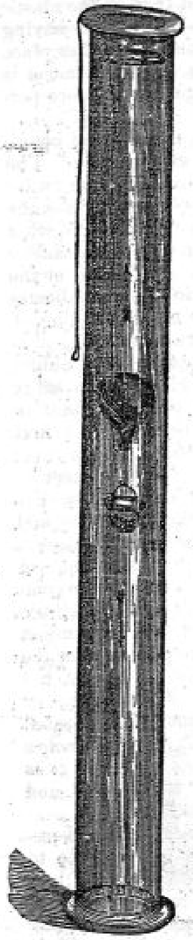


Fig. 4

Theory teaches us, then, that a fish is not fitted to live except at a certain depth; that it cannot all of a sudden transfer itself from a certain zone to which the state of its air-bladder assigns it; that if it emerges from that zone in which it possesses nearly the same density with the water, it must be impelled indefinitely, whether to the surface or towards the bottom of the sea. It may, moreover, be inferred that the animal can within certain limits extend this zone to which it is assigned, if it has the power of compressing or relaxing its air-bladder; that is to say, of modifying spontaneously its own density, whether in one direction or the other. It is to be understood, finally, that the fish has the faculty of contending to a certain extent, by the movements of its fins, against the effects of its own density, and thus still further enlarges the zone in which it can subsist.

The whole of these theoretical deductions can scarcely seem evident at the first glance, hence experimental control would appear to be indispensable. We know, by experience, that a fish drawn from a certain depth to the surface of the sea floats in spite of itself; but the inverse phenomenon, a fish precipitated to the bottom of the sea, is what no one has witnessed. Yet a very simple scheme will render this phenomenon perfectly evident. The apparatus for this purpose (*Fig.* 5) is analogous to the *ludion*, an instrument with which we are familiar. It is formed of a bladder of caoutchouc filled with air, and sustaining a weight graduated in such manner as to give to the whole system a density equivalent to that of water. This apparatus is placed in a glass gauge having such a length that the liquid column shall represent a rather strong pressure, when the Ludion is plunged to a certain depth. The volume of air contained in the ball is so regulated that the Ludion, when at the surface of the water, is a little less dense than the liquid, and emerges from it to some extent. Let it be now sunk to a slight depth; it is still not so dense as the water and tends to rise above its surface. Sink it a little deeper, and it will remain nearly immovable in the zone in which it is placed, indicating that its density is now equal to that of the water. It is thus that it is represented in the figure. Let it be sunk more deeply and it will be seen to have a tendency to descend of itself: it has become denser than the water.

Here, then, we have a new example of the synthetic reproduction of the phenomena which occur in living animals. Many analogous examples might be cited, but it is only my purpose here to signalize the utility of this method, and to show how important it is still further to extend its application. It may be added that any one, by the construction of a schema of his own, will find that the vague ideas which he may have at first conceived on an obscure subject, acquire singular precision and development. New conceptions will be constantly presenting themselves, and problems be suggested which the mind is impatient to verify by new experiments. In a word, this manual labor of the construction of schematic apparatus, far from absorbing the mind, sustains and guides it by furnishing it at each step with an experimental test.

An objection will not fail to be made by those who pretend that there are, in living beings, properties which such persons term vital, and which are altogether peculiar. They will tell us that synthesis may well reproduce the physical phenomena which accompany life, but that it is incapable of imitating the *vital* phenomena. I will answer, for my own part, that I recognize but two sorts of manifestations of life: those which are intelligible to us, being all of a physical or chemical order; and those which are not intelligible. As regards the last, it is better to avow our ignorance than to disguise it under a semblance of explanation.

IV.—LAWS IN BIOLOGY.

I have next to speak of *synthesis* considered as a mental operation, the opposite of analysis; as collecting dispersed ideas to form of them a whole; as ascending from particular facts to the general law which governs all of them.

The highest point which the natural sciences can reach is the discovery of the laws which govern the phenomena of life. This, as I have said, is the ideal we should pursue, but which we have not yet attained. At present it is the research for facts which occupies us; we labor in behalf of successors, perhaps far remote; we accumulate for them the materials of a vast synthesis, which will enable them to embrace all these facts under a general point of view, and to educe from them simple laws. Already, however, light seems to diffuse itself upon certain points of the sciences in question, and some of their laws have begun to emerge from the mass of details.

