

eries, when they come, will present one aspect under which their benefits will be undeniable and their fruits will be unmixed with any bitter; and that is their scientific aspect. When man takes possession of this new estate he will garner as his first harvest a complete meteorology, phenomena, and cause, through the whole depth of the atmosphere, and this knowledge, be sure, will have consequences that we can hardly imagine to-day. Agriculture, industry, navigation, will be transformed. The same knowledge will be utilized the better to avail one's self of the energy now wasted in the tides, in great waterfalls, and in the solar energy which in a given time is scattered over the earth in six hundred thousand times the amount of what is brought up from coal mines. Such will be the benefits which posterity will reap from those pacific conquests which I love to contemplate. Here, at least, we have no reason for other sentiments than those of joy and admiration. Happy are we to have been called to contribute our stone to such an edifice; happier still our posterity, who shall have the glory of crowning it. This seizure of a domain from which nature seemed to have closed all access will certainly constitute, by the constancy and intensity of the efforts it will have cost, by the discoveries and marvellous inventions that it will have provoked, one of the highest titles to glory, of which the human race will be able to boast.

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## THE GROWTH OF BIOLOGY IN THE NINETEENTH CENTURY.<sup>1</sup>

Address before Congress of Scientists at Aachen, September 17, 1900,

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The first of the series of addresses which, upon the close of the century, are to give you a short review of the acquisitions of the natural sciences, treated of a department in which the successes of the scientist have been particularly prominent; for the acquaintance with the forces of nature, which the chemist and physicist have earned by investigation in their laboratories, is the starting point for an expert mastery of nature that has reconstructed the life of civilized peoples from its foundation. From unpromising chemical and physical discoveries have arisen numerous giant industries, the basis of a commerce on an even more magnificent scale, and various technical contrivances by which men have more and more subjected space and time to their will, flitting by the force of steam, without fatigue, over wide stretches of land, or interchanging their ideas with the speed of lightning over the ocean.

The honorable task which has fallen to my lot is to report upon the development of biology during the nineteenth century. That science has no such glittering successes to show as those I have mentioned; yet I think I may venture to assert that the knowledge of nature which human sagacity has won even in the realm of biology is not inferior to the discoveries and inventions of the chemico-physical sciences in general scientific importance and in fruitfulness for human civilization. The insight into the complicated laws of nature that govern organisms as well as inorganic bodies, the inquiry into their structure, their origin, their vital processes, their relations to one another and to the cosmos, teaches us to subject the world of living creatures also to the domination

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of our mind, thereby to make them serviceable to our welfare in countless ways, or where they confront us as hostile powers to defend ourselves from them by hygienic protective measures. But what is much more important, biology enlightens us concerning our own human nature, both in its corporeal and in its spiritual aspects, and consequently leads to a greater mastery over ourselves; and in accordance with the progress of that knowledge biology influences even our religious, moral, and social ideas, and thereby arouses world-moving forces which have a no less transforming effect on the conduct of our life than does the expert mastery over inanimate nature, made possible by physics and chemistry.

The endless realm of biology is much more extensive than the chemico-physical sciences. For that reason, in the brief time during which I can venture to beg your attention I can only give a summary review of the development of the science during the nineteenth century, and can only refer to those particular directions in which our biological knowledge has made its principal progress.

A short definition can scarcely express correctly what a living being is, or what life is. It can only be said that life depends upon a special, peculiar organization of matter, and that with this organization are connected special functions (*Verrichtungen* oder *Functionen*) which are never met with in lifeless nature. The particular branches of science which relate to the study of animals and plants are, therefore, commonly divided into two groups, the anatomical and physiological sciences; that is to say, into those which deal with the structure or organization of the being and those which relate to its functions and its life processes.

In both directions our knowledge has been infinitely extended during the century. While the sixteenth and seventeenth centuries brought the great anatomists, an Eustachius, a Fallopius, a Vesalius, who, with knife and scissors, opened for us a glimpse into the numerous organs of the human body, biology in the nineteenth century has achieved its greatest victory in the province of microscopic anatomy. Equipped with the compound microscope, that wonderful instrument which eminent opticians have brought to the highest degree of efficiency, the anatomists were now in a position to discover a new and previously unsuspected world of life.

I believe, without hesitation, that I must indicate as one of the greatest acquisitions of biology during the nineteenth century the discovery that plants and animals are built up of cells, or, speaking in general terms, of innumerable minute elementary organisms. By the joint labors of famous biologists—I will name only Purkinje, Schleiden and Schwann, Hugo von Mohl, Nägeli, Remak, Kölliker and Virchow, Brücke, Cohn, and Max Schultze—our knowledge of the organization of living substance has been infinitely broadened and deepened. Anatomy

and physiology have received a solid foundation in the theory of cells and of protoplasm, just as chemistry has in the doctrine of atoms and molecules.

