A. I. Oparin

THE ORIGIN OF LIFE

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A. I. OPARIN
MEMBER OF USSR ACADEMY OF SCIENCE

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CONTENTS

CHAPTER ONE

THE ORIGIN OF LIFE—MATERIALISM VERSUS IDEALISM AND RELIGION

What is life? How did it originate? This question ranks among the greatest problems of natural science. Everyone, irrespective of his education, consciously or otherwise has asked himself this question and answered it in one way or another. No world-view, be it the most primitive, can exist without that question being answered.

The problem of life's origin has intrigued the human mind since time immemorial. There is no school of philosophy, no thinker deserving of the name, that has not given it the most serious attention. In various epochs and at different stages of cultural development the problem was solved in different ways, but at all times it remained a subject of sharp ideological combat between the two irreconcilable philosophical camps—materialism and idealism.

In observing our natural environment we usually divide it into two worlds—that of living beings and that of inanimate things, the inorganic world.

The world of living beings consists of an immense range of animal and plant species. But despite this variety, all living beings, from man down to the tiniest microbe, share something in common, something that sets even the simplest germ apart from the objects of the inorganic world. It is this "something" that we call life—in the term's most elementary sense.

But what is the essence of life? Is the nature of life, like that of the rest of the world, material or does its essence lie in some spiritual source which defies cognition by experience?

If life is material, it should be possible to investigate its laws and to change and refashion its bearers in a conscious and methodical manner. But if life has been created by a spiritual entity and its essence is unknowable, we can only be passive onlookers of living nature and remain helpless before what are alleged to be unfathomable phenomena of supernatural origin.

Idealists have always considered life as the manifestation of some sublime, spiritual, immaterial entity—the "soul", the "universal spirit", "vital force", "divine reason", and the like. In their eyes matter is lifeless and stagnant. It serves as the material from which animate beings are moulded, and these can exist, they assert, only when this material is made animate by the soul, which gives form and structure to substance.

This idealist conception of life lies at the bottom of all the world's religions. In spite of their diversity they unanimously lay down that a higher being—God—has breathed a living soul into perishable and lifeless matter, and it is this eternal divine particle which is animate and which motivates and preserves every living being. When this particle deserts the body, it leaves nothing but an empty material shell—a rotting, decomposing corpse. Life is the expression of divinity; man, therefore, cannot know the essence of life, nor can he ever learn to govern it. Such is the basic conclusion drawn by all religions as regards the essence of life; without it any religious teaching is unthinkable.

Materialism approaches this problem from a diametrically opposite standpoint. It holds that the nature of life, like that of the rest of the world, is material; its cognition does not depend on the recognition of a supermaterial, spiritual entity. Life is a special form of the existence of matter; its origin and disintegration is governed by special laws. Practice, objective experience, and observation of living nature are a reliable road leading to the cognition of life.

The entire history of the science of life—biology—shows us the fruitfulness of the materialist method of studying living nature through objective observation, experience, and social and historical practice; the completeness with which it reveals the essence of life and allows us to master living nature and consciously and methodically to change and refashion it in the interests of man, of the builder of communism.

The history of biology presents an uninterrupted chain of scientific achievements demonstrating the full cognoscibility of life, and an uninterrupted chain of defeats for idealism. And yet for a long time there existed a problem which did not lend itself, apparently, to a materialist solution and which, therefore, served as a welcome sanctuary for every kind of idealist pettifoggery—the problem of life's origin.

We daily observe that all animate beings are produced by their like—a woman gives birth to a human child; a cow brings forth a calf; a hen hatches a chicken; fish is developed from the roe of other fish of the same species; plants grow from seeds which have ripened on plants of the same kind.... But such, obviously, could not have been the case always. Our planet had its beginning. How did the progenitors of all animals and plants appear on the Earth?

According to religious conceptions all the various living beings were originally created by God. As a result of this divine creative act all the forebears of the plants and animals which today inhabit our planet appeared simultaneously and in a ready-made form. The first man, the father of mankind, was likewise created by a similar act.

For example, according to the Bible, the sacred book of the Jews and the Christians, God created the world within six days; he created plants on the third day, fish and fowl on the fifth, animals on the sixth, and, lastly, humans: first man, then woman. Adam, the first man, was moulded by God from an inanimate material—clay, after which he furnished him with a soul, thus breathing life into him.

The study of the history of religion shows that these naive stories about the sudden origination of plants and animals in a completely ready and organized form stem from an ignorant, uncritical interpretation of superficial observations of our natural environment.

Thus, for centuries it was held that the Earth is flat and motionless, that the Sun revolves about it, going up in the east and setting behind the sea or mountains in the west. The same kind of superficial observations often led man to believe that not only can various animate beings (such as insects and worms, and even fish, fowl, and mice) be produced by their like, but they can also originate spontaneously in silt, manure, soil, and other inanimate materials. Wherever man was confronted with an unexpected and large-scale appearance of living beings, he regarded it as a case of spontaneous generation. Even now ignorant people are convinced that worms generate in manure and rotten meat and that various domestic parasites appear from nothing in rubbish, dirt, and dung. The fact escapes their superficial observation that dirt and rubbish are only the seat or nest where parasites lay their eggs from which a new generation of living beings arises.

Ancient teachings of India, Babylon, and Egypt record cases of sudden self-generation of worms, flies, and beetles in manure and dirt; lice in human sweat; frogs, snakes, mice, and crocodiles in the mud of the Nile; fireflies from the sparks of bonfires. These legends concerning spontaneous generation were linked in those teachings with religious myths. The sudden appearance of animate beings was regarded as a manifestation of the creative will of gods or demons.

Already in Ancient Greece many materialist philosophers rejected these religious explanations of the origin of animate beings. However, it so came about in subsequent centuries that the idealist teaching of Plato, the ancient Greek philosopher, was developed and became dominant.

According to his anti-materialist conceptions, plant and animal matter is not animate in itself and can only be made so by the "psyche"—the immortal soul. This Platonic idea played a great negative role in the further development of the problem under consideration. To a certain extent the idea was embodied in the teaching of another ancient Greek philosopher—Aristotle, which later became the backbone of medieval culture and dominated the human mind for nearly two thousand years.

In his writings Aristotle not only described a number of cases when, in his opinion, living creatures appeared spontaneously, but gave this phenomenon a theoretical explanation. He believed that living beings, like all the other concrete entities, are created by the combination of a certain passive source—matter—with an active source—form. The form of all living beings is the "entelechy of the body", the soul, which forms the body and actualizes it. Matter, therefore, does not possess life, but is embraced by it, formed according to pattern, and organized with the help of the power of the soul which animates matter and preserves it.

Aristotle's views had a profound effect on the treatment of the question of life's origin in later epochs. All subsequent philosophical schools, whether Greek or Roman, fully concurred with the Aristotelian view on the sudden self-generation of living beings. With time the theoretical substantiation of sudden self-generation acquired a more and more idealist and even mystic character.

In particular, it acquired such a character at the beginning of our era in the teaching of the New Platonists. Plotinus, the head of this philosophical school, whose influence was very wide-spread at the time, taught that all living creatures had originated and were originating as a result of the sublimation of matter by a life-giving spirit. It was Plotinus, in all probability, who coined the term "vital force", which still lives in our day in the reactionary teaching of the modern vitalists.

The early Christians relied on the Bible for the solution of the problem of life's origin. The Bible, in its turn, lifted its data from the mystic legends of Egypt and Babylon. The ecclesiastical authorities of the end of the fourth and the beginning of the fifth centuries, the so-called Fathers of the Christian Church, edited these legends in conformity with the teaching of the New Platonists and on that basis elaborated a mystic conception of the origin of life which to this day has been fully preserved by all the Christian dogmas.

Saint Basil, the Bishop of Caesarea, who lived in the middle of the fourth century A. D., while sermonizing on the world's creation in six days, taught that at God's word the Earth itself produced various herbs, roots, and trees as well as locusts, insects, frogs, snakes, mice, birds, and eels. "That word of God," the saint wrote, "continues to this day to act with unflagging force."

Saint Augustine, a contemporary of Saint Basil and one of the most influential authorities of the Catholic Church, also strove in his writings to explain the spontaneous generation of living creatures on the basis of the Christian world-view. The phenomenon, he averred, was produced by an arbitrary act of God which animated dead matter by a "life-giving spirit", by "invisible spiritual seeds". Thus he made the teaching on self-generation fully compatible with the dogmas of the Christian Church.

The Middle Ages left this anti-scientific conception virtually intact. At that time any philosophical idea could exist only in a theological shell, in the garb of a church doctrine. The problems of natural science were relegated to the background. Men formed opinions on nature not on the basis of observation and experience, but from the study of the Bible and of theological writings. Only a meagre amount of information in the field of mathematics, astronomy, and medicine filtered into Europe from the Orient.

The works of Aristotle that reached the peoples of Europe were often grossly mistranslated. His teaching was thought dangerous at first, but later on, when the Church realized that it could well adapt his teaching for many of its purposes, it lauded Aristotle as "Christ's predecessor in natural science". Needless to say, "scholasticism and priestdom", as Lenin aptly put it, "took the dead from Aristotle, and not the living. . . ." (V. I. Lenin, *Philosophical Notes.*) Particularly as regards the question of life's origin, the teaching on the self-generation of organisms—the essence of which, as seen by the Christian theologians, consisted in the animation of lifeless matter by an "eternal divine spirit"—was widely developed.

By way of illustration we could refer the reader to one of the most notorious medieval divines—to Thomas Aquinas. The teaching of the "Angelic Doctor" is to this day regarded by the Catholic Church as the only orthodox philosophy. Saint Thomas laid down in his works that living creatures are produced by the animation of lifeless matter. Thus do frogs, snakes, and fishes appear in decomposing sea mire and manured soil. Even those worms which torture sinners in hell appear there, says the saint, as a result of rotting sins. Saint Thomas was in general an ardent advocate and propounder of demonology. He was convinced of the existence of the Devil and his horde of demons. He therefore declared that parasites appear not only at God's will, but also as a result of the machinations of the Devil and the lesser evil spirits. Translated into practice this principle led to the numerous medieval trials of "witches" accused of sending mice and other pests into the fields and thus destroying crops.

Through the reactionary teaching of Thomas Aquinas the Western Christian Church made a dogma of the principle of self-generation, i.e., the occurence of organisms in lifeless matter as a result of the latter's animation by a spiritual entity.

The ecclesiastical authorities of the Eastern Church adhered to the selfsame principle. Thus, for example, Dmitry, the Bishop of Rostov, a contemporary of Peter the First, advocated this principle in a manner most startling to the modern mind. He wrote that at the time of the Deluge Noah did not take upon his ark mice, toads, scorpions, cockroaches, mosquitoes, and all the other creatures which "in bogs and of decay are born ... and by heavenly dew are conceived". All these creatures perished in the Deluge and were "once again brought forth from the same substances after the Deluge".

To this day Christianity, as do all the other religions of the world, holds that living beings have appeared and are appearing as a result of a divine creative act in a ready-made form, by way of self-generation, independently of the development of matter.

However, a profound study of living nature has enabled scientists to establish the fact that no sudden selfgeneration of living organisms ever takes place in the world about us. This was proved as far back as the middle of the 17th century in respect to the more highly developed organisms, such, in particular, as worms, insects, reptiles, and amphibia. Subsequent research extended the range to include the less highly organized creatures down to the simplest micro-organisms which, though invisible to the naked eye, surround us on all sides and inhabit earth, water, and air.

Thus, the "fact" of the sudden generation of living beings, which the various religions attempted to put down to the animation of dead matter by a life-giving spirit, the "fact", which served as the foundation-stone for religious solutions

Frederic Engels

of the problem of life's origin, was found to be non-existent, a product of false observation and ignorant interpretation.

The 19th century dealt another crushing blow to religious conceptions of the origin of life. Charles Darwin and many other scientists, including the Russian researchers K. A. Timiryazev, the brothers A. O. and V. O. Kovalevsky, and I. I. Mechnikov, showed that our planet has not always been inhabited by the plants and animals we know now, as affirmed by the Holy Writ. The higher plants and animals, including man, did not appear on the Earth all of a sudden, but emerged during the latest epochs of our planet's existence as a result of a consecutive development of the less highly organized creatures. The latter, in turn, were developed from even more simply organized creatures which lived before them, and so down to the most primitive of living beings.

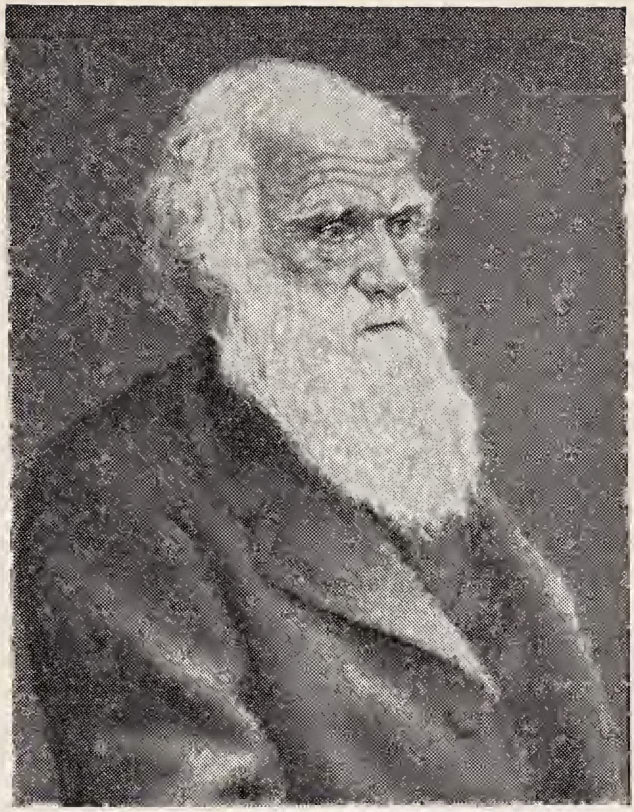
By studying the fossilized remnants of those plants and animals which inhabited the Earth many millions of years ago, we clearly see that in those times the living population of the Earth was not what it is today, that the earlier the age, the simpler and less diversified the population.

Climbing gradually down this stairway, and studying the more and more ancient stages of life, we at last find ourselves viewing the most elementary of living beings, akin to our modern micro-organisms, which were once the sole inhabitants of the world. And it is here that the question inevitably arises: what sources gave birth to the simplest and most primitive creatures of living nature, the progenitors of all that lives on the Earth?

Natural science, having refuted the concept of the possibility of the generation of living beings independently of the concrete conditions of the development of the material world, was confronted with the task of explaining the transition from lifeless matter to life, that is, with the task of solving the problem of life's origin.

The history-making works of Frederic Engels, *Anti-Dühring* and *Dialectics of Nature*, and his outstanding generalization of the achievements of natural science, provide the first genuinely scientific formulation of the problem of life's origin. Engels also determined the further channels of scientific investigations in this field, the roads along which Soviet biology is now successfully travelling.

Engels cast aside as anti-scientific the opinion which admitted the possibility of living creatures generating independently of natural conditions, and established the unity of living and lifeless nature. Basing himself on scientific evidence, he regarded life as a product of development, as the qualitative transformation of matter prepared



Charles Darwin

by historically conditioned, gradual changes of nature in the period preceding the origin of life.

The exceptional merit of Darwin's teaching consists in its having supplied a scientific, materialist explanation of the origin of the higher animals and plants as a result of the consecutive development of the living world, in its having applied the historical method of investigation to the solution of biological problems. However, the old metaphysical approach towards the problem of life's origin was still present in the method of Darwin's successors. The teaching of Mendel and Morgan, so wide-spread in American and West-European scientific circles, is responsible for the assertion that the bearers of heredity and all the other vital properties are particles of a special gene substance concentrated in the chromosomes of the cellular nucleus. These particles are said to have appeared suddenly on the Earth and to have preserved their life-determining structure basically unchanged in the entire course of life's development. Thus, in the Mendelist-Morganist view, the problem of life's origin boils down to the question of how did the particle of gene substance, possessing all the properties of life, suddenly appear.

The majority of foreign authors who have expressed opinions on this matter (for instance, Devillers in France and Alexander in the U.S.A.) chose a very crude line of approach. According to them, the gene molecule appeared by sheer accident, thanks to a "fortunate" combination of the atoms of carbon, hydrogen, oxygen, nitrogen, and phosphorus, which "of themselves" formed the extremely complex molecule of the gene substance that immediately acquired all the attributes of life.

But a "fortunate event" of this kind, they allege, is so exceptional and uncommon that it could have taken place only once during the Earth's lifetime. Since then it has been merely a case of the constant reproduction of an eternal and unchangeable gene substance which originated but once.

This "explanation", of course, explains essentially nothing whatever. The characteristic peculiarity of all living beings without exception is that their internal organization is extremely well, perfectly, adapted to the performance of definite vital functions: nourishment, respiration, growth, and reproduction in the given conditions of existence. How then could this internal adaptation which is so characteristic of even the most elementary living forms have arisen as a result of a sheer accident?

While anti-scientifically negating the law-determined process of life's origin and regarding this major event in the life of our planet as accidental, the adherents of the views stated above are powerless to answer this question and resort to the most idealistic and mystic concepts of the primary creative will of a deity and of a pre-ordained plan in life's creation. Thus, in *What is Life? The Physical Aspect of the Living Cell*, a book published recently by E. Schrödinger, in *Life, Its Nature and Origin*, by Alexander, an American biologist, and in a number of other books by bourgeois authors, we find flat assertions to the effect that life could have arisen only as a result of divine creative will. The Mendelists and Morganists attempt ideologically to disarm biologists in their struggle against idealism. They strive to prove that the question of the origin of life—that crucial problem in any world outlook—cannot be solved on materialist grounds.

