The Creation of "Artificial Life"

The Making of Living Matter from Non-living

By Benjamin C. Gruenberg

FROM time to time we are informed that the Riddle of the Universe has been solved by the artificial production of "life" from non-living materials. But each time we wondered how it was done, for a few days, and then find out that it wasn't done at all. The riddle is still there. The expression "artificial life" has been used in recent years for two entirely different sets of ideas.

On the one hand is the attempt to make artificial combinations of matter behave like living protoplasm—that is, to make live matter out of the non-living materials lying all about us. On the other hand is the attempt to make the eggs of various animals develop without the co-operation of the sperm—or to produce "artificial parthenogenesis," as it has been called. Both kinds of experiments are calculated to throw much light on the fundamental nature of "life;" but they differ considerably in their methods as well as in the point of view that prompts them. We shall discuss first what has been done toward the making of "artificial life" in the cruder sense.

The problem of artificial life is connected intimately with that of the origin of life, and also with that of the characteristics or distinctive properties of living matter.

From earliest times there has persisted the idea that plants or animals may arise "spontaneously" from non-living matter, notwithstanding the common experience of mankind that wherever the origin of a living thing could actually be observed, it was seen to arise from another living thing. This widespread belief in "spontaneous generation" no doubt owed its tenacity to the fact that in many cases the continuity between generations could not be directly observed. For example: Eggs of eels had never been seen until within our own times; maggots were known to develop in putrifying meat, but no one had seen the flies deposit their eggs in the meat; the presence of tape-worms and other parasites within the bodies of human beings and other animals; the presence of insects within the "galls" of plants, without any apparent means of entrance—all these facts served to perpetuate the idea that life can, and regularly does, arise spontaneously. The idea that all organisms arise from pre-existing organisms is a comparatively modern one; and it was accepted on philosophical grounds long before there was any actual demonstration of the principle. From the nature of the case, however, the principle *omne vivum e vivo* cannot be proven, since it involves a negative. It is equivalent to the statement that living matter does not arise from non-living matter. In the seventeenth century Francesco Redi, a physician of Florence, showed that by preventing the access of insects to meat, no grubs or maggots could be formed in it, no matter how much it putrefied. In opposition to these experiments, a Scotch clergyman named Needham attempted in the middle of the following century to show by means of experiments that "wheat-eels" and other animals do arise spontaneously. He showed incidentally that tiny animalcules appeared in extracts of vegetable matter, on long standing, even after these had been boiled. But his contemporary, the Italian monk Spallanzani, showed that if the decoctions were thoroughly boiled and closed against the entrance of dust, there would be no appearance of life. Although Spallanzani's experiments were not beyond criticism, his conclusions were in harmony with those accepted by practically all

biologists to-day—namely, that all existing plants and animals have originated from others of essentially the same kind.

But although the notion of "spontaneous generation" has been thus abandoned by all scientific thinkers in modern times, the question of the origin of life took on a new interest with the spread of evolutionary thought during the latter part of the nineteenth century. Darwin did not attempt to answer this ques-

tion. He took for granted the origin of life, in some simple form, as the beginning of that evolution to higher forms which he attempted to explain with his theory of natural selection.

Apart from the theory of special creation for each species, there is only one opinion possible as to the origin of life, and that is that at some time in the past non-living material passed into a living condition—in other words, that life did originate "spontaneously!" This notion of spontaneous origin of life must not be confused with the older notion of the spontaneous generation of plants and animals of all degrees of complexity.

Alfred Russell Wallace and others think it necessary to assume that the origin of life from non-living matter was brought about by the interposition of some spiritual or divine influence, of the nature of which we know nothing. Charlton Bastian and another school of biologists think that the transition of non-living matter into the living state has taken place continually from the first, and is taking place now. But most biologists accept the view that living matter originated from non-living in the very remote past, and that all living things now existing are derived by a succession of generations from the primitive origins.

The Swedish physicist Arrhenius and the Englishman Lord Kelvin are strong advocates of the view that life upon this earth was developed from primitive "germs" that were brought here in the remote past "upon the wings of light" or upon some meteorites, through lifeless space. It has been pointed out a number of times that this account of the origin of life simply shifts to some other planet or system the theater of the origin, without giving us any suggestion as to the manner of the origin.

The requirements of any evolution theory are met by the assumption that life originated "spontaneously" from non-living matter at some time in the history of this planet, or of the universe. But to know whether such an assumption is warranted, we should know more about the characteristics of living matter, especially in its relation to non-living matter. Until comparatively recent times the processes going on in living plants and animals had been so little studied that the idea of life being dependent upon external conditions was entertained by very few men. With the development of modern physics and chemistry, and with the application of the methods as well as of the results of these sciences to the study of living things, this idea rapidly spread, until it is now pretty generally accepted. Moreover, the strong tendency during the past two generations to unify all knowledge, and to extend the principles of one science to the problems of all others, have stimulated the search for the physical and chemical foundations for "vital" processes.