A series of very important ideas has arisen with the cell theory. If plants and animals represent in a certain way colonies or states of socially connected elementary living beings, vital processes are nothing more than highly complicated resultants of numerous elementary processes which are performed in the cells. Thus it was suggested to draw parallels and to institute instructive comparisons, on the one hand, between the individual members of a human state and the adjustments which a state necessitates, and, on the other hand, between the structure and the life of the vegetable and animal body. The law of the division of labor and of differentiation, which in human society causes separation into special professional classes and the immense diversity of social employments, was rightly adduced by Milne-Edwards, by Spencer, and by many others to illustrate the building up of the vegetable and animal body from its organs and tissues. With Lionel Beale and Max Schultze we learned to distinguish in histology between a formative substance, the protoplasm of the cells, and the product of their formation or work, and recognized that the various cells as they assumed in the service of the whole organism different functions or work, according to time and place and their relations to one another, became correspondingly diversified in their intimate structure, and that in this way the various tissues and organs came into existence.

The scientific elaboration of the theory of cells and tissues has occupied many naturalists for several generations; and they have erected the stately palace of the microscopic anatomy of plants and animals. Yet even here many important questions await solution, especially that of the finer structure of the cell-nucleus and of protoplasm, and the question of the microscopic structure of the nervous system and of the organs of sense, concerning which almost every year still brings us new investigations and new discoveries, sometimes of great importance.

With the aid of the compound microscope biological research has in the passing century opened to our inspection a second new and sovereign world of life, the world of the simplest unicellular organisms, which were introduced into classification by many investigators as an intermediate kingdom between plants and animals—the protista. Great was the wonder, in the middle of our century, when Ehrenberg discovered that whole geological formations originate from (erdschichten) very minute organisms, often hardly visible to the naked eye, which grow in fresh water and in the sea in immense numbers. For when, at death, their soft protoplasmal bodies decompose, their hard shells and skeletons of carbonate of lime or of silica still remain, and sinking by their weight to the bottom produce, in thousands of years,



in spite of their small size, yet in virtue of their inconceivable multitude, strata many meters thick. The chalk cliffs on the coasts of Rügen and of England are built up of the remains of foraminifera; many islands in the South Sea, of the wonderful siliceous framework of radiolaria, and strata, such as the diatomaceous earth of Bilina, of the siliceous shells of diatoms.

But still more important than these highly interesting facts for our general knowledge of nature was a second series of discoveries which I would place by the side of the cell theory as a second capital achievement of the century in the department of biology. Minute organisms are recognized as the cause of widely distributed processes of putrefaction, of fermentation, and of very numerous diseases of plants and of animals. They are unicellular algae, fungi, bacteria, and allied micro-organisms.

Three great investigators have here been the pioneers—in the botanical department, de Bary, who laid the foundation for the study of diseases of plants by the elaboration of suitable methods of observation and processes of cultivation; in the bacteriological department, Pasteur and Robert Koch. The great French investigator, equally distinguished as a chemist and as a biologist, and particularly Robert Koch, have by their experimental methods—among which pure cultures, artificial nutriment (Nährböden), the gelatin processes, and transfer by inoculation, stand at the head—afforded ways and means which we must thank for an immense enrichment of our knowledge.

Again, in the short span of two or three decades, an extensive department of science has been established—I mean bacteriology. For it is the characteristic phenomenon of our age, with its greatly increased interest in science, with its more perfect organization of expert work (*gelichsten arbeit*), with its numerous scientific institutions, with its enlightened and accelerated intercommunication of ideas by journals and by the daily press, that if a new mark is set up, and if the way to its attainment—the scientific method—is found, then everywhere the forces of work are roused to feverish activity as in no earlier time. How quickly were the first abortive experiments followed by a knowledge of microbes. The exciting agents of anthrax, of septicemia and pyemia, of erysipelas, of typhus, of intermittent fever and of cholera, of tuberculosis, of malaria, and of many other infectious diseases of men and of animals, down to insects and worms, were discovered, and their life histories studied.

It is a grand thing to enrich our stock of knowledge by new discoveries; yet it may be not less important and serviceable to refute and eliminate errors, and especially the errors which infest science itself. The less men knew in the past of the vital process the more ready they were to accept as an established fact the hypothesis of spontaneous generation (*Urzeugung*)—that is to say, the assumption that

the simplest living beings take their origin direct from lifeless nature. Just as in the eighteenth century intestinal worms and infusoria, also formerly called infusion-animalculæ (*Aufgussthierchen*), were supposed to arise by "equivocal generation," so at a later date bacteria and allied microbes, because they seemed so very small and simple, and so suddenly invaded liquids without anybody's knowing whence they came, were supposed to be so formed. It was not one of the smallest services which Pasteur rendered, that he irrefutably proved, by scientific methods, that for microbes, too, the saying is fulfilled, "*Omne vivum e vivo*," life comes only from life. By Pasteur's experiments we know that the germs of those organisms are everywhere more or less abundantly distributed in water, air, and earth.

In the doctrine of cells, too, in its first form, the idea of spontaneous generation made a pernicious nest, for, according to the view of Scheiden and Schwann, new cells arise in the bodies of animals and plants by a sort of crystallization from a nutritive solution, either within or without mother cells. The truth that the increase takes place solely by propagation by division was first made out by wearisome labor by the admirable investigations of Mohl and Nägeli, of Remak, Kölliker, and Virchow, and many other students, and raised to the rank of a universal biological law: "*Omnis cellula e cellula*."

