Tucholsky Wagner Zola Scott Sydow Fonatne Freud Schlegel
Turgenev Wallace
Twain Walther von der Vogelweide Fouqué Friedrich II. von Preußen
Weber Freiligrath
Kant Ernst Frey
Fechner Fichte Weiße Rose von Fallersleben Richthofen Frommel
Hölderlin
Fehrs Engels Fielding Eichendorff Tacitus Dumas
Faber Flaubert
Maximilian I. von Habsburg Fock Eliasberg Zweig Ebner Eschenbach
Feuerbach Eliot
Ewald Vergil
Goethe London
Elisabeth von Österreich
Mendelssohn Balzac Shakespeare Ganghofer
Lichtenberg Rathenau Dostojewski
Trackl Stevenson Doyle Gjellerup
Tolstoi Hambruch
Mommsen Lenz
Thoma Hanrieder Droste-Hülshoff
von Arnim
Dach Verne Hägele Humboldt
Reuter Hauff
Karrillon Rousseau Hagen Hauptmann
Garschin Gautier
Defoe Baudelaire
Damaschke Hebbel
Descartes
Hegel Kussmaul Herder
Wolfram von Eschenbach Schopenhauer
Dickens
Darwin Rilke George
Bronner Melville Grimm Jerome
Bebel
Campe Horváth Aristoteles Proust
Voltaire Federer
Bismarck Vigny Barlach Herodot
Gengenbach Heine
Storm Casanova Tersteegen Grillparzer Georgy
Lessing Gilm
Chamberlain Langbein
Brentano Gryphius
Lafontaine
Strachwitz Claudius Schiller Kralik Iffland Sokrates
Schilling
Bellamy
Katharina II. von Rußland
Gerstäcker Raabe Gibbon Tschechow
Löns Hesse Hoffmann Gogol Wilde Vulpius
Gleim
Luther Heym Hofmannsthal Morgenstern
Klee Hölty
Roth Goedicke
Heyse Klopstock Kleist
Luxemburg Puschkin Homer
Mörike
La Roche Horaz Musil
Machiavelli
Kraft Kraus
Kierkegaard
Navarra Aurel Musset
Lamprecht Kind Moltke
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Nietzsche Nansen
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Poe Liebermann
Korolenko
de Sade Praetorius Mistral Zetkin

The Story of the Living Machine A Review of the Conclusions of Modern Biology in Regard to the Mechanism Which Controls the Phenomena of Living Activity

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PREFACE.

That the living body is a machine is a statement that is frequently made without any very accurate idea as to what it means. On the one hand it is made with a belief that a strict comparison can be made between the body and an ordinary, artificial machine, and that living beings are thus reduced to simple mechanisms; on the other hand it is made loosely, without any special thought as to its significance, and certainly with no conception that it reduces life to a mechanism. The conclusion that the living body is a machine, involving as it does a mechanical conception of life, is one of most extreme philosophical importance, and no one interested in the philosophical conception of nature can fail to have an interest in this problem of the strict accuracy of the statement that the body is a machine. Doubtless the complete story of the living machine can not yet be told; but the studies of the last fifty years have brought us so far along the road toward its completion that a review of the progress made and a glance at the yet unexplored realms and unanswered questions will be profitable. For this purpose this work is designed, with the hope that it may give a clear idea of the trend of recent biological science and of the advances made toward the solution of the problem of life.

Middletown, Conn., U.S.A.

October 1, 1898.

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INTRODUCTION.

Biology a New Science.—In recent years biology has been spoken of as a new science. Thirty years ago departments of biology were practically unknown in educational institutions. To-day none of our higher institutions of learning considers itself equipped without such a department. This seems to be somewhat strange. Biology is simply the study of living things; and living nature has been studied as long as mankind has studied anything. Even Aristotle, four hundred years before Christ, classified living things. From this foundation down through the centuries living phenomena have received constant attention. Recent centuries have paid more attention to living things than to any other objects in nature. Linnæus erected his systems of classification before modern chemistry came into existence; the systematic study of zoology antedated that of physics; and long before geology had been conceived in its modern form, the animal and vegetable kingdoms had been comprehended in a scientific system. How, then, can biology be called a new science When it is older than all the others?