Of all the lines of research thus developed, only three need here be discussed.

The word "protoplasm" had a varied career for about twenty years; but about fifty years ago it began to be definitely applied to "the physical basis of life," or the substance found in the cells of all plants and all animals. We know a great deal about this peculiar substance—or rather combination of substances; but there is still a great deal more that we do not know. There have been many opinions as to the structure of this living matter—that it is fibrilla, that it is like a net-work, that it is a mass

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Fig. 1.—An "artificial plant" which was produced in a test-tube

Fig. 1a.—Artificial organs showing mushroom shape.

Fig. 2.—"Artificial cells" formed by the diffusion of drops of ten per cent potassium ferro-cyanide in a ten per cent gelatine solution.

Fig. 3.—"Artificial cells" produced by the diffusion of colored drops of salt solution in a less concentrated solution.

Fig. 4.—An imitation of the appearance of nuclear division produced by diffusion between two poles of the same sign.

Fig. 5.—Fields of force produced by diffusion. (a).—Monopolar, produced by a drop of blood in salt solution of higher concentration. (b).—Bipolar produced by a drop of blood and a grain of salt.

Fig. 6.—A bipolar field of force produced, according to the methods of Prof. Stéphane Leduc, by diffusion between two drops of blood in a salt solution of higher concentration.

Fig. 7.—Diffusion figures produced, according to the method of Prof. Stéphane Leduc, by drops of India ink in a solution of potassium nitrate.

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The New British Dreadnoughts

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accommodation is 3,500 tons of coal with considerably over 1,000 tons of oil fuel in addition; the subsidiary engines are driven by steam and not by Diesel engines as in previous battleship-cruisers. In spite of the high horse-power and heavy battery, sufficient proportion of weight has been found to adequately protect the ship against shell fire and submarine explosion. The belt is of 9¼-inch Simpson steel, thinning to about 4-inch at the bow and stern, leaving a space of 20 feet unprotected at the ends, the hull being minutely subdivided in lieu of the armor. The barbettes are of 11-inch plate, the hoods being 12-inch; a protected deck of 2¾ inches and subdivision by bulkheads is utilized on similar lines to the "Orion." The conning-tower is of a new and splinter-proof pattern, there being no apertures in the tower itself but a large dome-shaped projection rises from the rear of the roof provided with slots giving an almost all-round view. A second tower is situated aft of the after wireless telegraphy pole-mast.

Taking into account the speed, gun power, and protection of this ship, it is debatable whether the fighting power is not equivalent or superior to that of the "Orion." It must be admitted that the British Admiralty and their board of construction have evolved in these ships war-machines with an unprecedented potential power of destruction in view of the limitations imposed upon them by cost and displacement. The ships now building, or authorized ("King George V." and "Queen Mary" classes) are of the same general type as the "Orion" and "Lion," but improvements have added somewhat to the displacements. What further perfection and also whether the limit of size has yet been attained in these huge ships can only be shown by the passage of time.

Artificial Life

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of foam. The microscope does not tell us all that we should like to know—and it tells us one thing at one time, and other things at other times. It is quite possible that the "structure" of protoplasm is different in different organisms; or that it is different in different parts of the same organisms; or that it is different within the same cell under different conditions. At any rate, Prof. Bütschli, to demonstrate his idea of the "alveolar" or foam-like structure of protoplasm, mixed some finely powdered potassium carbonate with olive oil that had been heated from 125 to 140 deg. F. The oil becomes partly saponified, producing an acid. This acid reacts on some of the carbonate, producing minute bubbles of carbon dioxide. Under the microscope a drop of this frothing mixture looks like a speck of protoplasm, and the movements in it even resemble the streaming in a living cell.

Some fifteen years ago these experiments were hailed by certain journalists as successful attempts to produce artificial life. But no one who knows anything about the problem, least of all Prof. Bütschli, thought that these experiments had anything to do with the creation of life. The experiments were successful in the sense that they gave us a working model made of familiar materials, to help us understand the minute structures and movements within the cell. How hard error does die is suggested by the fact that these experiments have been described over and over again in all grades of publications as a method for making "artificial protoplasm" until this very year.