However, this assertion is false through and through. It is easily disproved if we approach the question armed with the only correct and genuinely scientific philosophy—dialectical materialism.

According to dialectical materialism, life is material. However, life is not an inalienable property of matter generally. Life is the property of living beings alone; it is absent in the objects and materials of the inorganic world. Life is a special form of motion of matter. But this form has not existed permanently, it is not isolated from inorganic matter by an impassable gulf, but has, on the contrary, emerged from the latter as a new quality in the process of the world's development.

Dialectical materialism lays down that matter never remains in a state of rest; it constantly moves, develops, ascends in its development ever higher stages and acquires more and more complex and perfect forms of motion. Rising to a higher stage of development, matter acquires novel qualities that it lacked before. Life is precisely such a quality; it occurs as a definite stage or step in the historical development of matter. Hence it is clear that the main road leading us straight to the solution of the problem of life's origin is the road of studying the history of the development of matter. It was this development that led to the emergence of a new quality—to the appearance of life.

But life did not crop up all at once, as those who believed in spontaneous self-generation endeavoured to prove. Even the most elementary living beings are too complex in structure to be able to appear suddenly; they could only emerge as a result of consecutive transformations, over a long period, of the substances of which they are composed. These transformations took place eons ago, during the Earth's formation and its infancy. Therefore, in order correctly to solve the problem of life's origin, we must turn to the study of these transformations, to the history of the formation and development of our planet.

In V. I. Lenin's *Materialism and Empirio-Criticism* we find a clear indication of the evolutionary nature of life's origin. "Natural science," he wrote, "positively asserts that the Earth once existed in such a state that no man or any other creature existed or could have existed on it. Organic matter is a later phenomenon, the fruit of a long evolution."

At the beginning of this century J. V. Stalin, propounding the fundamentals of the materialist theory in his work *Anarchism or Socialism?*, also pointed quite definitely to the evolutionary road of life's origin: "We know, for example, that the earth was once an incandescent, fiery mass; then it gradually cooled, plants and animals appeared, the development of the animal kingdom was followed by the appearance of a certain species of ape, and all this was followed by the appearance of man.

"This, broadly speaking, is the way nature developed."

It should be mentioned that this statement was made by J. V. Stalin at a time when Engels' *Dialectics of Nature* had not yet been published, and when most natural scientists (including the progressives) adhered to the mechanist principle in the question of life's origin. It was only in the second decade of the present century that the evolutionary approach towards the problem began to come into its own in natural science. In this connexion it may be appropriate here to quote the words of the famous Russian scientist K. A. Timiryazev. In his article *From the Scientific Chronicle of 1912* he stated the following as regards the question of the origin of life: "... We are forced to admit that living matter progressed in the same way as all the other material processes—in an evolutionary manner." And, "The evolutionary hypothesis, which now embraces not only biology, but all the other natural sciences—astronomy, geology, chemistry, physics—leaves us convinced that this process, probably, was also present during the transition from the inorganic to the organic world."

Among the works which have appeared in this country special mention should be made of *The Origin of Plants*, by Academician V. L. Komarov. Having examined and disproved the theory of the eternal nature of life, which held that the Earth was colonized by space-spores, Komarov wrote: "The only scientific theory of life's origin is the biochemical theory, the profound conviction that life's appearance was merely one of the consecutive stages in the general evolution of substance, the complication of a long series of carbonic compounds of nitrogen."

In our days the principle of the evolutionary development of matter has been accepted not only by Soviet natural scientists, but by many of their foreign colleagues. But the majority of researchers in capitalist countries extend this principle only to those periods in the evolution of matter which preceded the rise of living beings. However, when it comes to this most important stage in the historical development of matter, they invariably beat a retreat to their former mechanic positions, to the "fortunate event" and to fantastic physical forces.

Faced with the problem of life's origin, modern natural science is called upon to draw a correct picture of the consecutive evolution of matter which led to the appearance of the first living beings, to analyze the individual stages in the historical development of matter on the basis of scientific fact, and to lay bare the laws which consecutively appeared in the process of evolution and ushered in life.

CHAPTER TWO

THE PRIMARY ORIGIN OF THE MOST ELEMENTARY ORGANIC SUBSTANCES—HYDROCARBONS AND THEIR DERIVATIVES

The bodies of all animals, plants, and microbes are to a large extent composed of organic substances. Without them life is unthinkable. Therefore, the primary formation of these substances, the formation of that basic material which eventually led to the appearance of all living creatures, necessarily marks the initial stage of the origin of life.

Organic substances differ from substances of the inorganic world, first and foremost, in that they are built around the element of carbon. This is easily demonstrated by heating various materials of animal and plant origin to a high temperature. All these materials burn when they are thus heated in air or are carbonized when air is shut out, while materials of inorganic nature—stone, glass, metal—do not carbonize no matter how long they are heated.

In organic substances carbon is compounded with other elements: hydrogen and oxygen (these two elements are contained in water), nitrogen, considerable quantities of which are contained in air, sulphur, phosphorus, and so forth. Various organic substances present extremely diversified compounds of these elements, but carbon invariably forms their base. Hydrocarbons—compounds of carbon and hydrogen—are the most elementary of organic substances. Natural oil and such of its products as benzine, kerosene, etc., are mixtures of various hydrocarbons. On the basis of the latter chemists easily produce by synthesis numerous organic compounds, at times highly complex ones, possessing, in a number of cases, qualities akin to those of organic compounds extracted from living beings, as, for example, sugar, fats, essential oils, etc.

In what way, then, did these organic substances originally appear on our planet?

When I first turned to the study of the problem of life's origin—some thirty years ago—the question of the primary formation of organic substances seemed a mystery which defied investigation and understanding. For direct observations of our natural environment showed that the vast mass of the organic substances of the animate world now originates on the Earth as a result of the vital activity of organisms. Living green plants, absorbing inorganic carbon from the air, produce from it with the use of solar energy the organic substances they require. Animals, fungi, bacteria, and other organisms which are not coloured green obtain the necessary organic substances by feeding on plants or by decomposing their bodies and remains. In this manner, the entire modern living world owes its existence to this process of photosynthesis or the analogous process of chemosynthesis. Moreover, even all the organic substances which are deposited in the bowels of the Earth in the form of peat, coal, and oil also for the most part originated as a result of the vital activity of numerous organisms that once inhabited the Earth and were later interred in the Earth's crust.

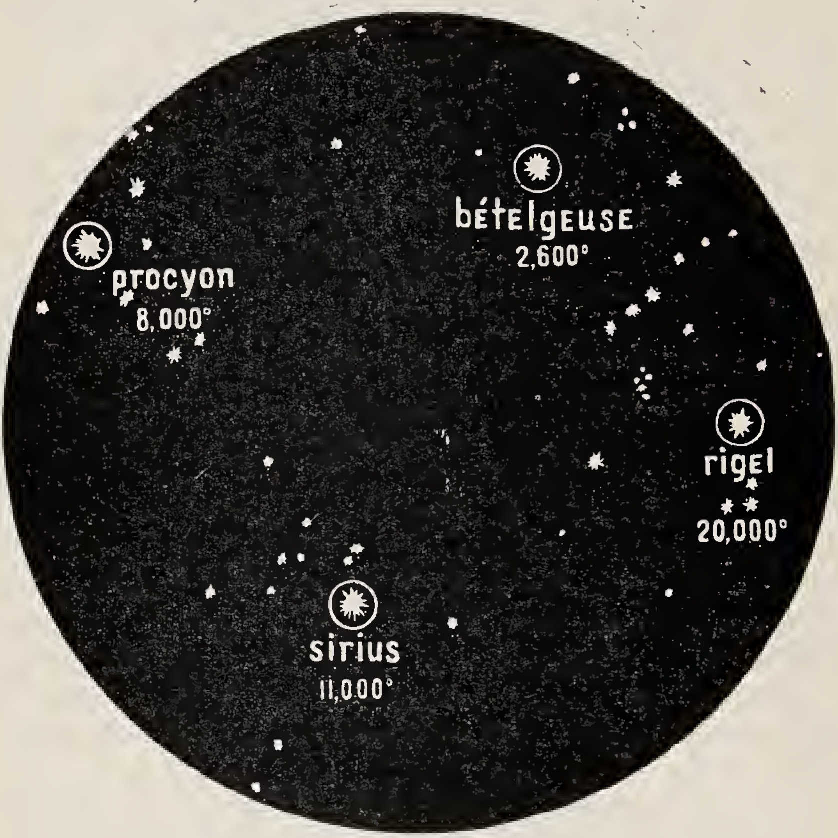
Late in the previous century and early in the present one, many scientists inferred from the aforesaid thought that organic substances on our planet can originate only biogenetically, that is, with the participation of organisms. This opinion which was predominant in science some thirty years ago set up serious obstacles in the way of solving the problem of life's origin. A vicious circle seemed to have arisen. In order to trace life to its sources it was necessary to know how organic substances are formed, but these latter, they alleged, were synthesized by living organisms alone. But that happens only when we restrict our observations to the confines of our planet. When we go further, we see that on a number of celestial bodies in our stellar universe organic substances are being formed abiogenetically, that is, in conditions which absolutely preclude the possibility of any organisms existing there.

The spectroscope enables us to study the chemical composition of stellar atmospheres in the laboratory, and we sometimes attain such a degree of precision as if we were basing ourselves on their actual specimens. We are able to detect carbon in the atmosphere of the hottest stars of the 0 type, which are distinguished by their exceptional brilliancy. Even the surface of these stars has a temperature of up to 20,000-28,000° Centigrade. Under such conditions, naturally, the existence of any chemical compounds is impossible. Matter there exists in a comparatively primitive form, in the shape of free and scattered atoms, of minute particles constituting the red-hot atmosphere of the stars.

The atmospheres of B type stars, which give off a brilliant bluish-white light and possess surface temperatures of 15,000-20,000° Centigrade, likewise contain red-hot vapours of carbon. But there, too, carbon does not yet enter into any chemical combinations and exists in the form of separate, rapidly moving, minute particles of matter—atoms.

Only in the spectrum of the white stars of the A type, with a surface temperature of 12,000° Centigrade, do we detect traces of bars pointing to the presence in the atmosphere of these stars of primary chemical compounds —hydrocarbons. There, for the first time, the atoms of two elements—carbon and hydrogen—formed a more complex compound, the chemical molecule.

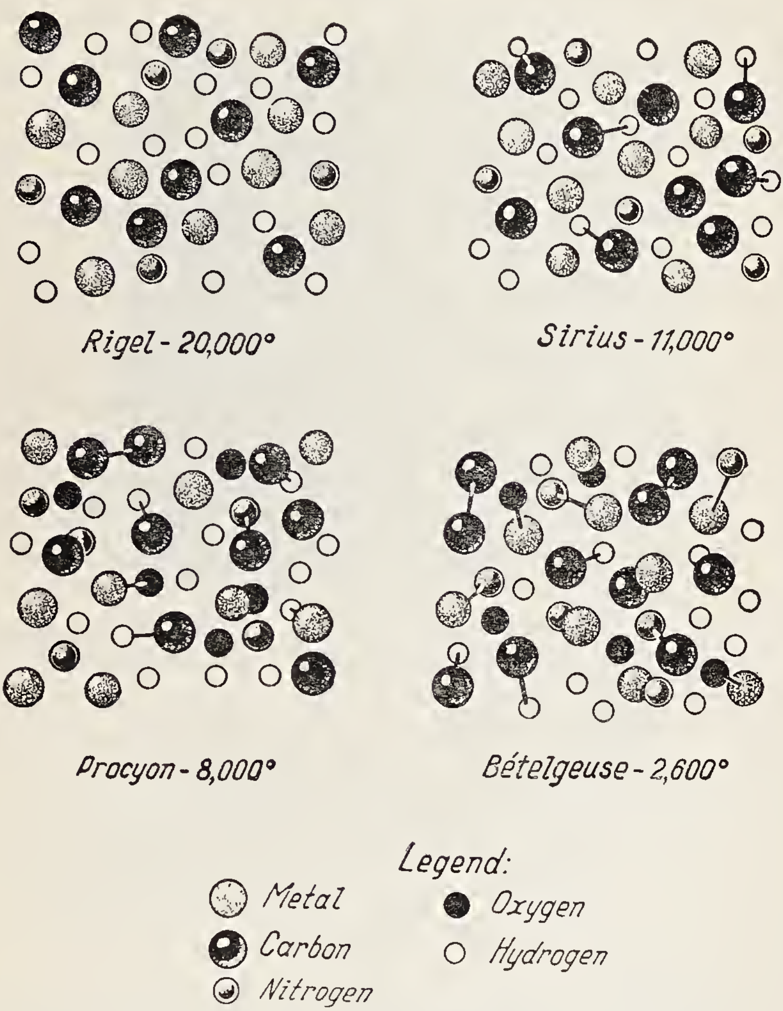
In the spectre of cooler stars hydrocarbonic bars become ever more sharply pronounced as the temperature falls and reach the utmost distinctness in the case of red stars with a surface temperature of 4,000° Centigrade.



Different stars are differently developed. All stars have carbon, but in various states.

Bluish-white stars, the youngest and hottest, have surface temperatures of over 20,000° Cent. All their elements including carbon exist in the form of scattered minute particles or atoms. On white and yellowish-white stars, which have surface temperatures of 10,000-12,000°, the atoms of carbon and hydrogen begin to form compounds.

CARBON



On yellow stars, with surface temperatures of 6,000-8,000°, other carbonic compounds are also formed.
Still more varied compounds exist on dying red stars, with surface temperatures of 2,000-4,000°.

The Sun occupies an intermediate position in this stellar system. It belongs to the class of yellowish stars of the G type. The temperature of solar atmosphere is between 5,800 and 6,300° Centigrade. In the upper strata it falls to 5,000°, rising in the lower ones, which permit of investigation, to 7,000° Centigrade. Spectroscopic investigation shows that a certain part of carbon exists there in the form of a compound with hydrogen (CH—methine). It is likewise possible to establish the presence in the atmosphere of the Sun of a compound of carbon and nitrogen (CN—cyanogen). Besides, it was there that so-called dicarbon (C_2), a compound of two interlinked atoms of carbon, was originally found.

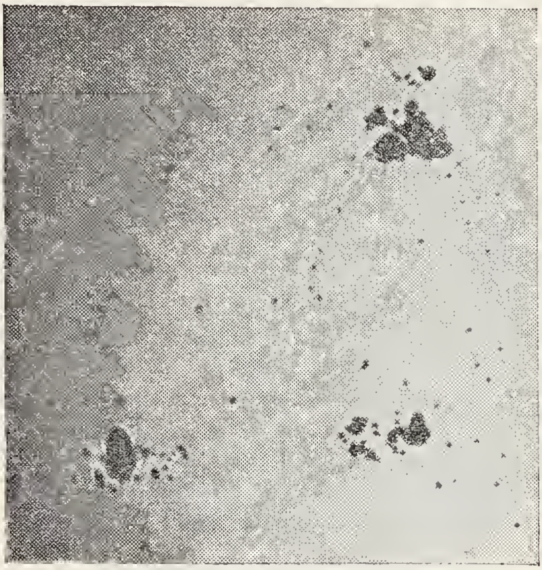
We thus see that in the process of the Sun's evolution the element of carbon already passed from one form of existence to another. Carbon in the atmosphere of the hottest stars is present in the form of free scattered atoms, while on the Sun it is partially present in the form of chemical compounds, in the form of molecules of hydrocarbons, cyanogen, and dicarbon.

The study of the atmospheres of the larger planets of our solar system is of vital importance for the solution of the problem of life's origin. It has shown that Jupiter's atmosphere largely consists of ammonia and methane. There is reason to believe that other hydrocarbons are also in evidence there. But because the surface temperature of Jupiter is low (—135° Centigrade), the mass of these hydrocarbons is in a liquid or solid form. Compounds of the same kind have been registered in the atmospheres of other large planets.

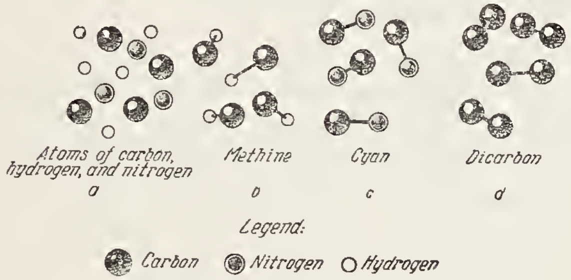
The study of meteorites, or aerolites, which sometimes fall to the Earth from interplanetary space, is of exceptional importance. These are the only non-terrestrial bodies which can be put to a direct chemical and mineralogical test. Both as regards the nature of their composite elements and their structure the meteorites are identical with the deepest

SOLAR CARBON

Our sun is a yellow star with a surface temperature of about 6,000°.



Surface of the Sun, with granules and spots



Carbon exists in the red-hot solar atmosphere not only in the form of free atoms but also in the form of compounds:

(a) free atoms of carbon, hydrogen, and nitrogen.
(b) Compounds of carbon and hydrogen (methine).
(c) Compounds of carbon and nitrogen (cyan).
(d) Compounds of two atoms of carbon (dicarbon).

zones of the earthcrust and the central nucleus of our planet. It is easy to grasp how important it is to study their composition for solving the question of the forms of the primary compounds at the time of the Earth's formation.

