The Mystery of Life.¹

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DURING the last forty years the sciences of physics and chemistry have made tremendous strides. The physico-chemical world has been analysed into three components, electrons, protons, and the electro-magnetic field with its streams of radiant energy. Concurrently with these advances astronomy has progressed to an extent undreamed of forty years ago. Amidst the vast cosmos disclosed to the mind of man, our sun winds its modest way, an unimportant star, old in years and approaching death. Once upon a time, so the astronomers tell us, its surface was rippled by the gravitational pull of a passing star, and the ripples becoming waves broke and splashed off. Some drops of this glowing spray, held by the sun's attraction in revolving orbits, cooled down and became the planets of our solar system. Our own planet, the earth, gradually acquired a solid crust. Then the water vapour in its atmosphere began to condense, and produced oceans, lakes, and rivers, as the temperature sank. It is probably at least a thousand million years since the earth acquired a solid crust of rock. During that period living beings, plants and animals, have appeared, and, as the story of the rocks tells us, have developed by degrees from small and lowly ancestors. The last product of this development is the mind of man. What a strange story! On the cool surface of this little planet, warmed by the rays of a declining star, stands the small company of life. One with the green meadows and the flowers, the birds, and the fishes, and the beasts, man with all his kith and kin counts for but an infinitesimal fraction of the surface of the earth, and yet it is the mind of man that has penetrated the cosmos and discovered the distant stars and nebulae. Truly we may say that life is the great mystery, and the study of life the greatest study of all. The understanding of the phenomena of life will surely be the crowning glory of science, towards which all our present chemical and physical knowledge forms but the preliminary steps.

Observing the apparent freedom, spontaneity, and indeed waywardness of many forms of life, we are at first lost in amazement. Is this thing we call life some strange and magical intruder, some source of lawless and spontaneous action, some fallen angel from an unknown and inconceivable universe? That is indeed the question we have to examine, and we may begin our examination in a general way by inquiring whether living things are subject to the laws of energy that control the mass phenomena of the inanimate world. The first of these laws, known as the law of the conservation of energy, says that work or energy can only be produced at the expense of some other form, and that there are definite rates of equivalence or exchange between the appearing and disappearing forms of energy. In a closed

system we can make up a balance sheet and we find that the algebraic sum of the increases and decreases, allowing of course for the fixed rates of exchange, is zero. That was one of the great discoveries of the nineteenth century. The physiologists have found that living beings form no exception to this law. If we put a guinea-pig or a man into a nutrition calorimeter, measure the work and heat produced and the energy values of the food taken in and the materials given out, we find our balance sheet correct. The living being neither destroys nor creates energy.

Another great discovery of the nineteenth century, the so-called second law of thermodynamics, restricts the direction of energy transformations. So far as is known, the facts of biology and physiology seem to show that living beings, just like inanimate things, conform to the second law. They do not live and act in an environment which is in perfect physical and chemical equilibrium. It is the non-equilibrium, the free or available energy of the environment, which is the sole source of their life and activity. As Bayliss so finely put it, equilibrium is death.

The chief source of life and activity on this planet arises from the fact that the cool surface of the earth is constantly bathed in a flood of high temperature light. If radiation in thermal equilibrium with the average temperature of the earth's crust were the only radiant energy present, practically all life as we know it would cease, for then the chlorophyll of the green plants would cease to assimilate carbonic acid and convert it into sugar and starch. The photo-chemical assimilation of the green plant is a fact of supreme importance in the economy of life. This transformation of carbonic acid and water into starch and oxygen represents an increase of free energy, since the starch and oxygen tend naturally to react together and give carbonic acid and water. A living being is not a magical source of free energy or spontaneous action. Its life and activity are ruled and controlled by the amount and nature of the free energy, the physical or chemical non-equilibrium, in its immediate environment, and it lives and acts by virtue of this. The cells of a human brain continue to act because the blood stream brings to them chemical free energy in the form of sugar and oxygen. Stop the stream for a second and consciousness vanishes. Without that sugar and oxygen there could be no thought, no sweet sonnets of a Shakespeare, no joy, and no sorrow.

To say, however, that the tide of life ebbs and flows within the limits fixed by the laws of energy, and that living beings are in this respect no higher and no lower than the dead things around us, is not to resolve the mystery. Growth and development seem to proceed on a definite plan, and apparently purposeful adaptation confronts us at many stages of life. How can the differential equations of physics or the laws of physical

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chemistry attempt to explain or describe such strange and apparently marvellous phenomena? The answer to this question was given more than fifty years ago by the great French physiologist, Claude Bernard. We must patiently proceed, he said, by the method of general physiology. Its method consists in determining *the elementary condition of the phenomena of life*. We must decompose or analyse the great mass phenomena of life into their elementary unit or constituent phenomena.