After the fact of cell-structure in organisms had become well established, one of the problems that interested the experimentalists was that of the growth of the cell wall, which to all appearances is not itself alive. To test the theory that growth is produced by a stretching of the membrane with subsequent deposition of new material in the interspaces of the old wall, Moritz Traube carried on some very suggestive experiments. He allowed a solution of sugar and gelatine to come in contact with a solution of tannin through the narrow opening of a small tube. Now as soon as the tannin touches the gelatine it forms a membrane through which the water

may easily pass, but through which the sugar cannot pass at all. The globule within the membrane continues to absorb water from the tannin solution by osmosis, stretching the membrane. The membrane grows, and under certain circumstances puts forth branches in various directions, the whole taking in the appearance of some weird plants or "sea-weeds."

Traube's further experiments, from 1865 on, and those of others, extended our knowledge of osmosis, threw some side lights on the mechanism of the cell-growth, and furnished amusement to many persons, for these osmotic gardens are curious and somewhat mystifying. But no biologist has in all these years suspected that Traube's phenomena were in any way related to "artificial life" until a few years ago Dr. Stéphane Leduc, professor of physics in the medical faculty of the University of Nantes, announced that he had discovered the physico-chemical foundations of life. He presented before the French Academy of Sciences a large number of demonstrations, in which he made "plants grow from artificial seeds." These seeds consisted of sugar plus some salt that would form a precipitation membrane with the substances of his growing medium. For example, copper sulphate in a "seed" would cause growths in a solution of potassium ferrocyanide. These growths were in no way different from those obtained by Traube and others, except that Leduc used a larger variety of substances in his experiments than had been used by other experimenters. Anyone can make for himself a garden of such "artificial plants" with very little trouble. Perhaps the easiest way is to place at the bottom of a jar a number of crystals of salts of heavy metals (e. g., sulphates of copper, iron, zinc, cobalt) and carefully pouring over them a 10 per cent solution of sodium silicate or "water glass." The insoluble silicates of the metals will form the membranes, osmosis will cause them to stretch, variations in the density of the medium will cause irregular branching, and the colors of the salts within the membranes will give a further resemblance to "plants." (Fig. 1 and Fig. 1a.)

Leduc went farther, however, and produced imitations of living structures down to the smallest details. By placing a drop of colored salt solution into another solution of lower concentration, he produced "artificial cells." More definite cell membranes are produced by placing drops of 10 per cent solution of potassium ferrocyanide in a 10 per cent gelatine solution. (Figs. 2, 3.) The appearance of nuclear division within a cell he produced by placing two drops of some solution near each other within another solution. (Fig. 4.) That all these phenomena are due to osmosis or diffusion is well known to all physicists; that they are not in any true sense identical with "growth" and "nuclear division" may be known only to the student of biology. Among other demonstrations made by Leduc in this connection was the formation of a "field of force" by the diffusion of liquids of different densities. (Figs. 5, 6, 7.)

That the "artificial life" of Leduc had no real bearing on the fundamental physiological problems has been shown repeatedly, and Prof. Leduc has in later statements denied that he confused his phenomena with life processes, although his original confusion is on record in the proceedings of the Academy. Perhaps the best analysis of Leduc's results is that of Prof. Maurice D'Halluin, director of the physiological laboratory at the University of Lille. This experimenter not only repeated all of Leduc's "demonstrations" but even showed that the various weird forms assumed by the "artificial plants" could be controlled by changing the concentration of the solutions, or by changing the proportions of the different materials used. Nevertheless we still find fairly frequent references, to Leduc's overstepping the threshold between the non-living and the living by means of "artificial seeds."

In the spring of 1905 we had another "artificial life" sensation in the announcement that Mr. John Butler Burke, "of the Cavendish Laboratory of Cambridge University," had obtained some curious, life-like structures from the action of radium upon sterilized bouillon. Mr. Burke was following up a sugges-

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tion made many years before by Prof. E. Pflüger of the University of Bonn, that the essential difference between living protein and non-living protein lay in the fact that in the former oxidation or transformation of energy is *internal*, and that this internal oxidation could perhaps have been induced by cyanogen, a compound of carbon and nitrogen which was probably produced during the incandescent stage of the earth's history. Having failed to induce phosphorescence or other indications of the internal transformation of energy in organic substances by means of cyanogen, Mr. Burke resorted to radium.

The test-tubes containing gelatine and beef-extract in the proportions used for bacteriological cultures were properly sterilized, and a minute quantity of radium chloride or bromide was added. The appearance of the gelatine changed, suggesting bacterial growths. Under the microscope there were seen tiny roundish bodies that increased in size, divided and moved about slightly! This was certainly life-like. In order to make sure that they were not bacteria due to contamination, the tubes were examined by Dr. Sims Woodhead, professor of pathology at Cambridge. This authority declared they were *not* bacteria at all. They were not even living things, for they dissolved in water; they disappeared entirely after standing in diffuse daylight for a little while, to reappear after a few days of darkness. Moreover, on being transferred to fresh bouillon, they did not increase in numbers.