It may be broadly said that, in spite of all the progress of science, the chasm between living and lifeless nature, instead of gradually closing up, has, on the contrary, become deeper and wider. More thorough study, aided by philosophical intuition, teaches year by year more distinctly that the cell, that elementary bed rock of living nature, is far from being a peculiar chemical giant molecule, or living albumen, and as such destined to become the subject of the chemistry of the future. The cell is itself an organism, compounded from numerous still smaller vital units. They are of various chemical composition, and are bound together through relations to the vital process of the cells unknown to us. Here lies hidden a world of minute life for the investigation of which the power of our microscopes and usual methods of research fall short, but which, we will hope, a biology of the future, with more perfect instruments and methods, may attain.

A beginning has been made by the elaboration of the method of staining, which we may expect to be extraordinarily perfected and its powers to be greatly increased. To this we must add the insight which the investigations of Bütschli, Strasburger, Flemming, van Beneden, and many others have afforded of the facts (*vorgang*) of the division of nuclei and cells. In karyokinesis we see how, at certain times, minute parts in the cell of diverse chemical nature, such as centrosomes, spindle filaments, chromosomes, nucleoles, and protoplasm tracts are distinguishable, and how, impelled by enigmatical forces,

they arrange themselves in a sequence of complicated figures, and so distribute themselves to two "daughter" organisms.

But the most impressive argument for the doctrine that the cell itself must, in its turn, be a highly complex organism is, above all, the part it plays in the developmental process of higher plants and animals, for the cells of egg and seed, as Nägeli has explained in a philosophical manner, are the vehicles of the numberless properties by which the different species of organisms are distinguished. They therefore consist of hereditary masses or idioplasm, which, in order to include the inherited properties which are destined to become manifest in growth, must be a highly organized body.

With this, I come to the third great advance which biology has effected in the nineteenth century. More than previous ages, our century has been dominated by the idea of development. It has made itself felt as a working leaven in many departments of knowledge, philosophy, history, philology, sociology, and geology; but nowhere more than in biology. Yet the living organism is the only natural object which puts before our eyes, in a short space of time, a complete cycle of development, from the fecundated egg to the perfect creation again productive of new life.

On closer examination the question of the development of the organism embraces two different questions: First, that of the development of the individual—that is, the cycle of phenomena through which it runs, starting from the egg until its natural death; and, secondly, the question as to how so extraordinarily complicated a product as we have found the vegetable or animal organism to be arose in a natural way in the course of the earth's history. Ontogeny and phylogeny, to avail ourselves of a pair of terms introduced by Haeckel, are the two fields of research into which the doctrine of development of organisms is divided.

Ontogeny alone is subject to direct scientific investigation. From the fertilized egg on it is possible, by the choice of suitable plants and animals, to follow their development step by step from one stage to the next. Here again the microscope has been the instrument with the help of which we have penetrated deeply into ontogeny and have set forth the universal laws of formation. Since the days of Pander and Carl Ernst von Baer, who has been called the "father of the history of development" on account of his immortal services, thanks to a great roll of German, French, English, Russian, and Italian embryologists, there has been erected a comprehensive, excellent, lordly, well-joined, systematic history of development. In details many processes have yet to be examined more nicely; but, on the whole, the essence of individual development has been explained upon its morphological side, and we have a right to be proud of the insight into it which we have gained, especially when we recall how the greatest men

of science and philosophers of former centuries—Haller, Leibnitz, Cuvier—were wrecked on the problem of development; how they stood impotent before it with their methods of research.

That every animal, man included, is at the beginning of his life temporarily a single cell; that this cell multiplies by frequently repeated divisions; that the cells arrange themselves into germinal layers from which again the single organs take their origin, and that it is by the association of the cell communities, as they multiply, after many metamorphoses, that the perfect creature is formed, are facts of the correctness of which everybody can easily convince himself. They are secure, permanent acquisitions of science.

With the second question, on the other hand, we pass to the sphere of hypothesis. How did the organisms that are living to-day arise in the course of the earth's history? Certainly an investigator well schooled in philosophy will consider it to be a universal truth that the organisms which to-day people the earth did not in bygone geological ages exist in their present forms, but they, too, must have gone through a process of development, beginning with the simplest forms, which Haeckel has distinguished from the ontogenetical process by terming it phylogenetical. The investigator will come to this conclusion by connecting different departments of biology. He will especially rely upon the facts of individual development, which actually teach a becoming of the complicated from the simpler. He will further appeal to comparative anatomy, upon that philosophical science whose erection has been brought in our century to high perfection by Cuvier and Meckel, by Johannes Müller and Gegenbaur.

But try to fully portray in detail in what special form a species of animals of our day lived in the hoary antiquity, and the ground of experience vanishes beneath you, for of the innumerable millions of creatures which lived in former geological periods—periods whose duration is estimated in millions of years—only scanty remains of skeletons have in exceptional cases been preserved in a fossil condition. Of course from them we can gather but a very incomplete and hypothetical idea of the soft bodies to which they once belonged. Furthermore, it remains in every case undecided whether the descendants of the ancient creature whose sparse remains we study did not die out altogether, so that he can not be claimed as the ancestor of any living form whatever.