There must be some reason why this, the oldest of all, has been recently called a *new* science, and some explanation of the fact that it has only recently advanced to form a distinct department in our educational system. The reason is not difficult to find. Biology is a new science, not because the objects it studies are new, but because it has adopted a new relation to those objects and is studying them from a new standpoint. Animals and plants have been studied long enough, but not as we now study them. Perhaps the new attitude adopted toward living nature may be tersely expressed by saying that in the past it has been studied as *at rest*, while to-day it is studied as *in motion*. The older zoologists and botanists confined themselves largely to the study of animals and plants simply as so many museum specimens to be arranged on shelves with appropriate names. The modern biologist is studying these same objects as intensely active beings and as parts of an ever-changing history. To the student of natural history fifty years ago, animals and plants were objects to be *classified*; to the biologist of to-day, they are objects to be *explained*.

To understand this new attitude, a brief review of the history of the fundamental features of philosophical thought will be necessary. When, long ago, man began to think upon the phenomena of nature, he was able to understand almost nothing. In his inability to comprehend the activities going on around him he came to regard the forces of nature as manifestations of some supernatural beings. This was eminently natural. He had a direct consciousness of his own power to act, and it was natural for him to assume that the activities going on around him were caused by similar powers on the part of some being like himself, only superior to him. Thus he came to fill the unseen universe with gods controlling the forces of nature. The wind was the breath of one god, and the lightning a bolt thrown from the hands of another.

With advancing thought the ideas of polytheism later gave place to the nobler conception of monotheism. But for a long time yet the same ideas of the supernatural, as related to the natural, retained their place in man's philosophy. Those phenomena which he thought he could understand were looked upon as natural, while those which he could not understand were looked upon as supernatural, and as produced by the direct personal activity of some divine agency. As the centuries passed, and man's power of observation became keener and his thinking more logical, many of the hitherto mysterious phenomena became intelligible and subject to simple explanations. As fast as this occurred these phenomena were unconsciously taken from the realm of the supernatural and placed among natural phenomena which could be explained by natural laws. Among the first mysteries to be thus comprehended by natural law were those of astronomy. The complicated and yet harmonious motions of the heavenly bodies had hitherto been inexplicable. To explain them many a sublime conception of almighty power had arisen, and the study of the heavenly bodies ever gave rise to the highest thoughts of Deity. But Newton's law of gravitation reduced the whole to the greatest simplicity. Through the law and force of gravitation these mysteries were brought within the grasp of human understanding. They ceased to be looked upon as supernatural, and became natural phenomena as soon as the force of gravitation was accepted as a part of nature.

In other branches of natural phenomena the same history followed. The forces and laws of chemical affinity were formulated and studied, and physical laws and forces were comprehended. As these natural forces were grasped it became, little by little, evident that the various phenomena of nature were simply the result of nature's forces acting in accordance with nature's laws. Phenomena hitherto mysterious were one after another brought within the realm of law, and as this occurred a smaller and smaller portion of them were left within the realm of the so-called supernatural. By the middle of this century this advance had reached a point where scientists, at least, were ready to believe that nature's forces were all-powerful to account for nature's phenomena. Science had passed from the reign of mysticism to the reign of law.

But after chemistry and physics, with all the forces that they could muster, had exhausted their powers in explaining natural phenomena, there apparently remained one class of facts which was still left in the realm of the supernatural and the unexplained. The phenomena associated with living things remained nearly as mysterious as ever. Life appeared to be the most inexplicable phenomena of nature, and none of the forces and laws which had been found sufficient to account for other departments of nature appeared to have much influence in rendering intelligible the phenomena of life. Living organisms appeared to be actuated by an entirely unique force. Their shapes and structure showed so many marvellous adaptations to their surroundings as to render it apparently certain that their adjustment must have been the result of some intelligent planning, and not the outcome of blind force. Who could look upon the adaptation of the eye to light without seeing in It the result of intelligent design? Adaptation to conditions is seen in all animals and plants. These organisms are evidently complicated machines with their parts intricately adapted to each other and to surrounding conditions. Apart from animals and plants the only other similarly adjusted machines are those which have been made by human intelligence; and the inference seemed to be clear that a similar intelligence was needed to account for the *living machine*. The blind action of physical forces seemed inadequate. Thus the phenomena of life, which had been studied longer than any other phase of nature, continued to stand aloof from the rest and refused to fall into line with the general drift of thought. The living world seemed to give no promise of being included among natural phenomena, but still persisted in retaining its supernatural aspect.