To-day general physiology in its application of physics, chemistry, and physical chemistry to the operations of the living cell, is the fundamental science of life. Patiently pursued and step by step it is unravelling the mystery. The future findings of general physiology may be as strange to the investigators of to-day as the relativity theory of Einstein and Minkowsky was to the physicists of a few years ago; yet they will be continuous and homologous with the science of to-day. Should, indeed, a new form of energy, 'a special nervous energy,' be discovered, as predicted by the eminent Italian philosopher, Eugenio Rignano, it will be no twilight will-o'-the-wisp, no elusive entelechy or shadowy vital impulse, but an addition to our knowledge of a character permitting of exact measurement and of exact expression by means of mathematical equations.

The chemistry and energy changes of muscle have been discovered recently by Meyerhof in Germany and by A. V. Hill and others in England. When the muscle tissue contracts and does work, it derives the necessary free energy, not from oxidation, which is not quick enough, but from the rapid exothermic conversion of the carbohydrate glycogen into lactic acid. When the fatigued muscle recovers, it recharges its store of free energy; that is to say, by oxidising or burning some of the carbohydrate, it reconverts the lactic acid into glycogen. Thus in the recovery stage we have the coupled reactions of exothermic oxidation and endothermic conversion of lactic acid into glycogen. Everything proceeds according to the laws of physics and chemistry. Here we see one of the elementary phenomena of life already to a great extent analysed and elucidated.

Another example is what I may call the blood equilibrium. The red blood cells are enclosed in a membrane which does not allow the hæmoglobin to escape, and only permits of the passage of inorganic anions, though water and oxygen can pass freely in and out. Between the red cells and the external blood plasma in which they are submerged there exists a whole series of delicate exchange equilibria, such as water or osmotic equilibrium, ion-distribution equilibria, etc. The entrance of oxygen, which combines with the hæmoglobin, converts it into a stronger acid and ejects carbonic acid from the bicarbonate ions within the cell. Any disturbance of one of these equilibria produces compensating changes in the others. The whole series of equilibria can be written down in a set of precise mathematical equations. Thus two of the most important elementary phenomena of

many forms of life, namely, respiration and the exchanges of the red blood cells, have been analysed, subjected to exact measurement, and described by exact mathematical equations.

What is the lesson to be drawn from these examples? No less than that the elementary phenomena of life are *deterministic*; that is to say, that events compensate or succeed each other just as in the physico-chemical world of inanimate things, and that their compensations and successions can be exactly measured and expressed in the form of precise mathematical equations. The investigations of general physiology, so far pursued, indicate that the elementary phenomena of life are quite as fully deterministic as phenomena on a corresponding scale of magnitude in the inanimate physico-chemical world.

Let us now make the daring supposition that general physiology, following the lead of Claude Bernard, has eventually succeeded in quantitatively analysing every side and every aspect of the elementary condition of life. Would such a supposedly complete and quantitative analysis give us a synthesis of life? That is one of the most fundamental and difficult questions of biological science. A living being is a dynamically organised individual, all the parts of which work harmoniously together for the well-being of the whole organism. The whole appears to us as something essentially greater than the sum total of its parts. This aspect of the living individual was fully recognised by Claude Bernard. It has been emphasised recently by General Smuts in his remarkable book on "Holism and Evolution." Life, as seen by General Smuts, is constantly engaged in developing wholes, that is to say, organised individualities. We may indeed learn how the regulative and integrating action of the nervous system, so beautifully and thoroughly investigated by that great physiologist, Sir Charles Sherrington, serves to organise and unite together in a harmonious whole the varied activities of a complex multicellular animal. We may learn, too, how those chemical substances, the hormones, discovered by Bayliss and Starling, are secreted by the ductless glands, and, circulating in the *milieu intérieur* of an animal, act as powerful means for harmoniously regulating and controlling the growth and other activities of the various organs and tissues. Nevertheless, in spite of these great discoveries, the harmonious and dynamic correlation of the various organs and tissues of a living organism ever confronts us as one of the great mysteries of life. In an inanimate physico-chemical system we think, if we know the situations, modes of action and inter-relations of the component parts, whether particles or waves (or both), together with the boundary conditions of the system, that we have effected a complete synthesis of the whole. Though very crudely expressed, some such view as that lies at the basis of the Newtonian philosophy which rules our thought in the inanimate physico-chemical world.