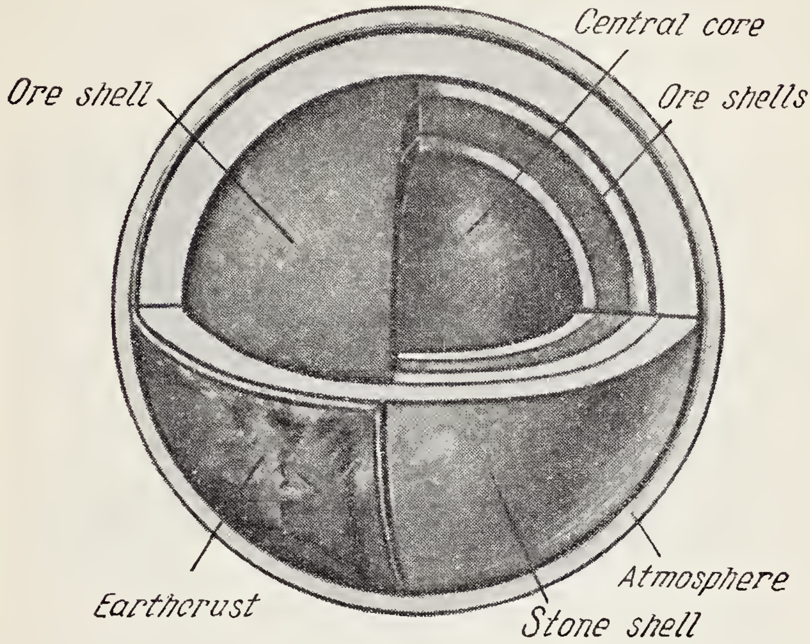
Meteorites are commonly divided into two basic groups: iron (metallic) and stone. Those belonging to the first group usually consist of iron (90 per cent), nickel (8 per cent), and cobalt (0,5 per cent). The stone meteorites have a considerably lower iron content (about 25 per cent). They contain a large number of oxides of various metals: magnesium, aluminium, calcium, natrium, manganese, etc.

Carbon is always present in this or that percentage in the meteorites; primarily, in its virgin state, in the form of coal, graphite, or diamond. But the most characteristic thing about meteorites is that they possess compounds of carbon with metals, which are called carbides. It is precisely in meteorites that there was first found a mineral which they commonly possess—cohenite, a carbide of iron, nickel, and cobalt.

Among the other carbonaceous compounds we find in meteorites, a special place belongs to hydrocarbons. As early as 1857 a certain quantity of an organic substance akin to ozocerite was extracted from a stone meteorite which fell near Kaba, Hungary. When analyzed the substance was found to be a highly molecular hydrocarbon. Compounds of a similar kind with molecules containing many atoms of carbon and hydrogen, and sometimes of oxygen and sulphur, were extracted from various other meteorites.

At the time when the presence of hydrocarbons in meteorites was first established the false opinion still prevailed that organic substances (and hence, hydrocarbons) can be formed in natural conditions only by living organisms. On the strength of it many scientists came forward with the assumption that the hydrocarbons of meteorites were a secondary formation which appeared on the respective celes-

GLOBAL STRUCTURE



Cross-section of global structure. In the middle is the central core with a radius of 3,470 kilometres. Above it lies the ore shell enveloped by layers of the stone shell. The last layer is the Earth's crust, which is surrounded by the atmospheric shell.

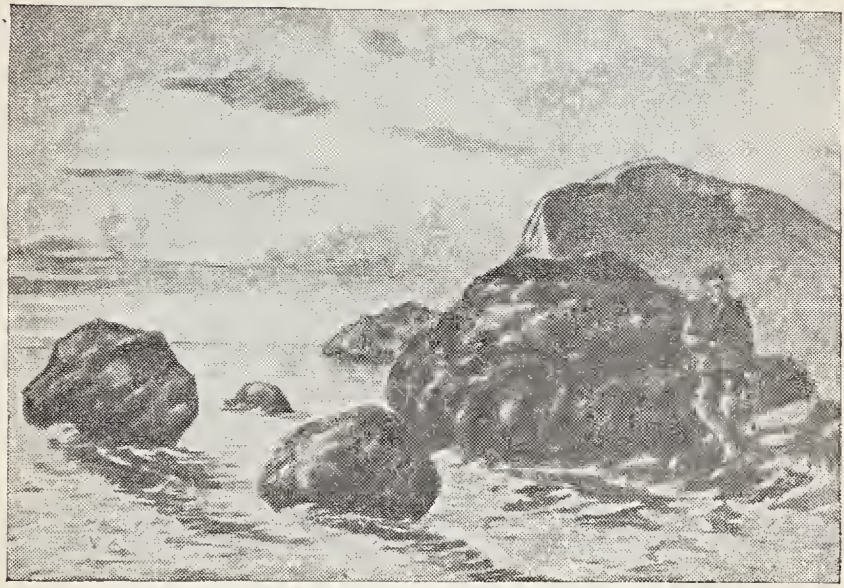
tial bodies from the decomposition of organisms which had once inhabited them. However, subsequent meticulous investigations exploded this assumption, and today we know that the hydrocarbons of meteorites, like those of stellar atmospheres, originated in an inorganic manner, that is, independently of life.

Thus, there can be no doubt whatever that organic substances may originate independently of organisms, prior to the appearance of that complex form of the movement of matter; that they were actually formed on various celestial bodies in conditions which precluded any possibility of life. But if that is true of all the various celestial bodies, what,

Specimen of iron meteorite

then, has made our Earth an exception? Would it not be safer to assume that the biological course of the formation of organic substances is characteristic only of the modern epoch of our planet's existence, that it began only after the appearance of life on the basis of a very highly developed metabolism, and that on the Earth, too, other abiogenic ways of synthesizing organic substances existed which led to the formation of hydrocarbons and their derivatives long before the emergence of organisms?

On the basis of data obtained from the study of the Earth's specific weight, of the gravity, and of the spread of earthquake waves, all geochemists and geophysicists agree that in the centre of our planet there is a metallic nucleus; its radius is 3,470 kilometres, and its specific weight is about 10. This nucleus is covered with a series of envelopes —geospheres. There is an intermediate geosphere 1,700 kilometres thick—the so-called ore envelope—directly above the nucleus. Next comes the stone envelope, or lithosphere, which is 1,200 kilometres thick. Then follows the aqueous mantle, or hydrosphere, composed of the seas and oceans on the Earth's surface; and, finally, there is the gaseous



"Ovifaq iron" off the shore of the Island of Disko

shell, or atmosphere. All these geospheres clothe the central nucleus of the Earth with a powerful impenetrable layer.

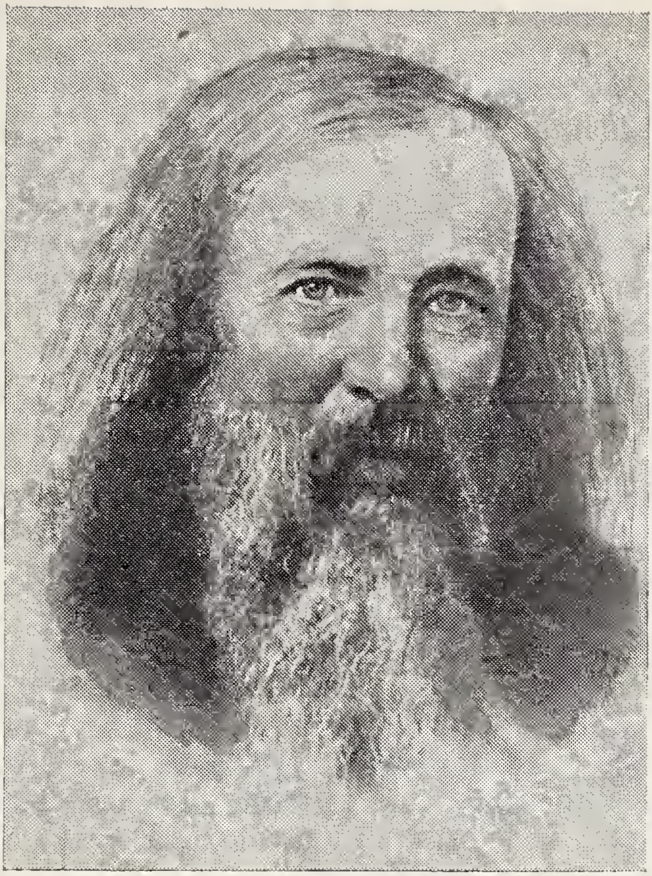
However, we have already succeeded in establishing the chemical composition of this nucleus to a reasonable degree of precision. It fully corresponds to that of the iron meteorites. It is largely composed of iron with an admixture of other metals such as nickel, cobalt, and chromium. Carbon is present there chiefly in the form of carbide of iron.

The masses of virgin iron found in the basaltic formations of the islands of Western Greenland are specimens of such hypogene rock. In particular, extremely large outcrops of such iron were found in the basaltic formations of the island of Disko, near the town of Ovifaq. The chemical composition of the "iron of Ovifaq" was so like that of metallic meteorites that at one time it was actually thought to be a meteorite. But now its earthly origin has been ascertained. It has a high content of carbon, which is present in the mineral cohenite.

Modern geological research has established that such outcrops of cohenite on the Earth's surface are not unique; they were found in other places, too. They obviously occurred on a large scale, especially in the distant eras of our planet's existence.

But whether erupted or flowing out onto the Earth's surface, the carbides of iron and other metals necessarily interacted with water or with steam, which was very much in evidence in the Earth's early atmosphere. As shown by our great chemist D. I. Mendeleyev, this interaction led to the formation of hydrocarbons. Mendeleyev strove even to prove that oil was produced in the same way.

This theory was rejected by geologists who established that the mass of oil is a product of decomposed organisms; however, the reaction of the formation of hydrocarbons by the interaction of carbides and water can, of course, be reproduced by any chemist. Direct geological research has shown that in natural conditions in our time, too, a certain amount of organic substances is actually being produced by carbides and water on the Earth's surface, where there are outcrops of cohenites, in an inorganic manner. Thus, even in our time, parallel with the large-scale biological formation of organic substances in the process of photosynthesis, hydrocarbons also originate on a certain scale abiogenically from carbides and water. The origination of organic substances independently of life doubtless took



D. I. Mendeleyev

place also in the past when carbides and water interacted on a much larger scale than they do now. This interaction alone could therefore have served as a source of the mass primary formation of organic substances in times when our planet was devoid of life, prior to the appearance on it of even the most elementary living beings.

The brilliant investigations carried out by Soviet astronomers and cosmogonists (V. A. Ambartsumyan, G. A. Shain, V. G. Fesenkov, O. J. Schmidt, and others), which revealed the process of the origination of stars and planetary systems, further advanced the solution of the question of the primary formation on the Earth of organic substances.

Direct observations performed with the aid of super-powerful instruments built and installed in an observatory near Alma-Ata, made it possible to carry out a detailed study of the structure and evolution of interstellar matter which previously had been but poorly investigated. In our stellar universe, in the Galaxy, matter is not wholly concentrated in the stars and planets. Modern science has shown that interstellar space is not a vacuum, that it contains a substance in the form of gas and dust. In a number of instances this interstellar matter forms comparatively solid formations—gigantic clouds. Such formations can be seen with the naked eye—dark spots on the bright background of the Milky Way. They attracted notice in ancient times, when they were called "coal sacks". These cold clouds of gas and dust in the Milky Way obscure the light of the stars behind them.

The study of the make-up of this interstellar matter has shown that in some places it has a fibrous structure. Observations conducted by Academician V. G. Fesenkov led him to the conclusion that it is in these threads or filaments of gas and dust that stars are formed which later go through a definite course of development.

An infant star initially has gigantic proportions. In the process of its development it solidifies, but is still surrounded by a cloud of the gas and dust which gave birth to it.

However, our interest lies not in the formation of stars only but also of planets—in particular, our planet. The conception recently announced by Academician O. J. Schmidt is therefore worthy of close attention.

O. J. Schmidt asserts that the Earth and the other planets of our solar system were formed not from gaseous masses, which were once part of the Sun, as held by his predecessors. Eons ago, the Sun, revolving round the centre of our Galaxy, collided with a huge cloud of cold, pulverized matter in the form of dust and attracted this mass of matter to its orbit. Gradually centres of accumulation appeared in the mass around which the particles of gas and dust built planetary formations.

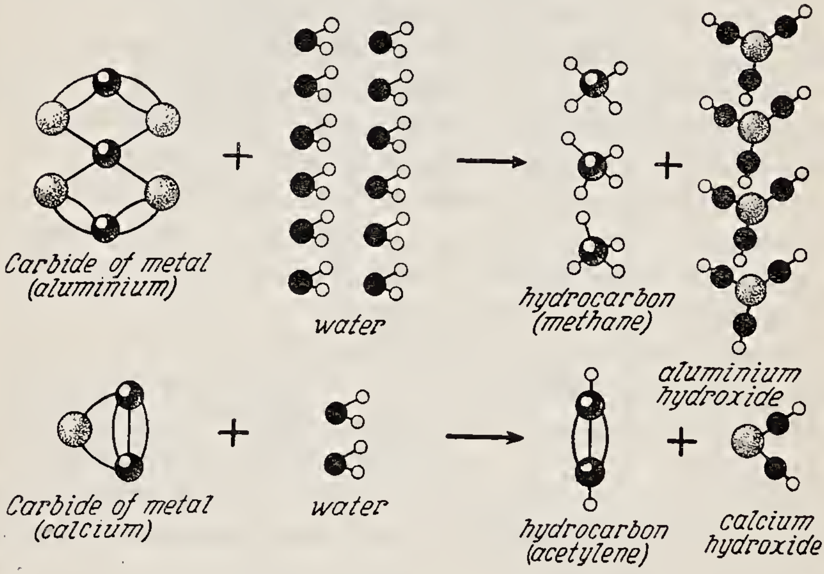
The idea of the Sun passing through a cloud of gas and dust and attracting matter in the form of dust seems a somewhat complex one. Today, in the light of new data on stellar formation, it is permissible to ask: Was the attraction of matter indispensable? Would it not be safer to assume that the material of which our planets were formed is that self-same matter in the form of gas and dust which envelopes infant stars, and that the Earth is roughly a coeval of the Sun? Is it not possible that in its infancy the Sun, like the other stars, was shrouded in a gigantic cloud of gas and dust which served as material for the formation of the Earth and all the other planets of our solar system?

These pregnant hypotheses, reliably grounded on factual observations, afford invaluable material for the solution of the question of the primary formation of organic substances during the formation of our planet.

The latest probes into the composition of nebular gas and dust matter have shown it to be composed of hydrogen, methane (and possibly even more complex hydrocarbons), ammonia, and water in the shape of minute crystals of ice. Consequently, in its earliest infancy the Earth absorbed elementary hydrocarbons, water, and ammonia from gas and dust matter, that is to say, everything required for the formation of primary organic substances. Hence, irrespective of precisely how the Earth was formed, organic substances were bound to appear on its surface already during the process of its formation.

The investigations conducted by quite a few chemists, and especially by Academician A. E. Favorsky and his school, have shown that hydrocarbons are comparatively easily hydrated, that is, their molecules combine with a whole molecule of water. It is beyond doubt that most of the hydro-

Carbides (compounds of carbon with metals) ejected onto the Earth's surface from the central core interacted with what was then the Earth's atmosphere which consisted chiefly of overheated water vapour. As a result, hydrocarbons—compounds of carbon with hydrogen—were formed.



Formation of hydrocarbons as a result of interaction between carbides and water. The oxygen present in the chemical particles (molecules) of water enters into combination with metal, producing metal oxides (rust), while the hydrogen of water unites with carbon

Hydrocarbons which appeared in the Earth's atmosphere formed compounds with water particles and ammonia.
This was accompanied by the formation of more complex substances.

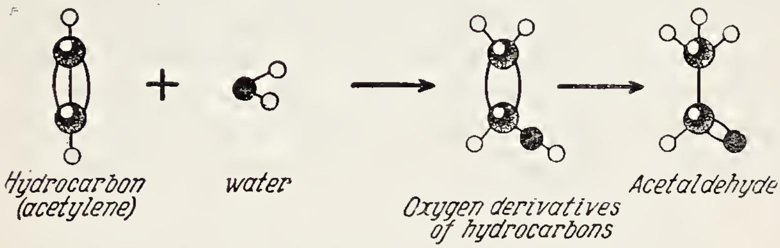


Diagram showing formation of compounds the molecules of which contain atoms of carbon, hydrogen, and oxygen

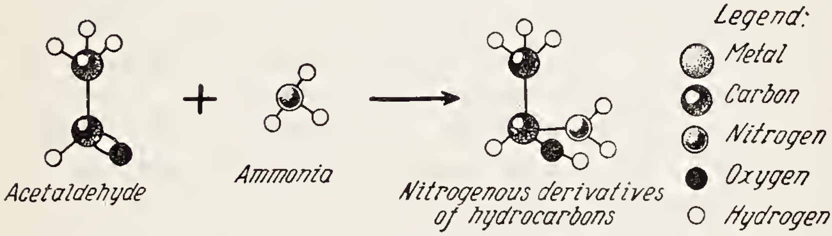


Diagram showing combinations of nitrogen carbons which first appeared on the Earth's surface also entered into combinations with water; thanks to that, new substances—products of the oxidation of hydrocarbons by the oxygen of water—appeared in the Earth's primary atmosphere: various spirits, aldehydes, ketones, acids, and other elementary organic substances the molecules of which combine three elements: carbon, hydrogen, and oxygen. The latter entered the combination as part of the molecule of water. In a number of cases the three elements were joined by a fourth, nitrogen, which figured in the composition of the Earth, during its formation, in the form of ammonia.