Twice in our century has the question of descent deeply stirred both scientists and laymen and injected a powerful ferment into the world of ideas. Brightly shine down upon us from history the opposite names of Lamarck and Darwin. Lamarck, the great French zoölogist, wrote at the beginning of our century, at the time of the German and French philosophy of nature, his famous *Philosophie Zoologique*, a monument of freer philosophical consideration of the

world of organisms. In 1859 Charles Darwin published his epoch-making work upon the origin of species, a work distinguished for the collection and sifting of a great and previously little-noticed mass of facts, and by being crammed with important new points of view. In particular much light was thrown by Darwin upon the relations of organisms to one another and to environing nature, a subject which had previously been neglected and even now is little understood, notwithstanding the partial insight into it which that great genius has afforded.

More fortunate than his forerunner, whose merit was only first recognized by posterity, Darwin saw his doctrine fall upon better prepared soil, so that it produced a scientific movement sustained by enthusiasm and adopting his name, Darwinism. He had the good luck to be supplemented by a powerful advocate, Haeckel, who in knowledge of anatomy and of the history of development far surpassed him. Men now believed that the secret of how new organic species arise was at last out; that the riddle of the "true causes of forms" had been guessed, and that the theory of selection furnished the elucidation of the theory of descent. "Struggle for existence," "survival of the fittest," "natural selection," were the formulæ by which the organic empire was to be laid open. Adherents and opponents to the new doctrine appeared. Hither and thither waged the battle with a vehemence which scientific hypotheses seldom inspire. Darwinists, Ultradarwinists, Antidarwinists, Neodarwinists, Haeckelians, and Weismannists mingled in the fray. Weismann, going beyond Darwin, published *The Omnipotence of Natural Selection*; Herbert Spencer hurled at him with *The Inadequacy of Natural Selection*.

This sort of thing is comprehensible in politics, but how shall we explain such a remarkable turmoil about a scientific question? It seems to me that not the least of the reasons was that the formulæ of explanation, "struggle for existence," "survival of the fittest," "selection," are very vague expressions, which only gain scientific value by the mode in which they are applied in the concrete case. Why has the term "struggle for existence" not been brought down to application? It has become a standing and favorite form of words in writings upon national economy and politics; and there it is excusable. But it begins to be less so when, at the Darwinian flood tide, Du Prel would use it as a formula to explain the motions of the heavenly bodies. With too general terms single cases can not be explained, or a mere shadow of an explanation is given, while the true causal connection remains as much in the dark as before. Now, the problem of scientific research is to make out the precise cause of an observed effect, or, more correctly, since nothing happens from a single cause, its different causes.

But surely the origin of the organic world by natural causes is an extraordinarily intricate and difficult problem. It is as little to be

solved by a magical formula as all diseases are to be cured by one medicine. While Weismann was announcing the "omnipotence of natural selection," he saw himself forced to the confession, "We can usually not prove that any given adaptation is due to natural selection." Now, this is as much as to say: In truth, we know nothing about the complex of causes which has produced the particular phenomenon. "Inadequacy of natural selection" therefore opposes itself, with Spencer.

In this scientific strife with which our century closes, the doctrine of development is to be distinguished from the selection theory. The two stand upon very different ground. For we may say, with Huxley, "If the Darwinian hypothesis were swept away, evolution would still stand where it was." In it we possess a permanent acquisition of our century; one of its greatest, and resting upon facts.

With the discussion of the doctrine of development and the theory of selection, we have already made a step into the realm of physiology. But every division of a science into special departments, including that of biology into anatomy and physiology, is artificial and scarcely capable of being strictly carried out. The construction and the action of a part, or its structure and its function, are intimately connected; so much so, indeed, that neither can truly be understood without studying the other.

Observation alone will afford a very insufficient insight into the mode of working of a particular organ, and in many cases none at all. In order to obtain an answer to the question, What is an organ for (was leistet ein organ)? the physiologist has to avail himself of the most various aids, by which alone he can draw any conclusion from what he has observed; and what the microscope is for the anatomist, that for the physiologist is systematically conducted experimentation, scientific investigation of vegetable and animal organisms.

By phytophysiological experiments, Sachs, Pfeffer, and many other trained experimenters have enlightened us concerning the geotropism and heliotropism of plants, concerning phototaxis, chemotaxis, and similar interesting phenomena. Especially experimental physiology has established in how high a measure plants in all their functions, even in their formation, are dependent upon external factors.

Animal experiments can be conducted in various ways. Against one kind, termed vivisection, which involves slighter or more severe surgical operations, an obstinate campaign has been conducted in general society, and here and there not without some success. It is surely an ill-placed sensibility. For what should all the suffering that the investigator inflicts upon the animal world, and which he takes pains humanely to reduce to a minimum by chloroform and morphine, signify in comparison with the infinitely greater and more numerous benefits suffering humanity enjoys from the medicinal art, which the animal experiment and the knowledge gained by it brings to greater

effectiveness? Or what should the victims of science, so trifling in number, signify in comparison with the numberless and much more grievous sufferings which in the unalterable order of nature one animal often inflicts upon another, it may be in bestial cruelty, or in comparison with the pain which the human race endures from accidents and diseases of all kinds, or which men inflict upon one another in murderous wars?