Let us premise this capital fact, that the laws of physics and of chemistry reappear in the manifestations of animal or vegetable life, and that every day the hypothesis which led to the admission of forces of a special nature in organized beings is becoming less and less necessary. As regards the laws of physics, we have seen them applied in the operation of the schematic apparatus by means of which we are enabled to imitate certain phenomena observed in living beings. We shall doubtless still continue to discover these same laws in proportion as we shall study in their more intimate details the functions of organized beings. As regards the laws of chemistry, Berthelot has shown them as presiding in the formation of the substances called *organic*. The hypothesis of a vital chemistry of a wholly peculiar nature is now useless. Researches based on synthesis in chemistry show us that the ordinary laws suffice to explain the formation of organic matter in the interior of vegetables.

The best known of all vegetable functions, the respiration of plants, presents this first experimental idea, that the green matter of plants, under the influence of solar light, decomposes the water and carbonic acid, thus setting at liberty the hydrogen and oxide of carbon. Now, these latter substances are the elements which chemical synthesis employs to form the ternary compounds, which may all be derived from the action of nascent hydrogen on the oxide of carbon.

If the chemist, in his laboratory, must proceed by a series of transformations in order to realize substances in which the elements are more condensed, nature attains the same end in a more direct manner, without, on that account, violating the ordinary laws of chemistry. In nature all the elements are in contact in a nascent state, so that the simpler compounds which result therefrom remain not long in their first phase of evolution, having close at hand every principle necessary for the formation of more complex bodies. Organic bodies arrive, therefore, with immediate effect at their highest degree of condensation, while, in the chemical reactions of the laboratory, we are obliged, in following up the conditions of the formation of these bodies, to create artificial and successive phases.

In the study of the functions of life, the physiologist finds himself confronted with phenomena so complex that he cannot at once comprehend the laws which govern them. But he is struck with certain characters which seem to him more constant than others. From these he deduces the existence of certain *vital laws*, an ephemeral hypothesis which disappears soon or late before a more profound investigation of the phenomena, and is absorbed in the more comprehensive generalizations of physical or chemical laws.

First of all, the production of heat and that of movement seem to him to be attributes of the animal kingdom. If some species appear to form an exception to this sort of general law which he has established, the physiologist explores the facts more attentively, and perceives that the animals which he had at first distinguished from others by calling them animals *with cold blood*, constitute but an apparent exception, and that they also produce heat, though in less quantity than others, besides that they have not the property of preserving this heat, but allow it to escape when they are placed in a cold medium. Eventually it is recognized that the chemical actions which take place in the organism are the cause of the production of heat in animals, and that the quantity of heat disengaged increases or decreases according to the intensity and nature of those actions. Thenceforth the production of animal heat presents itself only as a particular case of the disengagement of heat in chemical reactions.

Movement in animals was at first considered a direct result of life; in its apparent spontaneity, a character was even supposed to have been found which distinguished it from the movements whose laws are determined by mechanical principles. But it was at length recognized that the production of movement, like that of heat, requires in animals a chemical action; that its production, therefore, is not unlimited, but must be assimilated to the labor of our machines, which transform into movement the heat derived from the combustion of carbon. Considered under this point of view, the animal organism would not differ from our machinery, except in its more advantageous capacity of production, but can yield, on the whole, in labor only what the chemical actions exerted on the absorbed aliments will admit of. This extension of physical laws to the functions of organized beings commends itself so strongly to reason, that no hesitation is at present felt in pushing conclusions to their last consequences, and in seeking, for example, in the animal economy the verification of the law of the *equivalence* of heat and of mechanical labor.

Nothing can be more legitimate than this tendency to reduce all the phenomena of nature to simple and general laws; to me it even seems that this mode of procedure has every chance in its favor of being the right one; still, from probable hypothesis to demonstration is a long stride. On this account it is that we must recur indefatigably to the study of particular facts, and that, without renouncing the purpose of reducing them eventually to simple laws, it is necessary in the first place to refer them to other special laws, but to such laws as are susceptible of demonstration.