As a result of the interaction of hydrocarbons and their most elementary oxygen derivatives with ammonia, compounds were formed containing in their molecules various combinations of the atoms of carbon, hydrogen, oxygen, and nitrogen—numerous salts of ammonia, amides, amines, etc.

Thus, from the very first, in the hydrosphere of our planet, in the water of the Earth's primitive ocean, various substances must have been formed from carbon, which it would be quite justified to call the primary organic substances, although they appeared long before the first living beings.

They were relatively simple compounds with comparatively small molecules, but in spite of that they presented a qualitatively new form in the existence of matter. The properties of these primary elementary organic compounds and their subsequent development in the process of evolution were determined by new laws which arose from their elemental composition and from the definite arrangement of atoms in their molecules.

Thus, the theory I expounded thirty years ago, which presumes that organic substances were formed on our planet prior to the appearance of organisms, has now been fully confirmed by the latest cosmogenic theories of Soviet astronomers. Hydrocarbons and their oxygen and nitrogen derivatives were formed on the Earth's surface, in its humid atmosphere, and in the waters of the primitive ocean simultaneously with the formation of the Earth. Although this stage in matter's progress towards the origin of life seemed highly mysterious before, today the overwhelming majority of natural scientists entertain no doubt whatever as to the primary origin of the most elementary substances.

And so we have investigated the first, and presumably the longest, stage in the evolution of matter, a stage which lies between the scattered atoms of the hot stellar atmospheres and the most elementary organic compounds dissolved in the Earth's primitive hydrosphere. The next important stage leading towards the origination of life was the formation of a substance of a protein nature.

CHAPTER THREE

THE ORIGIN OF PROTO-PROTEINS

Early in the nineteenth century it was erroneously thought that complex organic substances which make up the bodies of plants and animals—various sugars, proteins, fats, etc.—can only be extracted from living beings, while their artificial production is entirely out of the question. A laboratory synthesis of these substances was held to be inconceivable, inasmuch as organic substances, it was believed, were formed only in living beings by a certain "vital force". However, extensive investigations by organic chemists of the 19th and 20th centuries did away with this prejudice. At present, by making use of hydrocarbons and their elementary derivatives, we can obtain by chemical means substances typical of organisms, such as various sugars, fats, numerous vegetative pigments, alizarin, indigo, substances which colour flowers, fruits, and berries, substances which lend them taste and fragrance—various terpenes, tannins, alkaloids, india-rubber, etc. In recent times even such complex and biologically extremely active compounds as vitamins, antibiotics, and certain hormones, have been obtained. Thus, "vital force" has been banished from scientific usage, and it has been proved beyond any shadow of doubt that all the substances which make up the bodies of plants and animals can be obtained from non-living nature, independently of life.

It is true, nevertheless, that on our planet we observe the formation of organic substances almost exclusively in living organisms, but this is characteristic only of the present period in the evolution of matter on the Earth. As we have seen from the preceding chapters, the most elementary organic substances—hydrocarbons and their immediate derivatives—originate in the celestial bodies around us wholly independently of life, in conditions precluding any possibility of its appearance. On our planet these compounds likewise originated as a result of the interaction of inorganic substances long before the emergence of life.

Hydrocarbons and their simplest derivatives possess immense chemical potentialities. They serve as the basic material with the help of which the organic chemist reproduces in his laboratory all the various organic substances which are present in living organisms and which have already been mentioned above.

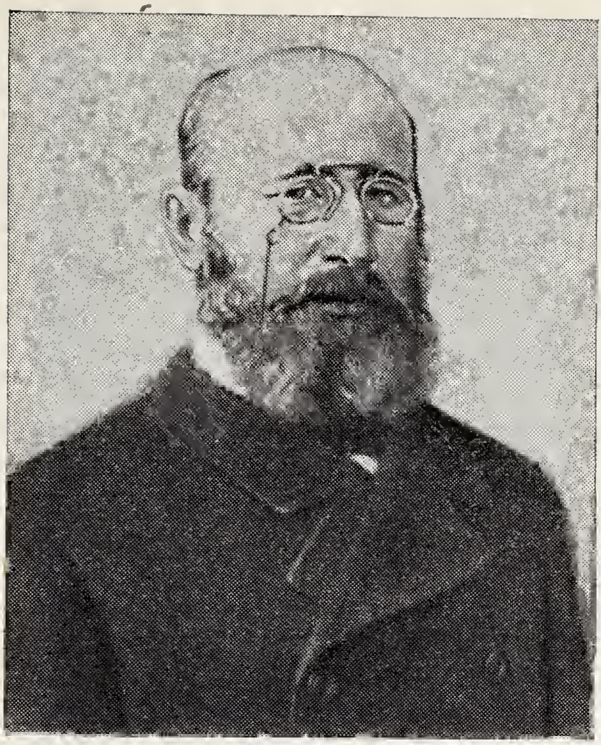
It should be emphasized that the chemist employs reactions in his syntheses other than those that occur in living organisms. To make organic substances react quickly and in the desired manner among themselves, the chemist frequently resorts to strong acids and alkalies, to high temperatures, pressures, and the like. He has an infinite variety of methods at his disposal which enable him to accomplish the most varied reactions.

The synthesis of various organic substances proceeds in an altogether different manner in natural conditions, in living organisms, where there are no potent agents, no high temperatures, where the reaction of the environment is always close to neutral. In spite of this there, too, take place a great number of varied and sometimes extremely complex reactions.

It is precisely this wide range of substances produced by the bodies of plants and animals that led the researchers of yesterday to believe that a great number of various reactions take place in the living cell. A detailed investigation, however, shows that this is not so. Despite the truly staggering number of substances which make up the living organism there can be no doubt that they came into being as a result of comparatively simple and, to a prevailing extent, homogeneous reactions. Chemical changes of organic substances occurring in the living cell are based on three principal types of reaction. These are: first, condensation, i.e., lengthening the carbonic chain and the reverse process of disrupting the link between the two atoms of carbon; secondly, polymerization, i.e., bridging the two organic molecules with oxygen or nitrogen and the reverse process of hydrolysis; and, lastly, the process of oxidation and the concomitant process of reduction (reaction of oxydoreduction). Besides, there are reactions involving the transference of phosphoric acid, aminonitrogen, methyl, and other groups, from one molecule to the other.

All chemical processes taking place in the living organism, all transformations of substances leading to the appearance of different compounds, are based in the final analysis on these elementary reactions. The study of the chemism of respiration, fermentation, assimilation, synthesis, and disintegration of various substances, shows that all these phenomena are based on long chains of chemical transformations, chains in which the reactions listed above are separate links. The crux of the matter is the sequence of reactions. Thus, if the first reaction was one of condensation, the second one of oxidation, and the third condensation again, we obtain one chemical compound, one product of transformation. Contrariwise, if condensation is followed by polymerization and the latter by oxidation or reduction, etc., we obtain another substance.

Consequently, the complexity and diversity of substances originating in living organisms are determined solely by the complexity and diversity of the combinations of those types of reactions described above. However, a closer study of these reactions is bound to show that very many of them have one characteristic feature in common, share one peculiarity—they take place with the direct participation of



A. M. Butlerov

elements of water. These elements are either added to or separated from the carbonic atoms of an organic molecule. This interaction between the elements of water and organic substances lies at the basis of the entire vital process. All the innumerable transformations of organic substance which are now taking place in natural conditions in an organism are the result of this interaction. In an organism reactions take place with great speed and in a strictly consecutive order owing to special conditions which we shall examine below. But even when these conditions are absent, outside the living organisms, the interaction between water and organic substances takes place nonetheless, although the reaction then is slower.

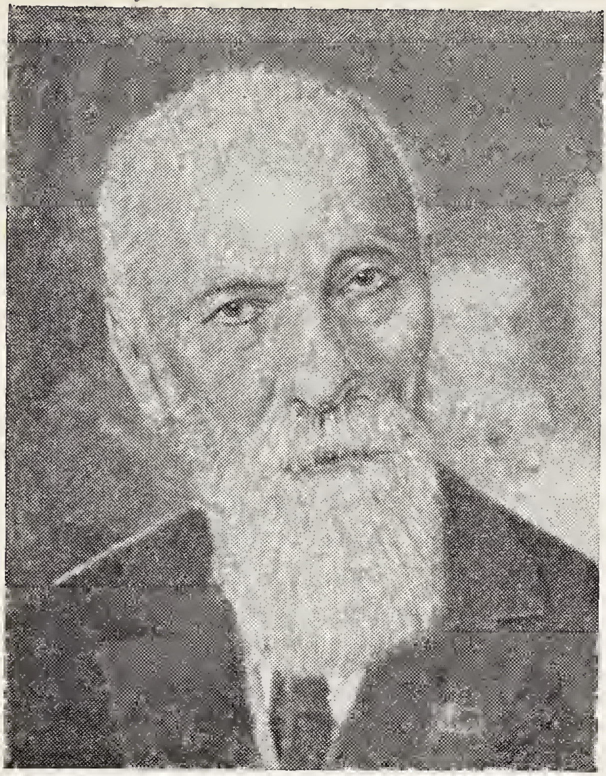
Chemists have known for a long time now that there are a large number of syntheses brought about by this interaction in the aqueous solutions of various organic substances when they are preserved for a more or less protracted period of time in ordinary conditions. Small elementary molecules of hydrocarbons and their derivatives consisting of a small number of atoms enter into various combinations in a multitude of ways and thus build up larger and more complex molecules. Back in 1861 our famous compatriot A. M. Butlerov demonstrated that a limewater solution of formalin (the molecule of which consists of one atom of carbon, one atom of oxygen, and two atoms of hydrogen) left for a certain period in a warm place acquires a sweet taste. It was subsequently established that in such conditions six molecules of formalin join and form a larger and a more complex molecule—that of sugar.

Academician A. N. Bach, the founder of Soviet biochemistry, found that a mixture of the aqueous solutions of formalin and potassium cyanide left to stand for a long time produced a nitrous substance which possessed a heavy molecular weight and produced reactions characteristic of proteins.

Dozens and hundreds of reactions of this type might be described here, but the aforesaid is sufficient to characterize the pronounced ability of elementary organic substances to form complex highly molecular compounds in aqueous solutions preserved in ordinary conditions.

The conditions which obtained in the waters of the primitive ocean of the Earth differed little from those created in our laboratories. Therefore, in any point of that ocean, in any lagoon or drying puddle, the same complex organic substances, which appeared in Butlerov's retort, in Bach's glass, and during other experiments of the same kind, were bound to be formed.

To be sure, in the primitive ocean, which was a solution of elementary organic substances, reactions took place not



A. N. Bach

according to any definite sequence or order but, to a large extent, in a chaotic manner. Organic substances were simultaneously undergoing several chemical transformations, following various chemical courses which yielded a great number of different products. But from the very outset there was a definite general tendency towards the synthesis of more complex and highly molecular compounds. This tendency led to the appearance in the warm waters of the Earth's primitive ocean of highly molecular organic compounds similar to those which we now find in the bodies of plants and animals.

While dealing with the origin of various complex organic compounds in the Earth's hydrosphere we must pay special attention to the formation in those conditions of protein substances. Proteins play a paramount, decisive part in the make-up of the "vital substance". Protoplasm, the material substrat, which forms the bodies of animals, plants, and microbes, always contains a substantial amount of proteins. Engels was the first to state in *Anti-Dühring* that "wherever we find life we find it associated with an albuminous body, and wherever we find an albuminous body not in process of dissolution, there also without exception we find phenomena of life."

This idea put forth by Engels has been fully confirmed by the findings of modern scientists. It has been established that albumins are not simply the passive formative material of protoplasm, as was believed before, that they play a direct and active part in metabolism and in other vital phenomena. Thus, the origination of proteins constitutes a most important link in the evolutionary process of material development which brought about the appearance of living beings.

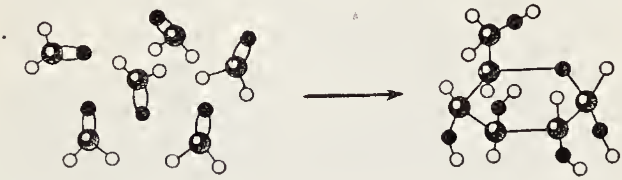
Late in the past century and early in the 20th, when the chemistry of proteins was still a virgin field of science, certain researchers assumed the existence of a peculiar unknown entity in the proteins, of specific atomic groupings which were the bearers of life. From this viewpoint their primary origination seemed mysterious and even improbable. But the problem will appear in an entirely different light if considered from the viewpoint of modern chemical conceptions regarding the protein molecule.

Briefly summing up the latest achievements of the chemistry of proteins, we must emphasize above all else that today we possess an adequate knowledge of the composite parts, the "bricks" of which the molecule of any protein is built. These "bricks" are known to all chemists as amino acids.

In the protein molecule the amino acids are linked among themselves by special chemical ties forming a long chain. The number of amino-acidic molecules in this chain is expressed in various proteins by figures ranging from

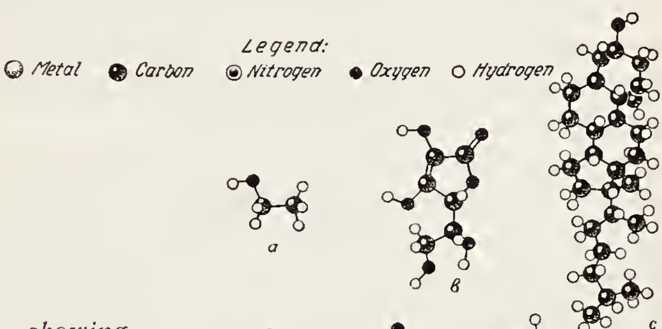
ORIGIN OF COMPLEX ORGANIC SUBSTANCES

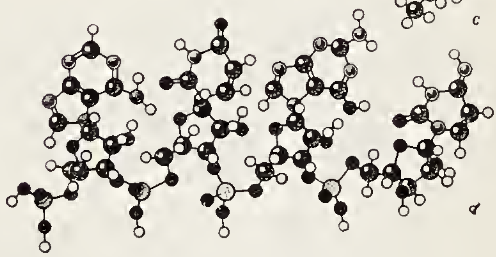
Originally the molecules of these compounds were composed of a small number of atoms of carbon, hydrogen, oxygen, and nitrogen. But in the waters of the primitive ocean these molecules gradually entered into combinations among themselves, forming larger and more complex particles of various substances.



In an aqueous solution of formalin, when left to stand for a long time, six of its particles unite among themselves, producing a larger particle of sugar.

In this way all those various organic substances appeared which went into the making of present-day plants and animals.





Diagrams showing the structure of molecules of various organic substances: (a) spirits, (b) vitamin C, (c) fatlike substance (cholesterol), (d) **nucleic acid.**

several hundred to several thousand. The chain, therefore, is a rather long one. In most cases it is interlaced in a complex but systematically structured knot which constitutes the protein molecule.

A factor of essential significance is that extremely diversified amino acids are included in the composition of an albuminous substance. A protein molecule is thus built of "bricks" of different sorts. Today we know about thirty various amino acids making up · natural proteins. The molecules of certain proteins contain all the known amino acids; others are less complex. At the same time the chemical and physical properties of every protein known to us are essentially dependent on its amino-acidic composition.

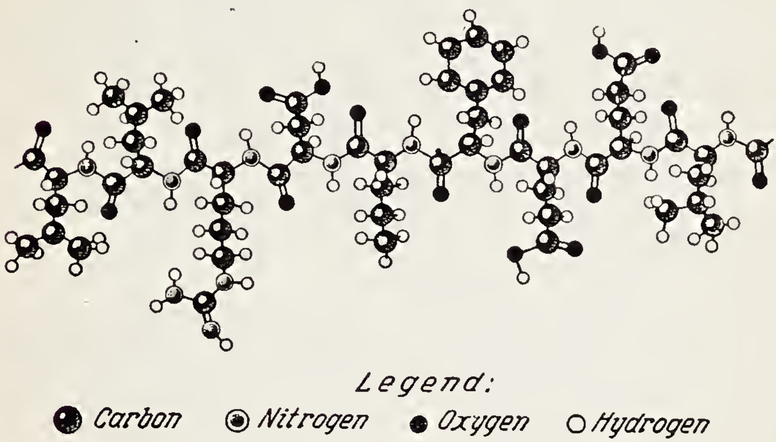
It should be borne in mind, however, that amino-acidic particles are linked in the albuminous chain not haphazardly, but in a strictly definite order characteristic of a given protein. Hence, the physical and chemical properties of this protein—its ability to take part in definite chemical interactions, its solubility in water, and so forth—depend not only on the number and diversity of the amino acids in its molecule, but also on the order in which these amino acids are arranged in the albuminous chain.

A structure of this kind makes possible an infinite diversity of proteins. Albumen, the white of an egg, so familiar to everyone, is only one simple representative of albumins. The proteins of our blood, muscles, and brain are much more complex. Many hundreds and thousands of different proteins are present in every living creature, in its every organ, and each plant or animal species has its own characteristic proteins. Thus, for example, the proteins of human blood differ somewhat from proteins in the blood of horses, oxen, or rabbits.

This great variety of proteins accounts for the exceptional difficulties encountered in their artificial production in laboratory conditions. At present we can easily obtain any amino

ORIGIN OF PROTEINS

Molecules of organic substances entered into combinations and produced particles of proteins—the most complex and most vital substances. In these particles tens of thousands of atoms are combined in a strictly definite order in long chains with numerous lateral branches.



A small section of the chain which lies at the basis of a protein molecule.