But the world was clamoring for artificial life; Burke could not lose so good a lead. Instead of calling his new discovery bacteria, which they were not, he called them "radiobes," implying that they were life-like things produced by radium. They were unlike any other living thing, so Burke set to work and elaborated a new definition of life, so that the radiobes could fit in. Otherwise he should not have created "artificial life."

That the radiobes were not living things, in the accepted sense of the word living, must be obvious to nearly everyone. But what are they then? Prof. Sir William Ramsay explains these structures are due to bubbles of hydrogen and oxygen gas (arising from the decomposition of water by the radium salt) and "radium emanation." The "growth" is due to the continuous production of more gas by further decomposition of water by the emanation within the bubble; the expansion of the gas might also lead to the breaking up of the bubbles into two or more. (Fig. 8.)

Fig. 8.—Radiobes in various stages of division. After Burke.

At any rate, the water-soluble radiobes are not alive, and it was later found that they could be produced in the bouillon by other substances besides radium, such as salts of barium, strontium, and lead. "Radiobes" produced by these substances also have "nuclei" consisting of insoluble sulphates of the metals used.

The failure of scientists so far to produce "artificial life" is not to be charged against the science of biology. Very few of the attempt to produce "artificial life" have been made by biologists, who realize too well the complexity of the problems involved. The biologists will be satisfied for a number of years to come if they succeed merely in analyzing what goes on in a living cell, in terms of physical and chemical processes. From time to time they will attempt to imitate a structure or a process by means of a working model; but they will not speak of artificial life until they are quite sure of all the conditions that play a part in this most intricate of phenomena.

The Solar Constant.—In the *Proceedings of the American Philosophical Society*, May-June, 1911, Mr. C. G. Abbot defines the solar constant as "the number

of degrees by which one gramme of water at 15 deg. C. would be raised, if there should be used to heat it all the solar radiation which would pass at right angles in one minute through an opening one centimeter square, located in free space, at the earth's mean solar distance." Experiments were begun about 1835 by Pouillet and Sir John Herschel for the measurement of this great constant of nature, and the investigation has been continued by Forbes, Crova, Violle, Radau, Langley, K. Angström, Chwolson, W. A. Michelson, Rizzo, Hansky, Scheiner, Abbot, Fowle, and others. The difficulty of the problem is shown by the fact that until a few years ago entire uncertainty prevailed as to the value of the solar constant, between the limits of Pouillet's value, 1.76 calories, and Angström's value, 4.0 calories per square centimeter per minute. The author and his colleagues have made over 400 observations with special apparatus, including the silver-disk pyrheliometer, an absolute water-flow pyrheliometer, and the recording spectro-bolometer, at Washington, Mount Wilson and Mount Whitney, to determine the value of the solar constant and its possible fluctuations; and they now announce a mean value of 1.922 calories, which may prove to be 1 or 2 per cent too low, as the observations have been made mainly near the time of sun-spot maximum, and hence of diminished radiation. This value is, moreover, subject to fluctuations amounting to about 8 per cent, at irregular intervals of a few days; and these fluctuations are thought to indicate a true variability of the sun itself. In other words, the solar "constant" is probably variable.

The Current Supplement

WE have previously had occasion to refer to the fact that the United States Post Office is finding it economical to do some of its own printing, instead of giving out the work to contractors, as heretofore. In the current issue of our SUPPLEMENT, Mr. Gunnaway describes the arrangements which have been made for printing money orders on the government's own presses.—In the second instalment of his article on the Great Star Map, Prof. Turner deals with the subject of "Star Counting." A note on the Variation in the Purchasing Power of Gold should prove of general interest.—We like to keep track, not only of progress at home, but also of the course of events abroad. An article on the electrification of suburban lines in the British capital is published with this object in view.—We have seen the automobile invading a great variety of fields of usefulness. The motor car to the rescue is the modern cry when fire threatens property and life, as is illustrated by an article on a new auto-fire-engine.—The article on Practical Aspects of Printing Telegraphy reaches its seventh instalment in this issue.—The Mechanical Handling of Freight is a most important technical problem, to the solution of which new contributions are added every day. One example of this is shown in an illustrated article.—Factory Economy is the guiding principle ever before the eyes of the works superintendent. A description of an immense superheater utilizing waste heat and installed in one of the plants of the United States Steel Corporation is interesting in this connection.—An article from the pen of the great genius, Prof. Wilhelm Ostwald, on the Biology of the Savant, brings us one of his lucid studies in the psychology of great personality.—The extraction of crude cocaine and its refining process is described in an article derived from the *Engineer*.

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