People ought rather to be thankful that by experiments upon animals physiology has in the nineteenth century most successfully increased the the treasure of our knowledge. The section and excitation of the spinal roots brought us Bell's theorem. In the same way the physiology of the most various peripheral nerves was brought into existence, including that most important of all this series of doctrines, that of the action of the vagus nerves. Johannes Müller established the law of the the specific energy of the nerves of sense. Partial sections of the spinal cord and the study of the heightened and lowered degeneration thereby produced enabled us to get a view of the different nervous paths of conduction. Acute experimenters even succeeded in penetrating into the secrets of the functions of the brain by localized lesions, by removal or other destruction of particular parts of the brain, and in discovering in the spinal marrow a special center of breathing and vascular control, in particular places of the cortex, here a center of language, there a seeing tract, a hearing tract, or a feeling tract, etc.

Experiments upon animals have put many other departments of physiology within reach of the scientific understanding. The celebrated Harvey's doctrine was refined to a mechanics of the circulation of the blood when the velocity of the current, as well as its pressure in different parts of the system of tubes, had been accurately measured by ingenious devices. The study of the physiology of digestion and of metabolism was well begun by making fistulas into the stomach and intestines or by otherwise obtaining juices of the different glands, and these, once obtained, were made the subjects of further experiments to discover their functions in the process of digestion.

A still greater blessing for mankind has come from experiments upon animals in two other directions, which in the nineteenth century have been systematically prosecuted and which are intimately connected with practical medicine, but do not require vivisection. One direction is that of the study of the effects of chemical bodies upon the organism into which they are absorbed. The investigator ought first to ascertain by numerous systematically conducted experiments upon animals what effects in every part of the system chloroform and ether, morphine, cocaine, antipyrine, or powerful poisons such as atropin, belladonna, strychnine, curare, and numerous other chemicals which chemical manufacturers are throwing in constantly increasing profu-

sion upon the market, produce in stronger and in weaker doses before he studies their application as medicines for this or that diseased condition of man.

Our materia medica has been greatly enriched in this way during the last half century, and the increase goes on yearly. I will here call to mind the new processes of cure first tested upon animals which are acquisitions of the latest dates: Koch's tuberculin, the diphtheria serum of Behring and Ehrlich, and the other different kinds of serum that have been proposed against lockjaw, the plague, and many diseases of animals, as well as Pasteur's peculiar method of treatment of hydrophobia.

In the second direction I mentioned I have in mind the study of that great host of maladies evoked by the invasion into the animal system of alien parasitic organisms as excitants of disease. Experiments upon animals have alone rendered possible that great triumphal march which the biological research of our century has traveled over, discovery treading on the heels of discovery. In order to acquaint themselves with the essence of the trichina disease, Leuckart and Virchow caused trichinous meat to be consumed by many animals selected for experiment, and in that way gained a knowledge of the history of development of the trichina and the mode in which, by its introduction into the body of the infected animal, it produces the different stages of the process of disease. Davaine and Koch cleared up the nature of anthrax by inoculating a healthy, susceptible animal with a tiny drop of blood from an animal suffering from anthrax, and in this simple way infected it so as to establish the development of the anthrax bacillus in all stages. The investigator pursues the same method in all cases, with erysipelas and septicæmia, typhus, cholera, the plague, tuberculosis, malaria, and, in a word, all the infectious diseases which are produced by the lowest fungi, bacteria, sporozoa, and other kinds of parasites.

But the modern physiologist contemplates with yet greater pride than that which the results of those animal experiments awaken, the extraordinary success which his science has achieved in our century in two other great fields, those of biochemistry and biophysics.

Under the rule of the vitalistic doctrine the scientific doctrine rife at the beginning of our century was that the organic substances of which the bodies of plants and animals are built could only be produced by the peculiar vital forces of these organisms, so that destiny refused to the chemist the power of imitating any such substances by his insufficient methods.

One brilliant discovery by Wöhler at length shattered the vitalistic error, for he succeeded in producing artificially in his laboratory one of the peculiar products of the vital process of animals, namely, urea. Soon, in the rapid progress upon which organic chemistry now entered,



the like was accomplished in many other cases, until now the audacious hope can be cherished that some day chemistry may perhaps even perform the synthesis of albumen, the most complex of all organic substances. Chemistry has, however, progressed further in the analysis than in the synthesis of these organic bodies from which the cells, tissues, and juices of plants and animals are built, having analytically investigated the carbohydrates, fats, albuminous bodies, and their numberless derivatives and products of decomposition. Thus has a physiological chemistry gradually been developed—a science rich in results, from which still more weighty disclosures are awaited in the future.