In a protein molecule these chains form intricate but definitely arranged balls.

acid from hydrocarbon and ammonia. It likewise presents no great difficulty to combine all these amino acids into long chains similar to those which form the basis of albuminous molecules and to obtain a genuine albuminoid substance. But that is not enough to artificially reproduce any of the natural proteins we know—the protein of our blood, for instance, or that of pea seeds. To do that we must link hundreds and thousands of various amino acids into a strictly consecutive chain—precisely that chain which they form in the given protein.

From a chain consisting of only fifty links of twenty different sorts we can obtain many different chains by changing the order in which the links are connected. It has been estimated that the number of such chains, each differing from the rest as regards the arrangement of its links, is expressed by the unit 1 and forty-eight noughts, i.e., by the figure we obtain by multiplying a milliard by a milliard and again by a milliard and so five times, and then multiplying the result by a thousand. If we were to take such a number of albuminous molecules and twine them into a braid as thick as your finger, we should be able to hang it up from one end of the Milky Way to the other across the whole of our stellar system.

But the amino-acidic chain of an average-sized albuminous molecule consists not of fifty but of several hundred links and includes not twenty but thirty different sorts of amino acids. The number of possible combinations here is therefore increased by many quadrillions.

In order artificially to obtain a natural protein we must select one definite combination from an infinite variety of combinations and secure that arrangement of amino acids in the albuminous chain which is characteristic of the given protein. It goes without saying that no fortuitous arrangement of amino acids in an albuminous chain can ever achieve our goal. It would be as hopeless an undertaking as trying to set up a poem by juggling type with all the letters of the alphabet.

We can tackle this task only if we know the arrangement of the letters and words in the poem. And only if we know the exact arrangement of amino acids in the chain of a given protein can we hope artificially to reproduce it in our laboratory. Unfortunately, the arrangement of amino acids has been established at present only in the case of the most elementary albuminous substances. That is why we have been unable as yet to produce complex natural proteins in artificial conditions. But this will be certainly done, and no one doubts any longer the possibility of producing proteins in this manner.

However, we are not so much interested here in the possibility of synthesizing proteins or protein substances as in the manner in which these most complex organic substances appeared in the natural conditions which once existed on the surface of our planet. Until recently this problem remained experimentally unsubstantiated. In the spring of 1953, however, an experiment conducted for this very purpose, and involving a mixture of methane, ammonia, the vapours of water and hydrogen, produced certain amino acids in conditions very much similar to those which once obtained in the atmosphere of the young Earth.

The problem of combining these amino acids to form molecules of protein substance is a more difficult task because a high energy barrier hinders synthesis in ordinary natural conditions. A considerable outlay of energy (about 3,000 calories) is needed to create a polypeptidal association between the molecules of amino acids. In laboratory syntheses this obstacle is surmounted with the help of special means, but when aqueous solutions of amino acids are preserved in ordinary conditions this reaction does not take place of itself as it does in the described cases of formalin and sugar.

In spite of this, encouraging results have been achieved in this field within the past few years. It has been shown, first of all, that when the amino acids are properly selected, the energy required for their synthesis can be appreciably reduced and in a number of instances compensated by the special selection of conjugate reactions.

Special mention should be made of experiments conducted recently by Professor S. E. Bresler in Leningrad. Allowing for the fact that the outlay of energy required for the creation of a polypeptidal association of amino acids in an aqueous solution can be compensated by the diminution of free energy owing to the action of external pressure, S. E. Bresler performed his syntheses under a pressure of several thousand atmospheres. At the same time from amino acids and other products of albuminous disintegration he synthesized highly molecular protein compounds in which the separate amino acids were linked polypeptidally. These experiments prove that the synthesis of protein and protein substances are fully possible under those powerful pressures which are easily created in the Earth's natural conditions, for instance, in the great oceanic deeps.

Thus, modern chemistry makes it clear to us that during the Earth's infancy albuminous substances were necessarily formed in our planet's hydrosphere. These "proto-proteins", to be sure, could not have been the full counterparts of any of our modern albumins, but they nonetheless bore a certain resemblance to them. In those proteins various amino acids were linked among themselves in the same ways as in our modern proteins, the only difference being that the arrangement of amino acids was somewhat different, somewhat less orderly.

However, "proto-proteins", like our modern ones, possessed gigantic molecules and great chemical potentialities. These potentialities predetermined the paramount role played by proteins in the further development of organic matter.

The carbonic atom of the stellar atmosphere was not yet an organic substance, but the element's exceptional ability of entering into combinations with hydrogen, oxygen, and nitrogen made it potentially capable of opening the road, under favourable conditions of existence, to the formation of organic substances. In the same way the exceptional properties of the "proto-proteins" had potentialities that, under certain conditions of material development, necessarily led to the origination of living beings.

Thus, during the process of our planet's development, numerous albuminous compounds and other complex organic substances, similar to those which make up modern living creatures, were bound to appear in the Earth's primitive ocean. They were, of course, but building material—bricks and cement with which a house could be, but was not yet, built. Organic substances were present in the waters of the ocean in a dissolved state; their molecules were scattered. The structure and organization which are typical of every living creature were so far absent.

CHAPTER FOUR

THE ORIGIN OF PRIMARY COLLOIDAL FORMATIONS

The preceding chapter has shown that during the Earth's evolution varied complex organic substances were formed in the primitive ocean. They were similar to the substances which make up modern living beings, although between the latter and the elementary aqueous solution of organic substances there is, of course, an essential difference.

Protoplasm, the material substrat in which vital activity takes place, forms the basis of every plant and animal organism, of the bodies of all the various bacteria, amoebae, fungi, and other most elementary organisms. It has the appearance of a greyish semi-liquid mass which besides water contains proteins and a number of other organic substances and inorganic salts. But it is not simply a mixture of substances; the protoplasm is intricately organized. The chief characteristics of this organization are, first, that it possesses a definite structure and special arrangement of the particles of the substances which form it, and, secondly, that physical and chemical processes take place in it in a harmonious manner, in a consecutive order, in conformity with definite laws.

Thus, contemporary living matter is represented by separate organisms—individual systems possessing both a definite form and an intricate internal structure and organization. There were no such organisms, naturally, in the waters of the primitive ocean, the history of which we have reviewed in the previous chapter. The study of various solutions, including those of organic substances, shows that the particles of the substance they contain are more or less evenly distributed in the entire volume of the solvent and are in a state of perpetual irregular movement. Thus, organic substances here are, firstly, welded inseparably with their environment, and, secondly, lack any structure based on a regular distribution of their particles. However, we cannot imagine an organism devoid of definite structure and completely dissolved in its environment. Therefore, on the way from organic substances to living creatures the origination of individual formations must necessarily take place, of systems spatially segregated from the environment and possessing a definite arrangement of the particles of matter in their bodies.

Organic substances of low molecularity, such as spirits or sugar, for instance, become extremely disintegrated when dissolved in water. They are evenly distributed in the solution in the form of separate molecules which exist more or less independently of one another. Their properties are therefore largely determined by the structure of the molecules themselves, by the distribution of the atoms of carbon, hydrogen, oxygen, etc., within these molecules.

But as the molecules increase in size, to these elementary laws of organic chemistry new and more complex relations are added which form the subject of colloidal chemistry. The more or less dissolved solutions of substances of low molecularity constitute thoroughly durable systems in which the degree of the disintegration of the substance and the regularity of its distribution in space do not change of themselves. By contrast, the particles of highly molecular compounds produce colloidal solutions of characteristically low durability. These particles tend to combine and form whole clusters, complexes, or aggregates under the influence of diverse factors. Very often this process leads ultimately to the separation of the colloidal substance in the form of a precipitate, a phenomenon known as coagulation.

In other cases the process does not lead to the formation of a precipitate, but there nevertheless takes place a radical change in the regularity of the distribution of matter in the solution. Dissolved organic substances concentrate at definite points in space, and coagula are formed in which individual molecules, or particles, are in some way interlinked, thus giving rise to new complex relations which are determined not only by the arrangement of atoms in molecules, but also by the mutual arrangement of these molecules.

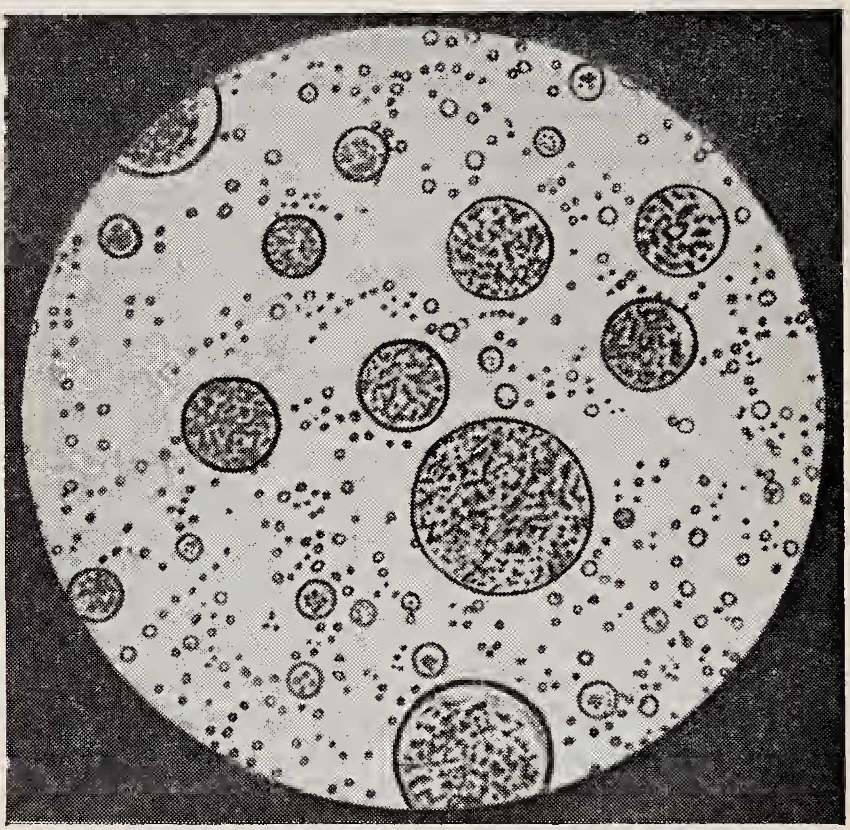
Let us take solutions of some highly molecular organic substances—for example, the aqueous solution of gelatine or a similar solution of gum-arabic. These solutions are transparent and homogenous; the organic matter in them is completely blended with its environment. Particles of the above substances are evenly distributed, diffused in the solvent. But if we mix the two solutions, we will immediately notice that the mixture is clouded. Examining it under a microscope, we find that small drops have separated from the once homogenous solutions and become strictly isolated from their environment.

An identical phenomenon is produced by mixing the solutions of other highly molecular substances; it is achieved with particular ease in the case of various proteins. When these are mixed their molecules form curdlike clots at definite points in space. The drops which separate during the process have been called coacervates (from the Latin word *acervus*, which means *pile*). These interesting formations have been and are being thoroughly studied at a number of laboratories; in the laboratories of Bungenberg de Yong and Kruyt, in Moscow State University's laboratory of plant biochemistry, and elsewhere. By subjecting coacervate drops and the liquid medium to a chemical analysis we can see that all the colloidal substance (for instance, in the case cited above, all the gelatine and gum-arabic) concentrates in coacervate drops and that there are hardly any molecules of this substance left in their environment. We have here almost pure water, while in the coacervate drops the substances are present in such a concentrated state that we now deal with a solution of water in gelatine or gum-arabic rather than otherwise. This is why coacervates possess that very peculiar property of not allowing their drops, though liquid and saturated with water, to mix with the surrounding water solution.

The same property is characteristic of the protoplasm of living organisms. If we break open a plant cell and squeeze out the protoplasm it contains into water, the protoplasm, despite its liquid consistence, will not mix with the surrounding water, but will float on it in the shape of sharply defined balls isolated from the surrounding solution. This similarity between artificial coacervates and protoplasm is not merely a superficial one. As has been shown by recent investigations, protoplasm actually exists in a coacervate state. Naturally, its structure is much more complex than that of artificial coacervates. For instance, in the protoplasm there is a combination of not two colloidal substances (as in our example) but many more. And yet a number of physical and chemical properties of protoplasm (as, for example, its ability to form vacuoles, the nature of its moistening, permeability, etc.) can only be assessed through the study of coacervates. An intriguing peculiarity of coacervate drops is that they have a definite structure in spite of their liquid state. Their molecules and colloidal particles are not scattered in a haphazard manner, but are arranged according to a definite spacial pattern.

Certain patterns can be detected in some coacervate drops with the help of a microscope, but these patterns are very unstable and exist only while there exist the motive forces which determine the arrangement of particles. A slight change in the water-holding or electrostatic forces acting inside the coacervate can refashion the arrangement of its particles. In some cases a change of this kind may even lead to the total disassembly of the coacervate into separate

Initially, protein substances were dissolved in a solution, but then their particles began to combine and form molecular piles until, finally, they separated from the solution in the shape of microscopic floating droplets, or coacervates.

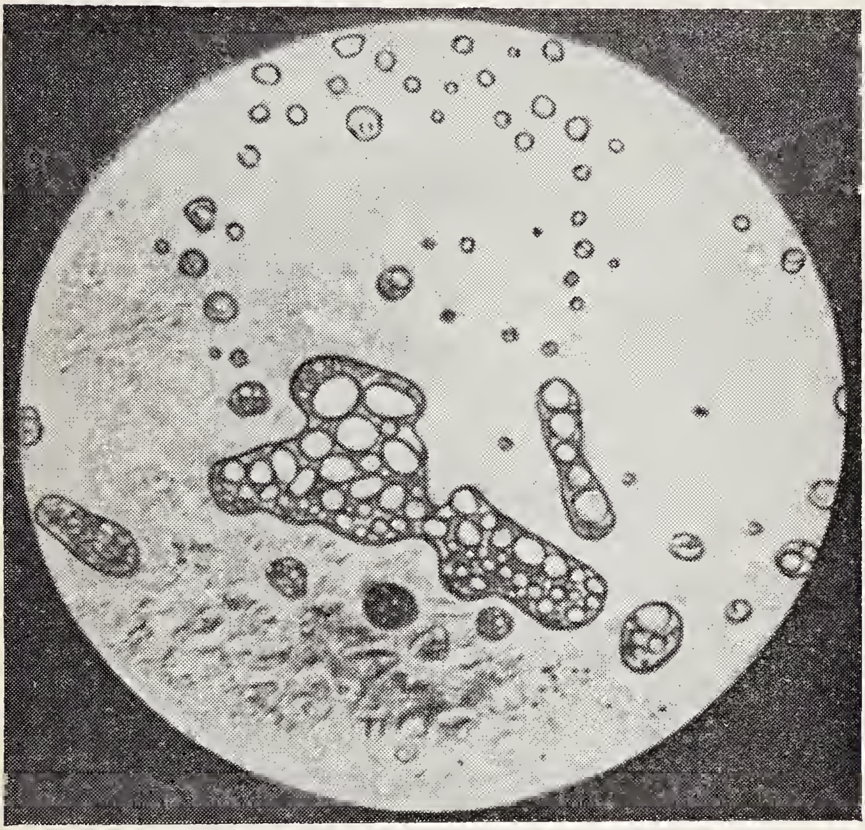


A microscopic photograph of artificially obtained coacervate drops

Coacervate drops adsorbed from the water solution in which they floated various organic substances, and at the latter's expense increased in volume and weight. This growth was uneven; some grew faster, others slower.

OF COACERVATES

The internal structure of the quickly growing drops became more and more complex and better adapted to nutrition and expansion.



A complex coacervate

Their structure changed and improved in the course of millions of years. The simpler coacervate drops perished; the more complex grew and multiplied by division. In the long run they gave rise to the simplest living creatures.

molecules, to its dissolution in the environment. In other cases, on the contrary, the coacervate may become more solid, its internal viscidity may be enhanced, and it may assume a jelly-like shape. In the latter cases its structure becomes somewhat more complex and at the same time more stable and durable. All these changes inside the coacervate may take place either as a result of external changes or of internal chemical transformations.

We thus find in the coacervates the rudiments of material organization, albeit a very primitive and unstable organization. Nevertheless, this organization already predetermines a whole series of properties in the coacervate drops. An especially striking property is the ability of the coacervates to adsorb various substances from the surrounding solution. This ability is easily demonstrated by adding various dyes to the liquid enveloping a coacervate drop. It will be observed that the dye-stuff rapidly passes from the surrounding solution to the drop of the coacervate.

Not infrequently this phenomenon becomes complicated by certain chemical transformations which take place inside the coacervate. The material particles adsorbed by the drop interact chemically with the substances of the coacervate itself. As a result, the coacervate drops may grow larger at the expense of substances they adsorb from their liquid medium. This leads not only to an increase in the volume and weight of the drop, but to an essential change in its chemical composition. Consequently, certain chemical processes are apt to take place inside coacervate drops. It is very important that the nature and speed of these processes are largely dependent on the internal physico-chemical structure of the coacervate drop, and this implies that they differ in various coacervates.