It is the attempt to explain the phenomena of the living world by the same kind of natural forces that have been adequate to account for other phenomena, that has created modern Biology. So long as students simply studied animals and plants as objects for classification, as museum objects, or as objects which had been stationary in the history of nature, so long were they simply following along the same lines in which their predecessors had been travelling. But when once they began to ask if living nature were not perhaps subject to an intelligent explanation, to study living things as part of a general history and to look upon them as active moving objects whose motion and whose history might perhaps be accounted for, then at once was created a new department of thought and a new science inaugurated.

Historical Geology.—Preparation had been made for this new method of studying life by the formulation of a number of important scientific discoveries. Prominent among these stood historical geology. That the earth had left a record of her history in the rocks in language plain enough to be read appears to have been impressed upon scientists in the last of the century. That the earth has had a history and that man could read it became more and more thoroughly understood as the first decades of this century passed. The reading of that history proved a somewhat difficult task. It was written in a strange language, and it required many years to discover the key to the record. But under the influence of the writings of Lyell, just before the middle of the century, it began to appear that the key to this language is to be found by simply opening the eyes and observing what is going on around us to-day. A more extraordinary and more important discovery has hardly ever been made, for it contained the foundation of nearly all scientific discoveries which have been made since. This discovery proclaimed that an application of the forces still at work to-day on the earth's surface, but continued throughout long ages, will furnish the interpretation of the history written in the rocks, and thus an explanation of the history of the earth itself. The slow elevation of the earth's crust, such as is still going on to-day, would, if continued, produce mountains; and the washing away of the land by rains and floods, such as we see all around us, would, if continued through the long centuries, produce the valleys and gorges which so astound us. The explanation of the past is to be found in the present. But this geological history told of a history of life as well as a history of rocks. The history of the rocks has indeed been bound up in the history of life, and no sooner did it appear that the earth's crust has had a readable history than it appeared that living nature had a parallel history. If the present is a key to the past in interpreting geological history, should not the same be true of this history of life? It was inevitable that problems of life should come to the front, and that the study of life from the dynamical standpoint, rather than a statical, should ensue. Modern biology was the child of historical geology.

But historical geology alone could never have led to the dynamical phase of modern biology. Three other conceptions have contributed in an even greater degree to the development of this science.

Conservation of Energy.—The first of these was the doctrine of conservation of energy and the correlation of forces. This doctrine is really quite simple, and may be outlined as follows: In the universe, as we know it, there exists a certain amount of energy or power of doing work. This amount of energy can neither be increased nor decreased; energy can no more be created or destroyed than matter. It exists, however, in a variety of forms, which may be either active or passive. In the active state it takes some form of motion. The various forces which we recognize in nature—heat, light, electricity, chemism, etc.—are simply forms of motion, and thus forms of this energy. These various types of energy, being only expressions of the universal energy, are convertible into each other in such a way that when one disappears another appears. A cannon ball flying through the air exhibits energy of motion; but it strikes an obstacle and stops. The motion has apparently stopped, but an examination shows that this is not the case. The cannon ball and the object it strikes have been heated, and thus the motion of the ball has simply been transformed into a different form of motion, which we call heat. Or, again, the heat set free under the locomotive boiler is converted by machinery into the motion of the locomotive. By still different mechanism it may be converted into electric force. All forms of motion are readily convertible into each other, and each form in which energy appears is only a phase of the total energy of nature.

A second condition of energy is energy at rest, or potential energy. A stone on the roof of a house is at rest, but by virtue of its position it has a certain amount of potential energy, since, if dislodged, it will fall to the ground, and thus develop energy of motion. Moreover, it required to raise the stone to the roof the expenditure of an amount of energy exactly equal to that which will reappear if the stone is allowed to fall to the ground. So in a chemical molecule, like fat, there is a store of potential energy which may be made active by simply breaking the molecule to pieces and setting it free. This occurs when the fat burns and the energy is liberated as heat. But it required at some time the expenditure of an equal amount of energy to make the molecule. When the molecule of fat was built in the plant which produced it, there was used in its construction an amount of solar energy exactly equivalent to the energy which may be liberated by breaking the molecule to pieces. The total sum of the active and potential energy in the universe is thus at all times the same.