Upon these grounds, certain phenomena of life may already be referred to demonstrable laws. M. Brown-Séquard, in particular, has given us, in his *Journal de la Physiologie*, a short note containing a very noticeable attempt at that generalization of which I have been speaking. This physiologist sets forth, as results of his own labors as well as those of the savants who have preceded him, *twelve laws* relative to the conditions under which nervous and muscular actions are either produced, increased or exhausted, together with certain other analogous phenomena which are observed in animals.*

Among these laws there are several which are not, perhaps, beyond the reach of criticism, and everything would lead us to believe that the further progress of science will reduce them to greater simplicity. Such as they are, however, they appear to me well worthy of remark and meditation. For some of my auditors, it is true, this generalization may be premature and difficult of comprehension; but for most of those who are somewhat initiated in biology, I would hope that they might lead to an enlarged conception of the facts with which they are already acquainted. Some of these laws, being those which are specially applicable to *muscular contraction*, are in substance as follows:

FIRST LAW.—*Muscular contraction seems inseparable from an organic change which nutrition alone can repair.*

It is now known that the muscle in repose presents the alkaline reaction, and that, under the influence of repeated contractions, it passes to the acid reaction; a chemical process has therefore been at work, which has modified the composition of the muscle. Again, if we seek in a muscle the proportion of matter soluble in water, before or after energetic exertion, we shall find, with Helmholtz, that the quantity of soluble substances has augmented under the influence of that exertion.

SECOND LAW.—*The rapidity of the circulation of the blood and the richness of that liquid in restorative substances, favor the recuperation of the muscle, and render it capable of new labor.*

This law, like the preceding, is susceptible of experimental verification. We can augment or diminish the time necessary for the recuperation of the muscle by abating or accelerating the course of the blood which traverses it. The need of alimentation which follows muscular exercise also confirms this law in what relates to the influence of the qualities of the blood on the muscular restoration. Even in the absence of circulation, the restoration still takes place within certain limits, which is explained by the presence of the blood with which the tissues are saturated, even when it ceases to circulate.

THIRD LAW, (flowing from the two preceding).—*A muscle is subjected to two influences, the one restorative, nutrition; the other exhaustive, its motive function; its actual faculty of producing movement varies according as one or the other of these influences has acted.*

Hence, after a prolonged repose, the muscle has attained its maximum of aptitude to act, since the restoration is produced without waste. Conversely, after prolonged action, the faculty of acting is at its minimum. It will be seen how closely this law approximates to laws purely physical, and how much the muscle resembles an apparatus which on the one hand receives electricity, and on the other dispenses it; as it does also a body subjected to a source of heat and to an intermitting cause of refrigeration.

FOURTH LAW.—*Recuperation after action is more rapid during the first few instants than it is afterwards.*

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* In the number of these would further appear the electric phenomena observed in certain fishes, the phosphorescence of certain animals, the movement of vibratory cilia, &c.

That is to say that if, after the action of a muscle, the repose lasts one minute, there will have taken place a certain degree of restoration of the faculty of acting, and that if the repose continues for two minutes, the restoration will not have doubled the muscular energy. This likewise offers a new analogy with physical phenomena. In effect, a chilled body submitted to a source of heat, gains much heat in the first few instants, and acquires but little afterwards in proportion to the duration of the process of heating.

FIFTH LAW.—*The habitual activity of a muscle and its nutrition stand in such relation to one another that repose too much prolonged produces atrophy of the organ, while action frequently repeated increases the volume of the muscle and augments its aptitude to produce movement.*

The examples which confirm this law are well known; every one has had an opportunity of observing the development of the muscles which, in some individuals, are more exercised than the rest, and, reciprocally, the atrophy of the muscles which, for whatever reason, have been consigned to a long repose. There are limits, however, beyond which this law ceases to be true; but these limits have not yet been ascertained in a precise manner.