Now that we have acquainted ourselves with the properties of coacervates, we can return to those highly molecular protein-like compounds which were formed in the Earth's primitive aqueous shell. As pointed out above, the molecules of these compounds, like the particles of modern proteins, bore on their surface various lateral chains having different chemical functions. Hence, parallel with the growth and development of the "proto-proteins", new inter-relations among the separate molecules inevitably evolved. No molecule of this kind could exist in isolation from other molecules, and this led to the inevitable and legitimate emergence of molecular piles—whole complexes of particles consisting of not homogenous albuminous molecules, but those differing in size and properties. This necessarily led, in turn, to the concentration of organic matter at definite points of space. Sooner or later, in this or that corner of the primitive ocean, the water solution of multiform albuminous substances was bound to form coacervate drops. For, as we have seen above, elementary conditions are needed for the appearance of coacervates. They appear when the solutions of two or more highly molecular organic substances are simply mixed. Consequently, as soon as more or less highly molecular protein-like compounds were formed in the Earth's primitive hydrosphere there also immediately appeared coacervate drops.

The formation of coacervate drops could not have been precluded by the relatively low concentration of organic substances which obtained in the primitive ocean of the Earth. The waters of contemporary seas and oceans contain only the faintest traces of organic compounds which are formed due to the decomposition of dead organisms. In an overwhelming majority of cases these substances are absorbed as food by micro-organisms which live in water. But in a few cases organic substances may for a while escape destruction by microbes in the ocean depths. Data acquired in the study of deep-sea soils containing silt indicate that jelly-like residues are formed in these conditions. The same phenomenon of the precipitation of complex coacervates from water containing but traces of highly molecular organic substances is not infrequently observed under artificial conditions precluding the action of micro-organisms.

And so, as a result of the mixing of colloids—first and foremost, of primary protein-like compounds—coacervate drops were bound to appear in the seas of our planet. The formation of coacervates was an important stage in the evolution of the primary organic substance and in the process of life's origin. Up to that moment organic substance was inseparably merged with its environment, evenly distributed in the entire mass of the solvent. The formation of the coacervate was a result of the concentration of molecules of organic substance at definite points in space and their isolation from the environment inside a more or less strictly defined shell. Each coacervate drop acquired certain individuality, or, so to speak, set itself off from the world around it. Only on the basis of this precipitation of coacervate drops could there come into being that dialectical unity of the organism and its environment which became the decisive factor in the origination and development of life on the Earth. At the same time the formation of the coacervates imparted a certain structure to organic matter. Hitherto, the solution contained only a mass of particles which moved in a haphazard fashion; in a coacervate drop these particles were stationed in a definite way. Hence, it contained the rudiments of organization, although that organization, it is true, was of an elementary kind. As a result of this, elementary organo-chemical relations were supplemented here by new colloido-chemical laws. These laws are characteristic also of the living protoplasm of modern organisms. That is why we can establish a certain similarity between the physical and chemical properties of the protoplasm and our coacervates.

But can we regard the coacervate drop as a living being on these grounds? Certainly not. And not only because this is a question of the complexity and fineness of the structure of protoplasm. An artificially obtained coacervate or a drop naturally derived from a solution of organic substances in the Earth's primitive ocean did not possess a rational structure, that fitness of its internal organization for the performance of definite living functions in the given conditions of existence which is so characteristic of the protoplasm of all living creatures without exception. This adaptation to the conditions of the environment could not stem merely from physical or chemical laws, or from colloido-chemical relations. New laws, namely, biological laws, had to arise in the process of material evolution simultaneously with the inception of living things.

CHAPTER FIVE

THE ORGANIZATION OF LIVING PROTOPLASM

To be able to trace further the pathway of evolution and the process of the origination of life we must make at least a cursory review of the fundamental principles underlying the organization of protoplasm, the material substratum which forms the basis of all living things.

Late in the 19th century and at the beginning of the present century certain scientists believed that organisms are merely a special kind of "living machines" possessing an extremely intricate structure. To protoplasm they ascribed a certain machine-like structure, a definite design made up of some sort of solid and invariable intertwined "beams" and "braces". According to them, it is this structure, this strictly defined mutual arrangement of the parts of the protoplasm, that constitutes the specific essence of life, just as the essence of the specific work done by a machine is determined by its structure, a definite arrangement of wheels, shafts, pistons, and the other components of the mechanism. They argued that if by our studies we attained a complete understanding of this structure, we would come to know the secret of life.

Practical research into protoplasm, however, disproved this mechanistic approach. It was established that protoplasm contains no machine-like design, be it the most complicated. The basic mass or protoplasm is fluid; it constitutes an intricate and complex coacervate composed of numerous and diverse highly molecular organic substances, primarily proteins, fat-like compounds, etc. Filamentous colloidal particles and, perhaps, individual gigantic protein molecules or, rather, whole complexes of the latter float freely in this basic coacervate substance. The size of these particles is so minute that they defy even the most powerful modern microscope. But besides these, visible formations are also present in protoplasm. Fragments of protein or other substances, forming large piles or clusters, may be dissociated from the main mass of protoplasm in the shape of microscopical drops, or of clots, having a definite structure—the so-called morphological formations—nuclei, plastid, mitochondria, etc.

These microscopic protoplasmic formations are essentially the external, visible expression of definite and very complex relations of the solubility of protoplasmic substances. As we shall see below, this mobile structure of protoplasm is, doubtlessly, of signal importance in the vital process, but it can in no way be likened with the role played by a machine's design in its specific work. That is natural, for machine and protoplasm are systems which differ from each other in every principle.

The work of a machine is characterized by the mechanic spatial movement of its separate parts. Therefore, the most essential characteristic of its organization is precisely the arrangement of its parts. The vital process is of an entirely different nature. First and foremost, it is expressed in metabolism, i.e., in the chemical interplay of the individual components of protoplasm. Hence, as distinct from machines, the spatial arrangement of the parts is less essential in the organization of protoplasm than is its order of chemical processes in point of time, their definite, harmonious combination, which is aimed at the preservation of the entire living system as a whole.

The mistake of the mechanists was that they failed to see this difference and that, striving to ascribe to living creatures the form of material motion which is characteristic of a machine, they did not differentiate between the organization of protoplasm and its structure, i.e., they reduced this organization merely to the spatial arrangement of its individual parts. This, of course, is a one-sided view, since organization must be regarded not only in point of space, but also in point of time. Thus, for example, we call a meeting "organized" not only because its participants have seated themselves in an orderly manner, but also because the speakers have kept within the time limit and the reports and speeches have followed the agenda.

Depending on the character of a given system either its organization in point of space or its organization in point of time comes to the fore. In the case of a machine spatial organization is most important. But we know many systems in which organization in point of time is most important. An example of such a system is furnished by any piece of music —a symphony, for instance. The latter's very existence is determined by the fact that the tens and hundreds of thousands of sounds which make it up are combined with strict regard for time. Any disruption of its harmonious unity would destroy the symphony, would lead to disharmony and chaos.

Structure, a definite intricate internal make-up, is an essential element in the organization of protoplasm. However, organization in point of time, a definite harmony of the processes which take place in protoplasm, is by far more important. Any organism—plant, vegetable, or microbe—lives only while it continues to receive and discharge a steady stream of new particles of substance and of the energy which goes with it. The organism receives from its environment diverse chemical compounds. Inside the organism they are subjected to various changes and transformations, as a result of which they become the substance of the organism proper and acquire the properties of those chemical compounds of which the living creature had previously been composed. This is known as the process of assimilation. But simultaneously with assimilation a reverse process takes place—that of dissimilation. The substances of a living organism do not remain unchanged, but are decomposed more or less swiftly, and their place is taken by newly assimilated compounds while the products of decomposition are discharged into the environment.

Thus, the substance of a living organism never remains in a stable state; it is being constantly broken down and built up anew as a result of numerous closely interlinked reactions of decomposition and synthesis. Our bodies are as fluid as streams; matter is renewed in them as water in a torrent—said Heraclitus, a dialectician of Ancient Greece. A stream or a torrent of water may for a certain period of time preserve a constant form, a constant external appearance, but that form is only the visible reflection of the uninterrupted *process* of the motion of the particles of water. The very existence of the described system depends on ever new molecules of substance rushing along the stream at a definite speed. Check this process, and the stream will disappear as such. This is characteristic of all so-called dynamic systems which are based on process.

Every living thing likewise presents a dynamic system. As in a stream of water, its form and structure are but the external, visible expression of a certain, extremely mobile equilibrium of the processes which in an uninterrupted chain take place in it as long as it lives. However, the character of these processes essentially differs from anything we observe in the dynamic systems of inorganic nature. In a stream the particles of water enter it in a ready-made form and pass through it unchanged. An organism, on the other hand, takes "alien" substances from its surroundings and by complex chemical processes converts them into substances of its own body, into substances identical with the material of which that body is composed. It is precisely this that creates conditions for the preservation of the constancy of the make-up and the structure of the organism despite the permanent decomposition and dissimilation.

From a purely chemical point of view metabolism is seen as a combination of a huge number of individual, comparatively simple reactions of oxidation, reproduction, hydrolysis, condensation, etc. A specific feature of protoplasm is that these individual reactions conform to a definite pattern of organization in point of time and are combined in it in a single complete system. They occur here not accidentally, not chaotically, but in a strictly consecutive and harmonious order.

This order lies at the basis of all the vital phenomena of which we are aware. Thus, in alcoholic fermentation, the sugar which enters a yeast cell from the fermenting liquid is consecutively subjected to a long series of chemical transformations, which is graphically pictured in the appended diagram. First it attracts phosphoric acid, then breaks up into halves. One of these is reproduced, the other oxidized and finally converted into pyruvic acid, which breaks up into carbon dioxide and acetaldehyde. The latter forms spirits of wine. In this manner, in the final analysis sugar produces spirits and carbon dioxide.

The origination of these substances in the yeast cell is determined by the strict observance of a definite order of all the reactions depicted in the diagram. If any link in this chain of transformations were to be changed or if their order was in any way revised, we would get a substance other than spirits of wine. Indeed, in lactic-acid bacteria sugar undergoes the same changes as in yeast, but as soon as it comes to the formation of pyruvic acid, the latter is not dissociated, but is immediately reproduced. Owing to this sugar is not converted into spirits in the bacteria of lactic acids but into lactic acid.

A deep study of the synthesis of diverse substances which takes place in protoplasm shows that these substances are not formed immediately in it, by some kind of special chemical act, but as a result of a long chain of chemical transformations. To assure the formation of a complex chemical com-

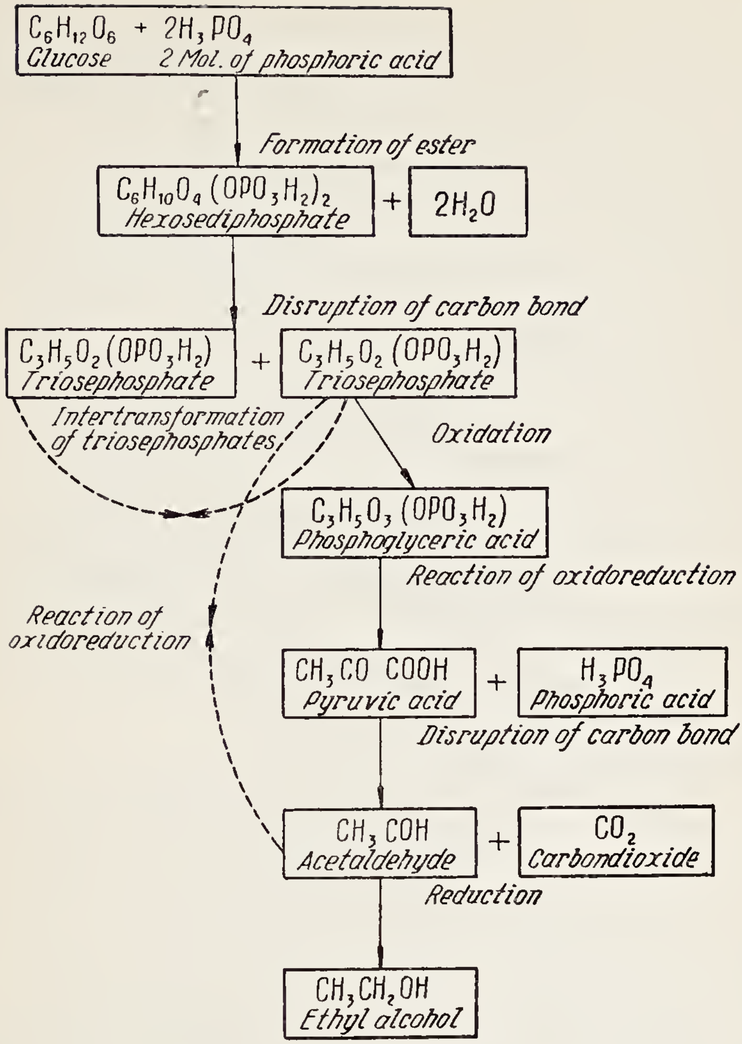


Diagram of alcoholic fermentation

pound characteristic of a given living creature, dozens and hundreds, and sometimes thousands, of individual reactions must take place in a rigid, consecutive order, in strict conformity with definite laws. This order forms the basis of the existence of protoplasm.

The more complex a substance, the more numerous the reactions which take part in its formation inside the protoplasm, and the more strict and precise the coordination of these reactions. Recent work has shown that in the synthesis of proteins from amino acids many separate consecutive reactions must take place. The living protoplasm acquires the rhythm of structure and the definite arrangement of amino acids which we find in present-day proteins only thanks to an extremely rigid coordination and definite order of the above reactions.

The protein particles of definite structure which appear in this way of necessity group themselves into more or less considerable molecular heaps and entire complexes, which are finally dissociated from the main mass of the protoplasm and are precipitated in the form of microscopic morphological formations, which constitute highly mobile protoplasmic structures. Thus, the chemical composition characteristic of protoplasm and its structure are an expression of a definite order of the chemical transformations which incessantly take place in living matter.

What determines the order which characterizes the organization of protoplasm? What immediate reasons lie at the basis of this order? A thorough study of the question shows that this order is not something external and independent of matter (as thought by idealists). On the contrary, we know now that the speed, direction, and inter-relationship of individual reactions—all that goes into the making of the order under discussion—are wholly dependent on the physical and chemical relations which are created in living protoplasm.

The leading role belongs to the chemical potentialities of the substances which make up protoplasm. They are, chiefly, the organic substances which we investigated in previous chapters. The chemical potentialities of these substances are immense. They can produce the most varied reactions. But they make use of their potentialities in an extremely "lazy"

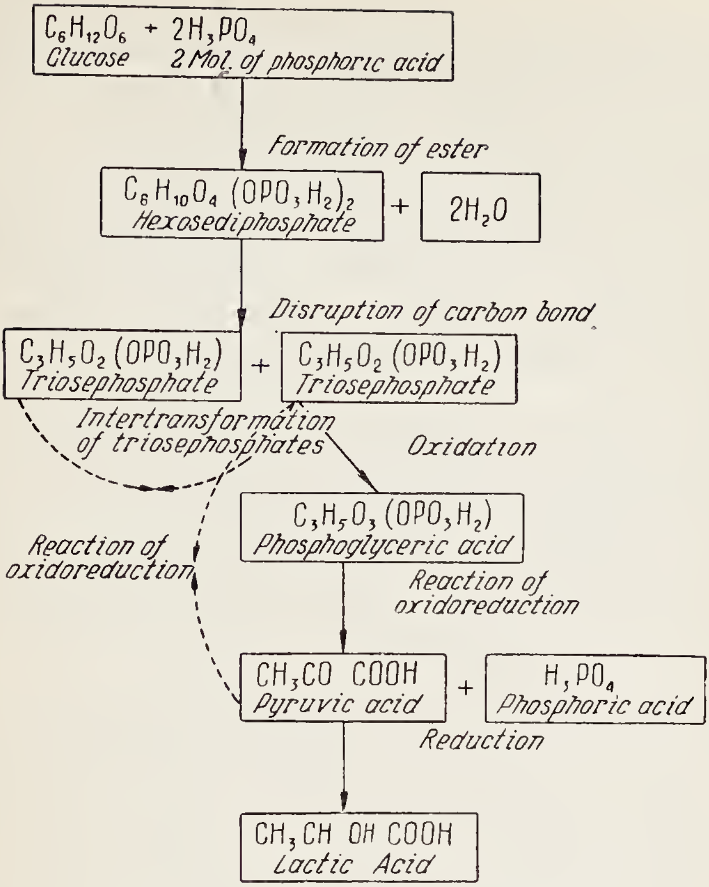


Diagram of lactic acid fermentation

fashion, very slowly, and at times at a speed so low as to be insignificant. Not infrequently it takes months and even years to complete a given reaction involving organic substances. That is why organic chemists resort as a rule to various drastic substances—strong acids, alkali, and the like—so as to spur onwards the course of chemical interaction among organic substances.

Substances used as accelerators of reactions are called catalysts. They are being used more and more frequently.

It has long been established that a very small quantity of a catalytic agent is sufficient to bring about a turbulent acceleration of a reaction. The catalyst itself is not destroyed in the process of the reaction and is recovered at the end in its initial quantity. Therefore, it takes but a very small quantity of catalyzer to speed up the transformation of a substantial mass of substance. This is being widely employed at present in chemical technique, which utilizes various metals as well as their oxides, salts, and other inorganic and organic compounds as catalytic agents.

In the bodies of animals and plants chemical interactions between organic substances take place at an astonishing speed. If this were not so, it would have been impossible for life to develop as rapidly as it actually does. Chemical reactions take place at such speeds inside protoplasm because it also contains a number of special biological catalysts—so-called enzymes.