The chemical processes upon the normal course of which life depends were naturally in great measure opened up to us by the increased knowledge of organic substances. Pflüger's invention of the mercurial gas pump and other important apparatus and the improvement of chemico-physiological methods generally imparted a powerful upward impulse to the physiology of respiration, of the formation of blood, of assimilation and secretion; while extensive and laborious experimental investigations by Claude Bernard, Pettenkofer and Voit, Ludwig, Pflüger, Heidenhain, and many others successfully elucidated the digestion of albuminous bodies, fats, and carbohydrates and the functions performed by the salivary glands, stomach, liver, and pancreas.

Simultaneously with triumphantly raising its head in the chemical direction, physiology did the same thing in the physical direction. In its contest with vitalism, which held to the assumption of special vital forces as needed for the explanation of life, thus erecting a rigid party wall between the inorganic world and the empire of life, the highest principle of physiology came to be that organisms are subject to the universal laws of nature. Its guiding star was the law of the conservation of force, which was established by Robert Mayer and Helmholtz; while the highest goal of its research was the introduction of physico-mathematical methods into physiology, by which it should become possible, by the methods of weighing, measuring, and counting, to penetrate the essence of the vital process and to render exact account of the different modes of energy which are distinguished as mechanical, chemical, thermic, and electric.

Then broke the dawn of that glorious day when physiology was enriched by apparatus of the most varied description and instruments invented with great ingenuity. By means of the cymograph and the myograph it succeeded in exhibiting to the eye upon the smoked plate and in measuring with the greatest exactitude the minutest features of motions of living organs, of the wall of the heart and those of the blood vessels, as well as the motions of the muscles. Galvanometer, rheostat, and slide-induction apparatus, tangent galvanometer, became common in the armamentarium of every physiological institute in order that the electrical phenomena of muscular action and the

velocity of nervous transmission might be investigated. The ophthalmoscope of Helmholtz and the laryngoscope of Czermak enabled the investigator to aid practical medicine by giant strides into the view of the interior of two important organs.

The improvement of the instrumental equipment of physiology has continued without cessation to the end of the century. Every new acquisition of physics is immediately made available to physiology and medicine. Thus the physician is already, immediately after Röntgen's epoch-making discovery, in condition to bring into clear view upon the photographic plate, by suitable application of the so-called X-rays, parts hidden in the depths of the human body and absolutely invisible to the eye, such as single sections of the skeleton.

So pioneer investigations of physiologists trained in physics—a Helmholtz and a Du Bois-Reymond, a Fechner, Weber, Ludwig, Brücke, and Pflüger—as upon another occasion I have in a few words summarily remarked, have in our century “created a special physics of the nerves and muscles, a physics of the organs of sense, a mechanics of the skeleton and organs of locomotion, a mechanics of respiration and circulation.”

“The eye was explained as a camera obscura arranged according to the laws of optics; the ear as a physical apparatus arranged to bring the nerves to the perception of acoustic vibrations by means of suitable organic structures, vibrating membranes and rods, which, like the wires of a pianoforte, are tuned to the different notes. The larynx became a reed pipe, adapted to the production of tones in vibrations, the lungs serving as the bellows. The laws of filtration and osmosis were adduced for the explanation of absorption and secretion. By a composition of intricate apparatus called a calorimeter the physiologist now determined the amount of heat reckoned in calories produced in the course of a day by an animal body, and undertook the difficult task of striking a balance sheet of the animal transformation of energy, the animal body being debtor to nutriment of different kinds in so many calories of energy, while upon the credit side were summed up the amounts of energy which the body had given in the form of heat produced or mechanical work, and which are absorbed in the processes of metabolism.”

In the face of the great triumphs which physiological science celebrated by the introduction of chemical and physical methods, the majority of investigators became accustomed to the view, to which they were led, too, by the brilliant exposition of it by Du Bois-Reymond, that physiology, imagined as complete, is nothing else than biophysics and biochemistry, and that it has no just pretension to rank as a true science, except so far as it is an application of chemistry and physics, dynamics and mathematics.

From the extreme of a “shallow vitalism,” as Du Bois-Reymond called it, physiologists mostly went to the opposite extreme of a deso-

late mechanism, and believed in the explanation of life as a purely chemo-physical process.

The first consequence was that physiologists in the regular line of the profession, with few exceptions, cultivated, by preference, only such fields as were adapted to chemo-physical methods of research, and left others, such as the physiology of development and generation, altogether untilled. But anatomists, zoologists, and botanists only insisted upon them so much the more. They penetrated deeper into the vital phenomena of the cell, of protoplasm, and of the nucleus. They discovered the wonderfully complicated process of the division of the nucleus, the spindle with its ray figures, and the centrosomes, the chromosomes, and their longitudinal segmentation, and finally they solved the old controversy which had once divided physiologists into the two camps of the animalculists and the ovisists, for now the secret process of fertilization was happily settled in all its phases by simple microscopical observation. The penetration of a spermatozoon into an egg cell, the coalescence of the egg nucleus and the sperm nucleus were successfully and directly observed. They deepened the comprehension of the entire process by the discovery that egg and sperm cells must be prepared, in some sort, for the fructification, by the reduction or expulsion of half the matter of their nucleus, and finally, supported by these and other facts, they ventured to lay the foundation for the problem of heredity by the hypothesis that in the matter of the nucleus the vehicles of inherited characters are found.