The laws here stated regarding the muscular function are sufficiently general to enable us to recognize them in other functions which seem to have no analogy with movement. Having incidentally mentioned the discharge of the torpedo, I may here add that it would be interesting to inquire, within what limits the laws above stated are verified in this order of phenomena. M. Brown Séquard thinks, as I have before said, that they are governed by the same laws with the muscular action; but experiment has not yet succeeded in proving the reality of this opinion, though it may be said to have every probability in its favor. The only point on which perfect identity has thus far been established consists in the fact that the discharges of the torpedo become weaker and weaker when a series of them is provoked. There is, therefore, a real exhaustion of the function simply by its own action; a fatigue of the electric organ, as there is a fatigue of the muscle.

The presence of blood in the organ and its rapid circulation seem to be essential conditions for the abundant production of electricity and its prompt restoration. Such, at least, is the conclusion which appears to result from the anatomy of the electric apparatus of these animals, so richly provided with bloodvessels; but the absence of exact means for appreciating the intensity of the discharges of the torpedo has heretofore precluded rigorous experiment on this subject.* We are able, however, as M. Moreau has shown, to verify the fact that a cessation of the current of the blood does not immediately prevent the electric apparatus from operating, any more than it extinguishes instantly the contractility of a muscle. But this suppression of the current of the blood would seem to render the exhaustion of the electricity more rapid.

It will be seen that there remain many *desiderata* in relation to the production of electric phenomena in fishes. The presence, however, of certain characters perfectly alike in the function of their electric apparatus and the muscular function should induce inquiry whether other analogies exist. It is thus that a knowledge of the laws of a phenomenon traces for us the path to be followed in the study of others, by indicating the most probable result of the researches which may be undertaken.

M. A. Moreau has happily been led by the analogy which exists between the production of electricity in the torpedo and the production of movement in the

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* The galvanometers which have been employed are too sensitive; the electric discharge of the animal communicates to the needle so violent a deviation that it makes the circuit of the dial-plate several times, and does not allow a comparison of the relative intensity of the different commotions. – It might be practicable, perhaps, by means of a circuit of *derivation*, to give to the instrument only a part of the current, and as, in that case, the intensity of the derived current remains proportional to that of the principal current, the variations of the intensity of the discharge might probably be appreciated.

muscle, to a study of the action of the nerves which proceed to the electric apparatus. In inquiring whether these nerves are similar to the motor-nerves, he has, in effect, found the resemblance perfect: 1. That the section of the former suppresses the spontaneous discharges of the animal, just as the section of the motor-nerves suppresses voluntary movement in the muscles to which they are distributed. 2. That the excitation of the peripheral end of an electric nerve provokes a discharge of the apparatus, as the excitation of a motor-nerve provokes a shock of the corresponding muscle. 3. That the excitation of the central end of the electric nerve provokes in the animal no phenomenon of sensibility, as none is occasioned when the central end of a nerve of movement is excited. 4. M. Moreau having poisoned a torpedo with strychnine, which communicates to the motor-nerves a series of repeated excitations and throws the muscles into tetanic convulsion, found that this drug provoked in the electric apparatus very frequent discharges, similar in all respects to the convulsions of a tetanized muscle.

The phenomena of *sensibility* are, within certain limits, subjected to the same laws with the phenomena of movement. We verify with regard to both the law which teaches us that activity exhausts the function, and that repose restores it. A lively sensation fatigues the sensibility, exhausts or abolishes it for a certain time, while by repose its previous intensity is renewed.

Let us take as an example the most complex, but at the same time most interesting of our sensitive manifestations, the sight. When we look at a very bright luminous object, the point of our retina on which its image falls is vividly excited; it becomes fatigued, and if we turn the eyes on a field of a uniform clear color, we see on it a darker spot, presenting the exact form of the bright object by which our vision had been impressed. This spot is owing to the fact that the fatigued point of our retina no longer perceives the luminous sensations with the customary intensity. The more brilliant the body observed, and the longer the time we have observed it, so much darker and more persistent is the ensuing image. Repose of the sight causes this subjective image, as it is called, gradually to disappear.

The fatigue of our retina may be restricted to certain elements of sensation, if we have received the impression of only certain elements of the light. Thus, our vision may be fatigued for the blue, the red, or the yellow separately. Suppose, for example, that a red wafer be placed on a sheet of white paper, and that we look upon it intently for some instants. Let us now remove the wafer without ceasing to look at the same point; we shall immediately see a *green* disk of the same dimensions with the wafer appear in its place. The reason thereof is: that in the white light of the paper our eye cannot perceive so vividly the red rays in the point of the retina which is fatigued with that color, and as all the other rays are there perceived, these form by their fusion the complementary color of red, namely, green. In the same way, a green wafer would leave after its disappearance a red subjective image; a yellow wafer would give a violet image, &c.