Enzymes were discovered long ago; they have always attracted scientific attention. It was found that they can be extracted from living protoplasm in the form of either a water solution or even a dry easily dissolved powder. Not so long ago crystallic preparations of enzymes were obtained and their chemical properties were established. All enzymes were found to be proteins, pure or sometimes combined with non-protein substances. As regards the nature of their action, enzymes bear full resemblance to inorganic catalysts, from which they differ only as regards the strength of action. In this sense enzymes are exceptional, for they are hundreds of thousands and even millions of times stronger than inorganic catalysts of analogous action. Thus enzymatic proteins are an exceptionally potent and extremely rational apparatus for the acceleration of chemical interaction between organic substances.

At the same time enzymes are characterized by the strict specificity of their action, which is due to the peculiarities of the catalytic action of proteins. The organic substance (substratum) which changes in the metabolic process first of all forms, for a very short time, a complex compound with its corresponding protein—enzyme. This complex is an unstable one. It swiftly undergoes further change—the substrate changes in a corresponding direction whereas the enzyme regenerates and becomes able to form a complex with a new dose of the substrate.

Thus, for any substance of living protoplasm to take a real part in metabolism, it must interact with a protein and form with it a complex compound. Or else its chemical potentialities will mature so slowly as to have no effect on the swift momentum of the vital process. That is why the direction in which any organic compound changes during the metabolic process depends not only on the molecular structure of the compound, on its inherent chemical potentialities, but also on the specificity of the enzymatic action of those protoplasmic proteins which draw this compound into the general metabolic process.

Enzymes provide living matter not only with powerful acceleration of chemical processes, but also with an internal chemical apparatus which helps to direct these processes into definite channels. In virtue of the extremely fine specificity of enzymatic proteins, each one of them can only form complexes with definite substances and catalyze only certain individual reactions. Hence, in any vital process, not to mention metabolism as a whole, hundreds and thousands of individual proteins—enzymes—take part. Each one of them is capable of specifically catalyzing only one definite reaction, and only in combination, by strict coordination of their action, can they create that regularity of phenomena which lies at the basis of metabolism.

By utilizing individual enzymes extracted chemically from a living organism we can reproduce separate biochemical reactions, separate links of metabolism, in an isolated form under laboratory conditions. This helps us to unravel the intricate tangle of metabolic chemical transformations, which is made up of thousands of individual reactions. In that way we can divide metabolism into its separate chemical stages, and analyze not only the substances of living matter, but the processes which occur in it. This method helped A. N. Bach, V. I. Palladin, and their successors to show that respiration, a process highly typical of life, is based on a series of strictly consecutive reactions of oxidation, reduction, etc., and each of them is catalyzed by its own specific enzyme. The same has been established by S. P. Kostichev, A. N. Lebedev, and other authors, in respect to chemism of fermentation.

This leads us from an analysis of vital processes to their reproduction, to synthesis. For example, by mixing some two dozen diverse enzymes extracted from living matter in an aqueous solution according to a strictly definite combination, we can reproduce the phenomena of alcoholic fermentation. In such a solution of a whole complex of individual proteins the transformation of sugar takes place in conformity with the same laws which obtain in living yeast, although here there is, naturally, no cellular structure.

In this case the process is determined by the qualitative composition of the enzymatic mixture. However, strict quantitative regulation of the catalytic action of proteins also takes place in the organism. It is based on the exceptional sensitivity of enzymes to various influences. Indeed, there is no physical or chemical factor, no organic substance or inorganic salt, that does not in one way or another affect the course of enzymatic reactions. Any decrease or increase of temperature, any change in the acidity of the environment or of the oxidation potential, salt content, or osmotic pressure, transforms the correlation among the speeds of individual enzymatic reactions and, consequently, changes their inter-relationships in point of time. Herein lie the precursors of that unity between the organism and its surroundings which is so characteristic of life, and which has been comprehensively substantiated and elaborated in the scientific works of I. V. Michurin. In the cells of present-day organisms the order and direction of enzymatic reactions, which lie at the basis of metabolism, are also determined to a large extent by the spatial organization of living matter. Associating proteins can exfoliate from the main mass of the solution in the shape of various highly mobile protoplasmic structures. Many enzymes concentrate on the surface of these structures.

Investigations conducted by the Institute of Biochemistry of the USSR Academy of Science have shown that the extent of the cohesion of enzymes with protoplasmic structures determines not only the speed of enzymatic action, but also its direction. This makes the connexion between metabolism and the environment even stronger. Very often a given influence, which does not itself have any noticeable effect on the work of isolated enzymes, radically changes the balance between break-down and synthesis, inasmuch as this influence transforms the cohesive potency of protein structures, which are quite sensitive in this respect.

To sum up, the order characteristic of the organization of protoplasm is based on the chemical properties of substances which make up living matter. The great variety of these substances and their exceptional role in chemical reactions make possible innumerable chemical changes and transformations. But in living protoplasms these transformations are regulated by a whole series of internal and external conditions: the presence of a given assortment of enzymes, their quantitative correlation, the acidity of the environment, the oxidation and reduction potential, the colloidal properties of the protoplasm, its structure, etc. Each new substance, each new structure, arising in the protoplasm and separating from it, changes the speed and direction of certain chemical reactions and, consequently, influences the order of vital phenomena in its entirety.

We thus have a circle of closely linked inter-penetrating phenomena. The regular order of chemical reactions characteristic of living protoplasm leads to the occurrence of definite substances, definite physical and chemical conditions and morphological structures. But all these phenomena—definite composition of protoplasm, its properties and structure—as soon as they occur become factors which determine the speed, direction, and inter-relationships of the reactions which take place in the protoplasm, and, consequently, that regular order which fathered the composition and structure of protoplasm.

An especially important feature, and one which sets living organisms apart from all the systems of the inorganic world, is the definite purposiveness of the above order. This feature is a major characteristic of life. The tens and hundreds of thousands of chemical reactions which occur in living protoplasm are not only strictly coordinated in point of time, are not only harmoniously fitted within a single order, but that order itself is directed towards a single purpose—to the self-renovation and self-preservation of the entire living system as a whole, in law-governed conformity with environmental conditions.

This is precisely why protoplasm presents a dynamically stable system, and why, despite the permanent process of dissimilation going on within it, it preserves its intrinsic organization generation after generation. All the separate links of this organization may be investigated by us and understood on the basis of physical and chemical laws. We may in this way ascertain why this or that substance or definite structure originates in protoplasm and how the substance or structure influences the speed and consistency of chemical reactions, the correlation between synthesis and break-down, the growth and formation of organisms, etc.

But we will never be able to answer the question: Why is this vital order such as it is, why is it so rational (adapted to environmental conditions) if we base ourselves only on the above laws, on the study of protoplasms in their present-day form. To answer this question we must study matter in its historical development. Life occurred during this development as a new and more complex form of the organization of matter, an organization dependent on laws of a higher order than those prevailing in inorganic nature.

Only the dialectical unity of the organism and its environment, which could have arisen only on the basis of the formation of individual multi-molecular systems, brought life into being and determined the entire course of its subsequent development on our planet.

CHAPTER SIX

THE ORIGIN OF PRIMARY ORGANISMS

The first coacervate drops in the seas and oceans did not yet possess the properties of life. However, from the very first they had latent potentialities of paving the road, granted the necessary conditions of development, to the formation of primary living systems.

As we have seen in the foregoing chapters the same state of affairs was characteristic of all the previous stages in material evolution. The peculiar properties of the carbonic atoms of cosmic bodies already possessed the possibility of forming hydrocarbons and their simplest derivatives. The latter, thanks to the definite structure of their molecules and to their chemical properties, necessarily had to form diverse highly molecular organic substances, including protein-like compounds, in the warm waters of the primitive ocean. In the same way the peculiar properties of proteins predetermined the subsequent formation of complex coacervates. As they grew and became more complex their particles inevitably had to combine and to fall out of the solution in the shape of isolated coacervate drops.

This segregation of drops from their environment, this emergence of individual colloidal systems, was a pledge of their further development. Even those drops which appear simultaneously in a solution differ somewhat from one another as regards composition and internal structure. But the individual peculiarities of the physico-chemical organization of each single coacervate drop had a definite effect on the chemical transformations which took place in it. The presence of this or that substance, the presence or absence of the simplest inorganic catalysts (such as iron, copper, calcium, etc.), the degree of concentration of proteins and other colloidal substances which form the coacervate, and, lastly, a definite structure—be it even the most unstable structure—all this affected the speed and direction of separate chemical reactions occurring within the coacervate drop, and imparted a specific character to the chemical processes which took place in it. Thus there appeared a certain relationship between the individual structure and organization of a coacervate drop and the chemical transformations which took place in it under the given environmental conditions. In various drops these transformations occurred in various ways.

Further, we must note that the various chemical reactions which took place in a coacervate in a more or less haphazard manner affected its future fate. In this regard some of them were of a useful, positive significance, making for a greater stability and prolonging the existence of a given system. Others, on the contrary, had a detrimental, negative effect, led the coacervate drop to destruction and to complete disappearance.

The above should suffice to show that the very formation of individual systems brought forth completely new relations and regularities. In application to a simple, homogeneous solution of organic substances the terms "useful" and "detrimental" are of course meaningless. But when applied to individual systems, they become pregnant with real meaning and determine the further fate of these systems.

While an organic substance was merged completely with its surroundings, while it was dissolved in the waters of primitive seas and oceans, we were able to study the evolution of that substance as a whole, in the aggregate. But new and more complex relations appeared as soon as the organic substance became concentrated in various points of space as coacervate drops, as soon as these formations set themselves apart from the environment by more or less clearly defined borders and assumed a certain individuality. The further history of each coacervate drop could then differ considerably from that of its neighbour, an individual system of the same kind. Its fate was then determined by the correlation of environmental conditions and its own specific structure, the details of which were its exclusive property, while the other drops had a somewhat different and likewise individual structure.

What determined the individual existence of each drop of this kind in the given environmental conditions? Picture to yourself the appearance of coacervate drops in a primitive water reservoir as a result of the mixing of solutions of highly molecular organic substances. Trace the development of each drop. A coacervate drop in the Earth's primitive ocean was not immersed simply in water, but in a solution of various organic and inorganic substances. These substances were adsorbed by the coacervate drop and reacted chemically with its own substances. This resulted in the growth of the drop. But parallel with the above synthetic processes, other processes took place in the drop—those of decomposition and dissociation. The speed of both types of processes was determined by the correlation of environmental conditions (temperature, pressure, concentration of organic substances and salts, acidity, etc.) and the internal physico-chemical organization of the drop. But the correlation of the speeds of synthetic and analytic processes had a definite bearing on the fate of our colloidal formation. It was either useful or harmful, it had either a positive or a negative effect on the very existence of the drop and even on the possibility of its appearance.

Those coacervate drops alone were capable of a more or less protracted existence which possessed a certain dynamic stability and synthetic speeds exceeding or at least balancing the speeds of break-down. Contrariwise, those drops in which chemical changes in the given environmental conditions were directed primarily at break-down, were doomed, in consequence, to a more or less swift disappearance, or did not originate at all. In any case, their individual life story soon came to an abrupt end, and such formations, therefore, no longer played a consequential role in the further evolution of the organic substance. That role was played only by dynamically stable colloidal formations, and any digression from this stability put them swiftly out of existence and destroyed these "unfortunate" forms of organization. Such inadequately organized drops disintegrated, and the organic substances they contained were again scattered in the solution, rejoining the depot on which the more "fortunate" and better organized coacervates depended for their nutrition.

However, the drops in which synthesis held sway over break-down, were not only preserved, but grew and increased in weight and volume. In this way, it was the drops which possessed an organization best suited to the given environmental conditions that gradually increased in size. Furthermore, each separate drop that grew was bound to break up into separate parts or pieces on the strength of purely mechanical reasons. The "filial" drops which thus came into being possessed roughly the same physico-chemical organization as the "parental" coacervate. But henceforth they each followed their own path; peculiar changes now began to take place in each of them, which either increased or decreased chances for their survival. To be sure, all this holds good in the case of drops whose individual organization led in the given environmental conditions to the creation of an internal dynamic stability. Only such coacervate drops could exist for a long time, could grow and break down to form "filial" formations. Any change which occurred in the organization of coacervate drops under the influence of the constantly varying environmental conditions was preserved only if it answered the above requirements, if it increased the dynamic stability of the coacervate in the given conditions of existence. Hence, parallel with a quantitative increase of organized substance, with the growth of coacervate drops, the quality of their organization changed constantly in a definite direction, namely, towards the origination of chemical processes of such an order which would ensure the constant self-preservation and self-reproduction of the system as a whole.

At the same time, together with the increase in dynamic stability of colloidal formations, their evolution necessarily took the path of augmenting the very dynamism of these systems, of increasing the speed of reactions taking place in them. As a matter of course, the dynamically stable coacervate drop which became capable of a speedy transformation of substances thus acquired considerable advantages as compared with other drops floating in the same solution of organic compounds. It began to assimilate the latter much more swiftly, grew more quickly, and so its own importance and that of its progeny in the aggregate mass of coacervates became more and more substantial.

The simplest organic coacervates, with their unstable elementary structure, were destined to vanish sooner or later from the face of the Earth, to disintegrate and become part of the initial solution, and their immediate issue, which had developed a certain stability, were also doomed to lag behind in their evolution if they failed to hasten their chemical reactions. Those formations alone could grow and develop further whose organization had undergone significant change resulting in an increased speed of chemical reactions and, at the same time, in a definite coordination and orderliness of these reactions.

As we have seen in Chapter Five, enzymes are the internal chemical apparatus which accelerate and direct processes within living protoplasm. It was established not long ago that the exceptional catalytic power of enzymes and their striking specificity are determined by the peculiar structure of the proteins they contain. Enzymes are complexes comprising catalytically active substances and specific proteins increasing the activity of those substances. For example, let us take catalase, an enzyme which in living protoplasm accelerates the decomposition of hydrogen peroxide into oxygen and water. This reaction can be accelerated by inorganic iron too, but the action of iron in the required direction is very weak. However, by uniting iron with a special organic substance, pyrrole, we can make that action a thousand times more effective. Catalase, a natural enzyme, also contains iron in a combination with pyrrole, but its action is about ten million times stronger, because it contains besides a specific protein. Thus, in the final analysis, the catalytic power of one milligram of iron contained in the catalase complex is equal to that of ten tons of inorganic iron. For all our advanced technique, we have not yet approached the level of "rationalization" possessed by living nature.

This increase in catalytic power is a result of the specific structure of enzymatic proteins, of a definite and marvellously perfect combination of their active and activating groupings. The individual components of the enzymatic complex have but a weak catalytic power. The enzyme achieves its exceptional power only by a strictly definite combination of those components. It is perfectly clear that such a combination of the above groupings, which we find in enzymes, and the relationship so characteristic of enzymes, which exists between their chemical structure and their physiological function, could only have arisen as a result of constant perfection of these systems and of their structural adaptation to those functions which they perform in the given conditions of existence.

The numerous transformations of organic substances, which they underwent first in a water solution and then in primary colloidal formations, were comparatively slow. Individual reactions could have been accelerated only by the action of inorganic catalyzers (e.g., salts of calcium, iron, copper, etc.), which were doubtless present in the waters of the primitive ocean in considerable quantities.

In individual colloidal formations the inorganic catalyzers combined with various organic compounds in hundreds and thousands of ways. Among these combinations some were fortunate and increased the catalytic activity of a compound, while others were unfortunate and decreased that activity, thereby diminishing the aggregate dynamism of the entire system. But under the influence of the medium these unfortunate combinations kept constantly vanishing from the face of the Earth. Only such complexes as performed their functions more swiftly and efficiently could develop further.

As a result of the evolutionary process described above, the simplest inorganic catalysts which, acting together in the solution of primary organic substances, accelerated groups of homogeneous reactions, were gradually ousted from colloidal formations by more and more complex and developed enzymatic complexes, which not only possessed colossal activity but were also highly specialized, affecting only definite individual reactions. It is easy to see what great advantages the emergence of such chemical complexes gave the aggregate organization of processes which occurred in a given colloidal formation.

To be sure, the evolution of enzymes could successfully take place only when this was accompanied by a certain regularity and coordination of the individual enzymatic reactions. Every appreciable increase in the speed of a reaction was sustained in the process of evolution only when it was progressive in the sense that it did not detract from the dynamic stability of the entire system, but, on the contrary, was conducive to a greater internal orderliness in the organization of a given colloidal formation.

In the first coacervate drops this coordination among separate chemical reactions was comparatively poorly developed. Organic substances adsorbed from the medium and intermediate products of disassembly could still undergo chemical changes in many various directions. Of course, random syntheses could also facilitate the expansion of organized substance in the initial stages of development of the coacervates. But then the organization of newly arising colloidal sectors changed constantly and was to a large extent susceptible to decomposition, self-destruction. Only then did the colloidal systems acquire a more or less permanent dynamic stability when the syntheses which took place in them became coordinated, when there appeared a certain regularity, a certain rhythm, in the repetition of these syntheses.

While investigating the evolution of individual colloidal systems our attention should be focussed not on the fortuitous emergence in them of this or that compound, but on the repetition of the latter's formation, the appearance of a definite coordination of reactions which led to the repeated synthesis of the compound in the course of the expansion of the organized substance. In this way a new phenomenon emerged, which we now describe as the ability of protoplasm to reproduce itself.

On that basis there arose a certain compositional permanency of colloidal systems. In particular, the already mentioned rhythm of regularly repeated syntheses was vividly reflected in the structure of protein substances. The coordination of numerous synthetic reactions which in their totality led to the formation of a protein molecule excluded the possibility of a random arrangement of individual links in the polypeptidal chain. That is why the fortuitous distribution of amino-acidal residues characteristic of primary protein-like compounds was gradually substituted by a more definite structure of the protein globule.