Leibnitz once remarked that "the machines of nature, that is to say, living bodies, are still

machines in their smallest parts *ad infinitum*." Anatomy and histology have progressively disclosed the structure of living things. Histology has revealed to us the cell with its nucleus and cytoplasm as the apparently fundamental unit of all organs and tissues of a living being. What is contained within the membrane of a living cell? Here we approach the inner citadel of the mystery of life. If we can analyse and understand this, the first great problem—perhaps the only real problem—of general physiology will have been solved. The study of the nature and behaviour of the living cell and of unicellular organisms is the true task of biology to-day.

The living cell contains a system known as protoplasm, though as yet no one can define what protoplasm is. One of the fundamental components of this system is the class of chemical substance known as protein, and each type of cell in each species of organism contains one or more proteins which are peculiar to it. Strange to say, the living cell contains within itself the seeds of death, namely, those so-called autolytic enzymes which are capable of hydrolysing and breaking down the protein components of the protoplasm. So long, however, as the cell continues to live, these autolytic enzymes do not act. What a strange thing! The harpies of death sleep in every unit of our living bodies, but as long as life is there their wings are bound and their devouring mouths are closed.

It appears from A. V. Hill's work on non-medullated nerve cells and on muscle that the organised structure of these cells is a *chemodynamic* structure which requires oxygen, and therefore oxidation, to preserve it. The organisation, the molecular structure, is always tending to run down, to approach biochemical chaos and disorganisation. It requires constant oxidation to preserve the peculiar organisation or organised molecular structure of a living cell. The life machine is therefore totally unlike our ordinary mechanical machines. Its structure and organisation are not static. They are in reality dynamic equilibria, which depend on oxidation for their very existence. The living cell is like a battery which is constantly running down and requires constant oxidation to keep it charged.

The last great problem which I shall venture to consider in this brief sketch concerns the origin of life. If the living has arisen on this planet from what we regard as the non-living, then various extremely interesting points arise. It is already fairly certain that it originated, if at all, in the primeval ocean, since the inorganic salts present in the circulating fluids of animals correspond in nature and relative amounts to what we have good reason to believe was the composition of the ocean some hundred million years ago. The image of Aphrodite rising from the sea is therefore not without scientific justification. The question arises as to how organic substances could have arisen by degrees in a primeval ocean originally containing only inorganic constituents? The late Prof. Benjamin Moore took up this subject and endeavoured to prove that colloidal iron oxide, in the presence of light, moisture, and carbon dioxide could produce formaldehyde, a substance from which sugar can be derived. This work of Moore's has been actively taken up and developed by Prof. Baly in recent years. He has conclusively proved that, in the presence of light, moisture, and carbon dioxide, formaldehyde and sugar can be produced at the surface of certain coloured inorganic compounds, such as nickel carbonate. We may therefore conclude that the production of the necessary organic substances in the primeval ocean offers no insuperable obstacle to science.

The sincere and honest men who are advancing science, whether in the region of life or death, are those who measure accurately, reason logically, and express the results of their measurements in precise mathematical form. A hundred or a thousand years from now mathematics may have developed far beyond the extremest point of our present-day concepts. The technique of experimental science at that future date may be something undreamed of at the present time. But the advance will be continuous, conformal, and homologous with the thought and reasoning of to-day. The mystery of life will still remain. The facts and theories of science are more mysterious at the present time than they were in the days of Aristotle. Science, truly understood, is not the death, but the birth, of mystery, awe, and reverence.

Obituary.

ROALD AMUNDSEN.

HAD Ibsen lived to write the Saga of Roald Amundsen, he might have analysed the emotions which surged through the explorer's soul in a tempest of ambition, triumph, and tragedy. The dramatic episodes of the adventurous life seem to demand a psychological nexus more likely to be found in philosophy than in science, and only capable of full expression in poetry.

Roald Amundsen was born at Borgo in the south of Norway on July 16, 1872; he lived in Oslo from his infancy, going through the ordinary Norwegian educational course. His father, who was a ship-owner, died when the boy was fourteen years of age, and his mother, being desirous of seeing him in the

medical profession, induced him reluctantly to begin the preliminary studies at the University of Oslo. Since as a boy of fifteen he had been enthralled by the story of Sir John Franklin, he had secretly set his heart on becoming a polar explorer, and to fit himself for the life he took every opportunity of exercising himself in ski-running, and slept with open windows throughout the Norwegian winters. His first journey in Arctic conditions very nearly proved his last adventure in exploration. In the Christmas holidays of 1892 he started with a companion to cross the Norwegian plateau from a farmhouse near Oslo to one near Bergen, an uninhabited stretch of 72 miles, with no possibility of reaching Bergen if the house which marked the only practicable