So by the side of the chemo-physical school of physiology an anatomo-biological bias gained strength. This endeavored to deepen our inspection of life by microscopical research. But the anatomo-biological bias, the more it enforces itself (*sich geltung verschafft*) by its investigation of the organization of the substratum of life, will the more lead to the insight that the mechanical standpoint in biology is just as one-sided as the vitalistic. Truly one of the chief champions of the mechanistic doctrine—Du Bois-Reymond—has himself applied the critical probe to it and, in principle, has recognized its insufficiency. In his address upon the limits of the knowledge of nature he has set up two insoluble interrogation marks, which later, in his seven world riddles, he has increased to seven, and, really, I do not know why he should have restricted himself to so modest a number. Du Bois-Reymond characterizes the impossibility on the one hand of conceiving the essence of matter and force, and on the other hand of explaining even the lowest degree of consciousness mechanically, as a trite truth, and says that it is an old experience, which no discovery of natural science has in the least modified, that one equally fails whether one adopts the theory of atomism, of dynamism, or the opinion of plenism.

Du Bois-Reymond, it is true, has not himself drawn the conclusion which necessarily follows from this. But the conclusion which in the

biology of the new century will victoriously break its way is that the mechanistic dogma that life, with all its complex phenomena, is nothing at all but a chemo-physical problem is as groundless as vitalism; groundless, at least, so long as one does not understand by physics and chemistry sciences of quite other nature than those which in their purport and their scope from the point of view of their historical development now present themselves. For, as I remarked upon another occasion, "If the problem of the chemist is to investigate the numberless combinations of different kinds of atoms to form molecules, he can, in strictness, not touch upon the problem of life, for this begins where his inquiry ends. Over the structure of the chemical molecule rises the structure of the living substance as a broader and higher kind of organization. Over the structure of the cell rises again the structure of plants and animals, which exhibit the yet more complicated, elaborate combinations of millions and milliards of cells coordinated and differentiated in the most extremely various ways."

What has chemical science, as it now is, to do with this entirely new world of organizations of matter, upon which the first manifestations of life depend? If the chemist wishes to set himself to the task of investigating these, the first thing he has to do is to become a biologist, and especially a morphologist. But then his methods and his aim must be very different from what they are, and far more comprehensive.

As for physics, it stands in precisely the same relation to biology that chemistry does. At present the physiological [physical?] school commonly argues with Du Bois-Reymond thus: In the living being, in the cell, no other forces are efficient than those which the atoms of the cell—carbon, hydrogen, oxygen, nitrogen, phosphorus, etc.—have displayed outside of the cell. "A particle of iron is and remains the very same sort of thing whether it flies through the solar system (Weltkreis) in the meteorite or dashes along upon the rim of the locomotive wheel or trickles in a blood cell through the temples of a bard. As little as in the mechanism of the human hand is there in the last case anything added to the properties of the particle or anything subtracted from them. Those properties are eternal. They are inalienable, untransferable." "But if the atoms have developed no new forces, everything of the physico-chemical kind will happen in the cell precisely as it would in a test tube."

That is the way the argument runs for the standpoint of "everything in the world is chemistry and physics." But our reply is that the word "atom" is merely a fiction useful for science in its present condition; that we know nothing of the sum of the properties and forces in an "atom in itself," and still less how from the properties and forces of different kinds of atoms we are to pass to the properties and forces of their compounds. That from the properties of carbon, combined with those of oxygen, hydrogen, nitrogen, etc., in certain proportions, albumen must result, is a fact as inconceivable in its

essence as that from different albuminous bodies with special organization will come a living cell.

We therefore prefer, in the question which is occupying us, to leave out both the concept of an atom and also the extraordinarily difficult concept of a force of which so much misuse is made, and to confine ourselves to that by which alone a force can be known; that is to say, to its effects. But in reference to these I think and may assert the same thing as in reference to the organization of matter.

Just as by the joining together of atoms to make molecules, of the molecules to make the higher material units of the living cells, of living cells to make plants and animals, ever new, more numerous, and higher forms of organizations are created, so it is with the effects which proceed from them. With every one of the endless stages and forms of organization new modes of action are produced; and when the investigator comes to plants and animals he has to do with an entirely new world of uncommonly manifold effects, which do not occur in lifeless nature and which can not occur there, since the requisite organization is wanting. I will instance only the preservation of the species by growth and reproduction, metabolism, the different kinds of irritability, phototaxis, chemotaxis, geotropism, etc., consciousness, faculties of sense and thought, and, finally, all the different effects which single parts of cells exert upon each other, cell upon cell, organ upon organ, animals and plants upon one another.

Is it the business of the physicist to concern himself with effects of every kind which proceed from all the possible bodies in the world?

Certainly not. As the chemist concerns himself only with the simplest organization of matter, the chemical, but not with biological combinations, so the physicist, as a man of the science as it has historically grown to be, concerns himself only with a certain class of effects, which may be called the elementary ones—a class of effects, in itself considered, extraordinarily large, yet, in comparison with all the modes of action in the world, very small. Should the physicist not choose to impose this limitation upon himself, he would be obliged to unite in one person the labor of the physiologist and psychologist, the sociologist and historian, and whatever other study there may be.