This magnificent conception has become the cornerstone of modern science. As soon as conceived it brought at once within its grasp all forms of energy in nature. It is primarily a physical doctrine, and has been developed chiefly in connection with the physical sciences. But it shows at once a possible connection between living and non-living nature. The living organism also exhibits motion and heat, and, if the doctrine of the conservation of energy be true, this energy must be correlated with other forms of energy. Here is a suggestion that the same laws control the living and the non-living world; and a suspicion that if we can find a natural explanation of the burning of a piece of coal and the motion of a locomotive, so, too, we may find a natural explanation of the motion of a living machine.

Evolution—A second conception, whose influence upon-the development of biology was even greater, was the doctrine of evolution. It is true that the doctrine of evolution was no new doctrine with the middle of this century, for it had been conceived somewhat vaguely before. But until historical geology had been formulated, and until the idea of the unity of nature had dawned upon the minds of scientists, the doctrine of evolution had little significance. It made little difference in our philosophy whether the living organisms were regarded as independent creations or as descended from each other, so long as they were looked upon as a distinct realm of nature without connection with the rest of nature's activity. If they are distinct from the rest of nature, and therefore require a distinct origin, it makes little difference whether we looked upon that origin as a single originating point or as thousands of independent creations. But so soon as it appeared that the present condition of the earth's crust was formed by the action of forces still in existence, and so soon as it appeared that the forces outside of living forces, including astronomical, physical and chemical forces, are all correlated with each other as parts of the same store of energy, then the problem of the origin of living things assumed a new meaning. Living things became then a part of nature, and demanded to be included in the same general category. The reign of law, which was claiming that all nature's phenomena are the result of natural rather than supernatural powers, demanded some explanation of the origin of living things. Consequently, when Darwin pointed out a possible way in which living phenomena could thus be included in the realm of natural law, science was ready and anxious to receive his explanation.

Cytology.—A third conception which contributed to the formulation of modern biology was derived from the facts discovered in connection with the organic cell and protoplasm. The significance of these facts we shall notice later, but here we may simply state that these discoveries offered to students simplicity in the place of complexity. The doctrine of cells and protoplasm appeared to offer to biologists no longer the complicated problems which were associated with animals and plants, but the same problems stripped of all side issues and reduced to their lowest terms. This simplifying of the problems proved to be an extraordinary stimulus to the students who were trying to find some way of understanding life.

New Aspects of Biology.—These three conceptions seized hold of the scientific world at periods not very distant from each other, and their influence upon the study of living nature was immediate and extraordinary. Living things now came to be looked upon not simply as objects to be catalogued, but as objects which had a history, and a history which was of interest not merely in itself, but as a part of a general plan. They were no longer studied as stationary, but as moving phases of nature. Animals were no longer looked upon simply as beings now existing, but as the results of the action of past forces and as the foundation of a different series of beings in the future. The present existing animals and plants came to be regarded simply as a step in the long history of the universe. It appeared at once that the study of the present forms of life would offer us a means of interpreting the past and perhaps predicting the future.

In a short time the entire attitude which the student assumed toward living phenomena had changed. Biological science assumed new guises and adopted new methods. Even the problems which it tried to solve were radically changed. Hitherto the attempt had been made to find instances of *purpose* in nature. The marvellous adaptations of living beings to their conditions had long been felt, and the study of the purposes of these adaptations had inspired many a magnificent conception. But now the scientist lost sight of the purpose in hunting for the *cause.* Natural law is blind and can have no purpose. To the scientist, filled with the thought of the reign of law, purpose could not exist in nature. Only cause and effect appeal to him. The present phenomena are the result of forces acting in the past, and the scientist's search should be not for the purpose of an adaptation, but for the action of the forces which produced it. To discover the forces and laws which led to the development of the present forms of animals and plants, to explain the method by which these forces of nature have acted to bring about present results, these became the objects of scientific research. It no longer had any meaning to find that a special organ was adapted to its conditions; but it was necessary to find out how it became adapted. The difference in the attitude of these two points of view is world-wide. The former fixes the attention upon the end, the latter upon the means by which the end was attained; the former is what we some-