I shall not dwell longer on examples of the very general law that *every function which is exerted is momentarily exhausted, and that it is restored by repose.* Let us proceed to a brief consideration of laws of another order in the phenomena of life. We will take, for example, the influence of functions upon one another. On this subject I may be allowed to adduce certain general views which appear to me to result from the observation of phenomena and from physiological experiment. A *law of harmony among the functions of life* will, I think, be admitted without difficulty; that is to say, that if one function reacts on another it influences the latter in such manner as to derive therefrom advantage for itself. To develope this idea, I will present a few examples: It has been already said that any muscular action has need of being maintained by the circulation of the blood; now the action favors this circulation and renders it more rapid.

To leave no doubt regarding the first proposition, I proceed to support it by experimental facts. It is in effect easy to demonstrate the necessity of the sanguineous current in the exercise of a muscular action. Thus, when we tie the lower aorta in an animal, we find that the muscles of the hind quarters are quickly paralyzed. The same result follows if we inject into the arteries of a limb a fine powder, which has the effect of obliterating the small vessels. M. Flourens has shown that, under these circumstances, the muscles soon become incapable of acting. There is a malady which veterinary surgeons call intermittent claudication, and which has been attentively studied in the horse by M. Bouley and Dr. Charcot. This malady is produced by an obliteration of the iliac arteries. In this state of things a new circulation is established by the collateral vessels, but these have not the easy permeability of the large trunks whose place they tend to supply. The animal thus affected can move for some time in the usual way; but presently the afflux of blood to its muscles being no longer sufficient, a sudden paralysis takes place and the horse stops. A moment of repose re-establishes the muscular function, which is exhausted anew after a few steps. The case wholly arises from the fact that the current of blood in the muscles is no longer sufficiently rapid to maintain their function in a durable manner.

Again, let us take a frog in which the vessels of one of the hinder feet have been tied, and suppose that both feet have been excited by induced currents, and that in both the contractility has been fatigued by prolonged action. If we now excite the two feet of the animal, it will be seen that the sound foot has recovered its contractility, while that whose vessels were tied still evinces in a high degree the exhaustion consequent upon its fatigue.

Granting then the necessity of a circulation so much the more rapid as the muscular act is one of more energy and duration, it is easy to prove the second proposition which I just now advanced, namely: that this muscular act communicates of itself a greater rapidity to the circulation of the blood. Every one is aware that in venesection, if the member is motionless, the blood escapes slowly from the vein, while the flow becomes much more copious if the patient exerts contractions of the muscles of the fore-arm. The question here is not that of a simple compression of the veins by the muscles, which would mechanically express the blood contained in those vessels. Such a cause would speedily have exhausted its effect, and extruded but an inconsiderable quantity of blood. There is exerted, on the contrary, a continuous action which accelerates the course of the blood as long as the contractions of the muscles of the fore-arm are continued. A still more convincing demonstration of the influence of the muscular act on the current of the blood may be given, by showing that the arterial system is depleted in an animal which has just desisted from running and presents in its interior a more feeble pressure than in a state of repose.* From such facts as these it results that the muscular act operates on the circulation in such a way as to accelerate the course of the blood through the muscles, and thus promotes that action by which the acceleration was occasioned.

We might cite a great number of examples of this law of harmony of the functions, and show, for instance, that the venous blood, when it arrives in abundance at the lungs, stimulates that organ and provokes the respiratory movements destined to arterialize it, while the respiration, at the moment when it is executed, opens a passage for the blood on which it is to act, &c. But these reciprocal influences of the functions would exact too long developments to be thoroughly treated on this occasion. I confine myself to a notice of the existence of this *law of harmony* of which I have been speaking, the recognition of which I consider of the greatest utility, as enabling us often to foresee phenomena which experiment will verify.

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[*] See, for further development of this subject, Marey, *Physiologie médicale de la circulation du sang*, p. 223, Paris, 1863.