Finally, let it be remarked that the current opinion that the investigation of life is nothing but a chemo-physical problem, and that everything in the world is physics and chemistry, is commonly connected with a gross overvaluation of chemo-physical science. It seems to be forgotten that this science, like everything human, is but a work of detail (*ein Stückwerk*), and at every point jostles against limits of natural knowledge which, for the time being, seem to be insuperable, and that chemistry and physics in this regard have no advantage over biology.

Nägeli well said, in 1877, in his address before the Munich congress upon the "Limits of the knowledge of the natural sciences," that

"Nature in her simpler inorganic phenomena presented the same difficulties for research as in the question of the occurrence of sensation and consciousness from material causes."

The simpler is by no means always the best known, and, indeed, the ordinary course of science is that from the study of the more complex we come to be acquainted with the simpler. In chemistry, analysis, for the most part, precedes synthesis. We have learned what a wonderful sort of element carbon is by having found analytically that it is the base of the carbohydrates, fats, albumens, and now develops in them properties which certainly nobody would have suspected in advance of the carbon in a piece of anthracite. What part the albuminous bodies play in the vital process we know, not by the chemical study of albumen, which can teach us nothing at all about it, but by the study of vegetable and animal cells. Thus science is built not merely from below upward, but quite as much, or even more, from above downward; there penetrating from the simple to the more compound, here from the compound to the simpler.

We have referred above to this syllogism: "If the atoms develop no other forces in the cell than what they have outside of it, then everything of a chemo-physical kind that happens in the cell takes place as it would in a test tube." In the same way and with equal justice we can contrapose this syllogism and so get something like the following: Man feels, remembers, and is conscious; he thinks and builds a world of thought. Since, now, man consists of cells, cells of molecules of albumen, and these, again, of atoms; since every higher stage of organization is naturally developed from the stage next below it, and since the conservation of energy allows no room for Thought to be introduced at any step of the process, it follows that the cell, the molecule, and the atom must feel, remember, be conscious, and think, each after its kind.

Indeed, just such views have already been put forth; and according to them, upon the most important questions, not only of the doctrine of cells but of chemistry and physics, the psychologist would have to be consulted for information.

But by such general reasonings, whether of the progressive or the regressive variety, which leave the solid earth of natural science to float, as it were, in the air, the man of science can reach no useful result. He ought to avoid them both.

The physicist and chemist refuse to recognize atoms that feel, have memory, or think, because they perceive no sign of such properties and their methods can not detect them. With the same justice the biologist must enter a protest against his science being regarded from the restricted standpoint of the chemist and physicist, since its problems and methods for the most part are quite of another sort (*ganz anders geartet*), and are at any rate much more comprehensive and are not near to being exhausted by physics and chemistry.

The man of science, in order to make his researches successful, must limit them to a small part of the immeasurable world problem, quite in contrast with the philosopher. Is it, then, any part of his task to set forth a general conception of the world (*die Welt begreiflich erscheinen zu lassen*) according to a formula? Is not the best notion for him to entertain that the world is capable of being investigated, but that for us, children of the present, the empire of the uninvestigated and of the obscure is a thousandfold greater than the empire of the investigated, of that which has already entered into our science and into human recognition?

The man of science, guided by such considerations, will be conscious that the explanation of the world as a mechanism of jostling atoms rests upon nothing but a fiction, which may be useful for exhibiting many relations, but yet does not correspond to the truth. So that world, deprived of properties, supposed by Laplace, who saw in the world process nothing but effects of atoms whirling past one another, together with a single great sum in arithmetic to be done by knowing the world rule, will seem to the man of science to be, in comparison with the real world, which speaks to him with its infinite properties through all his senses, as a nugatory shadow picture, comparable with those shades in the under world that, like fog, eluded the arm of Ulysses when he tried to seize them.

The scientific man who listens to reason will assent to the propositions in which Carl Ernst von Baer briefly, pertinently, and beautifully described the essence of science: "Science," said he, "is, in its source, eternal; in its operation, not limited by time and space; in its scope, immeasurable; in its problem, endless; in its goal, unattainable."

This last is particularly true of biology, the science of life. Its problem is of the most difficult. Its field extends in all directions, having the closest relations to all sorts of other sciences. In one direction, supported by chemistry and physics, it becomes biochemistry and biophysics. In a contrary direction it forms a connection with the psychical sciences, which relate to mere human nature, with psychology and sociology, with ethics and religion. By it the material and spiritual worlds are placed in connection. And so biology, in the newly dawning century, if its cultivators, free from dogmatic fetters of every kind, shall continue to convert the empire of the uninvestigated into the empire of human knowledge, will be summoned to cooperate, in an eminent way, in the inward civilization of the human race, elevating it to a higher stage, not only of intellectual insight, but also of social and moral conduct. It will so help to bring on the time when the wonderful progress which the nineteenth century has brought in the chemophysical field by the expert mastery over the forces of nature shall first bring to coming generations its full blessing.