This permanency of chemical composition in individual colloidal formations gave birth to a certain permanency in their structure. Built in a definite way, the proteins characteristic of this colloidal system were combined not fortuitously but in a strictly regular manner. Therefore, the structure of primary coacervates, unstable, transient, and too greatly dependent on fortuitous outside influence, was necessarily replaced in the process of their evolution by such a dynamically stable spatial organization which guaranteed a definite superiority in enzymatic reactions of synthesis over break-down.

Such were the evolutionary pathways which led to the inter-coordination of phenomena, the fitness of internal structure to the performance of definite vital functions in concrete conditions of existence, which is a prime characteristic of the organization of all living things.

We can trace the gradual complication and perfection of the organization of the above formations by studying the organization of the simplest living beings of our day. This process, in the long run, led to the advent of a qualitatively new form in the existence of matter. In this way there came about that "leap" which brought into being the simplest living creatures on the surface of the Earth.

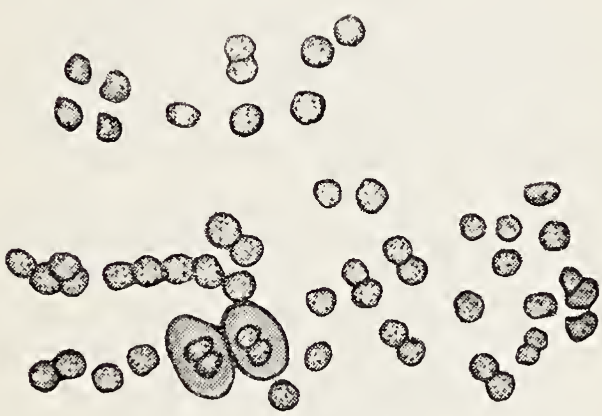
The structure of those first protozoon organisms was already greatly superior to that of coacervate drops, although it remained incomparably more elementary than the structure of the simplest living beings which are known to us today. They lacked cellular structure. This structure appeared at a much more advanced stage in the development of life.

As hundreds and thousands of years passed, the structure of living things improved and became better adapted to those conditions of life in which life developed. They became more highly organized. At first they fed on organic matter alone. But with time the quantity of such substances diminished and primitive organisms had either to perish or to work out in the process of their development a method of building up organic substances out of materials of inorganic nature—out of carbonic acid and water. Certain living beings succeeded in this. In the process of development

PROTOZOA

The first living creatures were akin to our present-day microbes.

Various species of present-day bacteria



Blue-green algae

they became capable of absorbing the energy of the sun, decomposing carbonic acid with its help, and building up organic substances out of its carbon in their bodies. Thus arose the simplest plants—Blue-green algae, the remnants of which are to be found in the most ancient deposits in the earthcrust.

Other living creatures continued to feed in the old way, but algae now became their source of food, from which they took organic substances. In this way the animal world appeared in its initial form.

"At the dawn of life", early in the so-called Eozoic period, both plants and animals were minute unicellular living beings akin to our present-day bacteria, Blue-green algae, and amoebae. The appearance of multicellular organisms, consisting of many cells united in one organism, was a major event in the history of the consecutive development of living nature. Living organisms became more and more complex and varied. During the Eozoic period, which lasted for millions upon millions of years, the population of the primitive ocean became extremely varied and changed beyond recognition. Gigantic algae inhabited the waters of seas and oceans, and in their thickets there appeared numerous medusae, mollusca, echinoderms, and marine worms. Life had stepped into a new age, the Paleozoic Time. Evolution during this age is illustrated by fossils of living creatures which inhabited our planet many millions of years ago.

About 500 million years ago, during the so-called Cambrian period in the Earth's history, life was still confined to seas and oceans. The vertebrate animals we know (fishes, amphibia, reptiles, birds, and beasts) had not appeared. Nor were there any flowers, herbs, or trees.

Plant life was represented solely by seaweeds, animal life by medusae, fungi, annelida, trilobites akin to crawfish, and various echinoderms.

During the next period, the Silurian, the first plants appeared on land, and the first vertebrate animals much like present-day lampreys, appeared in the seas. In contrast with fishes the latter had no jaws; the bodies of many genera were covered with bony testa.

Three hundred and fifty million years ago, during the so-called Devonian period, real fishes appeared in rivers and lagoons, the near and distant relatives of present-day sharks. But there were still no osseans such as zander, bream, or pike.

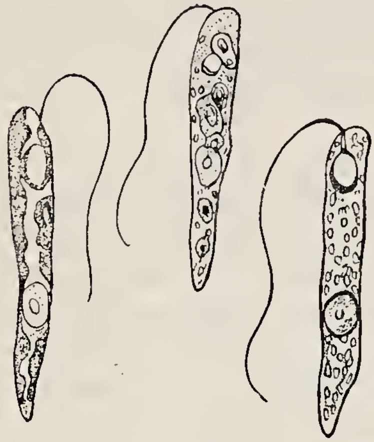
Another 100 million years later, in the Carboniferous period, the Earth was covered with a luxuriant growth of gigantic ferns, horse-tail, and club-moss. The banks of rivers and lakes crawled with numerous and varied amphibia. Like fish they spawned in water. Their wet slimy skin which dried rapidly in the air kept them near water reservoirs. Towards the end of the Carboniferous period the first reptiles appeared. Their corneous skin protected them from drying up. This enabled them to travel far inland and spread over vast territories. They no longer spawned, but laid eggs.

Two hundred and twenty five million years ago the Permian period began. Fern-like plants were gradually ousted by the relatives of present-day conifers and Sago-palms. Primitive amphibia are replaced by reptiles, which were better fitted for a dry climate. The forbears of the "terrible lizards", or dinosaurs, came into being. They were gigantic reptiles which dominated animal life in the periods which immediately followed the Permian. Neither bird nor beast had yet appeared.

The Age of Reptiles was in its heyday in the Jurassic and Cretaceous periods, when the first trees, flowers, and herbs resembling present-day flora appeared. The reptiles reigned supreme on land, in water and air. Huge dinosaurs wandered on land, "flying dragons", or pteranodons, soared

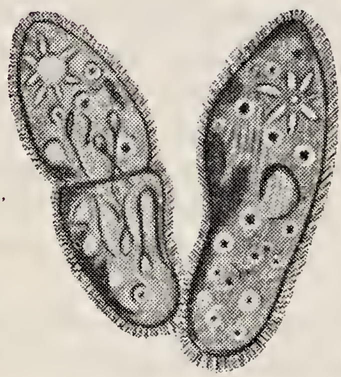
UNICELLULAR ANIMALS AND PLANTS

Their internal structure became more complex as time went on, and unicellular living creatures appeared.

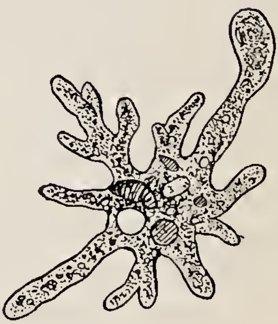


Flagellata

Infusoria



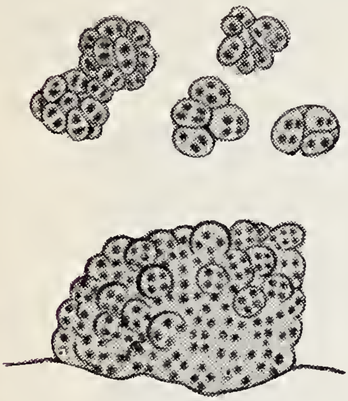
Unicellular algae



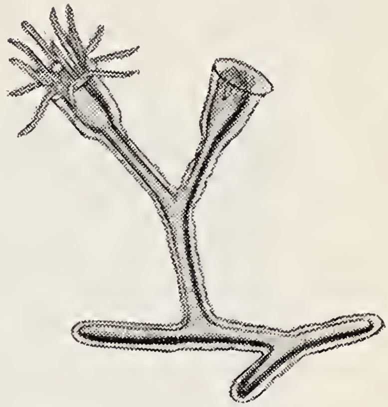
Amoeba

ELEMENTARY MULTICELLULAR ORGANISMS

Later on multicellular living creatures appeared in the water of the primitive ocean.



Colonies of Blue-green algae



Hydroid polyp

Green algae

Brown algae

in the air, snakes, ichtyosauria, and plesiosauria infested the seas.

The Age of Mammals began thirty five million years ago. By the middle of the so-called Tertiary period most of the larger reptiles had died out. Numerous species of birds and mammals appeared and soon became predominant in the animal world. However, they differed greatly from present-day animals. In those times our apes, horses, oxen, deer, and elephants had not yet come into existence.

It was only gradually, during the second half of the Tertiary period, that mammalia began to bear an ever stronger resemblance to their present-day descendants. By the end of the period deer, oxen, horses, rhinoceroses, elephants, and various predatory beasts appeared. At the beginning of the second half of the period apes came into being; the low order, hylobates, first, and then the higher order—anthropoid apes.

A million years ago, on the borderline of the Tertiary and the Quaternary period, the present period, the ape man, or pithecanthropus, appeared, the intermediate link between ape and man. The pithecanthropi learned to use the simplest work tools. They died out; their descendants were our forbears. In the Quaternary period, during the rigorous Ice Age, in the time of the mammoth and the reindeer, the Earth was already populated with real men, the structure of whose bodies did not differ from that of modern man.

EVOLUTION OF LIFE IN PRIMITIVE OCEANS AND SEAS

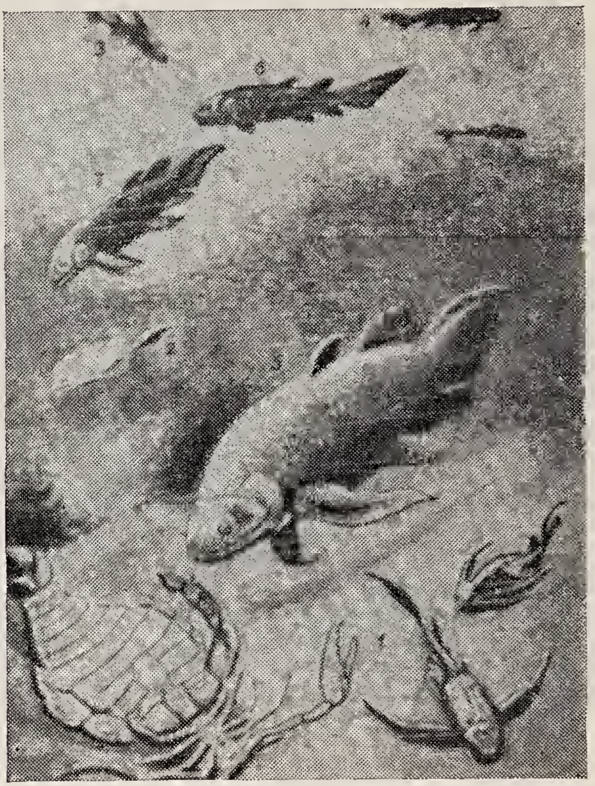
Over 500 million years ago, during the Cambrian period of the history of the Earth, life was confined to the seas and oceans. By this time lower (1) as well as higher seaweeds had already appeared. All the types of invertebrate animals were also present.

The sea population in the Cambrian period

They were microscopic unicellular animals, sponges and their relatives archaeocyathii (2), medusae (3), annelida (4, 5), sagitta (6), brachiopoda with a bivalve shell (7, 8), and the first mollusca (slugs). Trilobites (9) akin to crawfish were especially numerous. Various echinoderms also appeared. Some of them grew fast to subaqueous objects (10), others, such as holothurioidea, or sea cucumbers, crawled in the bottom (11,12) or swam about (13).

THE FIRST FISHES APPEAR

At the end of the Silurian period fishes much like our present-day ones appeared. In the Devonian period (350 million years ago) they greatly increased in number in former sea lagoons. Among them were the near and distant relatives of present-day



Fishes of the Devonian period

sharks. The bodies of some were covered with a bony testa (1, 2), bones developed in the skeletons of others (3, 4). There were no osseans like zander, bream, or pike in those days. Instead, there were many crossopterygii (5, 6) and dipnoi (7). They could breathe air with the aid of their swimming-bladder. The first land vertebrate animals, amphibia, were a derivation of the crossopterygii. They appeared at the end of the Devonian period.

LIFE BEGINS THE CONQUEST OF LAND

In the Carboniferous period (250 million years ago) the Earth was already covered by a luxuriant growth of ferns, horse-tail and club-moss. Numerous varied amphibia crawled along the

Amphibia of the Carboniferous period

shores of lakes and rivers. Among them were such giants as eogyrinus (1) and baphetes (2), and such pygmies as branchiosaurus (3). At the close of the period amphibia gave birth to reptiles, which were no longer forced to stay by water reservoirs and could spread all over the land.

LIFE TRIUMPHS ON LAND

In the Permian period (225 million years ago) the ferns were gradually ousted by gymnospermous plants, the relatives of present-day coniferae, Sago-palms appear. The ancient amphibia (1) give way to reptiles, which are better fitted to the dry

Ancient reptiles of the Permian period

climate. Some of the latter were very much like amphibia (kotlassia—2). The reptiles were represented by large herbivorous animals, such as pareiasauri (3) and mammal-like reptiles, such as the predatory (inostranzevia—4) and the toothless herbivorous (dicynodon—5). During this period the forbears of the "terrible lizards" appear—gigantic dinosaurs which later reigned supreme on the Earth.

THE AGE OF REPTILES

In the Cretaceous period, which ended 60 million years ago, the first trees, flowers, and herbs appeared on the Earth. They were related to their present-day counterparts. This period saw the reptiles reach the peak of their development; at its close they

Animals of the Cretaceous period

died out in a mass. In their heyday they populated land, water, and air. There were numerous varieties of dinosaurs. Some of them moved about on their hind feet: the harmless trachodon (1), the terrible carnivorous tyrannosaur (2), the struthiomimus (3), a smaller predatory dinosaur. The horned triceratop (4) crawled about on all fours. Flying dragons, the pteranodons (5), infested the air. Predatory marine reptiles—snakes, ichtyosauri, and plesiosaurla—swam in the seas. Birds and animals which had developed from reptiles in preceding periods were already in evidence.

THE AGE OF BIRDS AND BEASTS

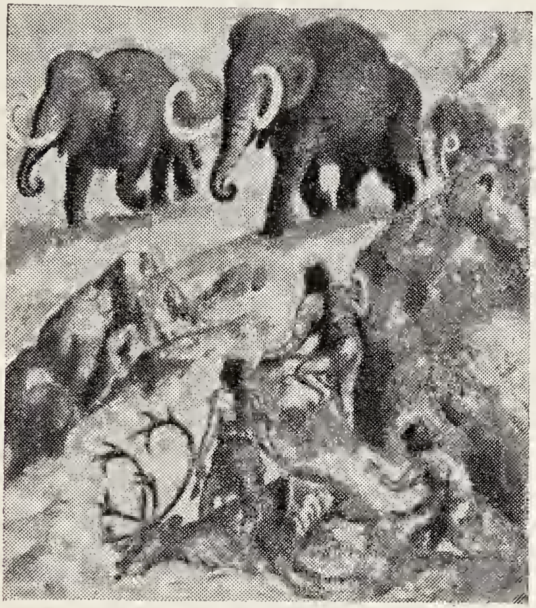
By the middle of the Tertiary period, 35 million years ago, most of the larger reptiles had already died out. Numerous and varied species of birds and mammals now ruled the animal world. The mammals of those times differed considerably from their present-day counterparts. There were such hoofed animals as the uin-

In a forest of the middle Tertiary period

tatherii (1), the distant forbears of elephants, and the pliohippii (2), partially related to horses. Ancient predatory mammals, the creodonts were represented by dog-like dromocyon (3) and otter-like patriofelis (4). There were also the tillotherium (5), a remarkable mammal whose teeth resembled those of a rat and a hedgehog. The first armadillos (6) and apes (7) had already appeared.

MAN APPEARS ON THE EARTH

During the second half of the Tertiary period the mammals became more and more like their present-day descendants. By the end of the period deer, oxen, horses, rhinoceroses, elephants, and various predatory mammals, were already in existence. Early in the second half of the Tertiary period apes appeared. At first they



Life in the Quaternary period

were dog-like apes; then the higher-type anthropoid apes came into being. A million years ago at the close of the Tertiary period and at the beginning of the present, Quaternary period, ape man, or Pithecanthropus—the intermediate link between ape and man—appeared on the Earth. The Pithecanthropi learned the use of the simplest work tools. They died out. Their descendant, the Neanderthalman, or "primitive man", is the immediate forbear of present-day man, although he differed from modern man. Late in the Quaternary period, during the last Ice Age, at the rigorous time of the mammoth and the reindeer, man no longer differed from his present-day descendants.

CONCLUSION

We have thus traversed the long road of the development of matter which led to the origin of life on the Earth. At first we found carbon scattered in the form of separate atoms, in the red-hot stellar atmospheres. We then found it as a component of hydrocarbons which appeared on the surface of the Earth. With time these hydrocarbons were transformed into their oxygenous and nitrogenous derivatives, into the simplest organic substances. In the waters of the primitive ocean these substances formed more complex compounds. Proteins and similar substances appeared. Thus the material of which the bodies of plants and animals are formed came into being. At first this material existed in a dissolved state, then it began to separate from its environment in the form of coacervate drops. The first coacervate drops were of a simple structure, but gradually substantial changes took place in their structure. They acquired a more and more complex and improved structure and were finally transformed into primary living beings—the forbears of all life on the Earth.

Life continued to develop. The first living beings were not cellular. But at a definite stage of life's development, the cell appeared; unicellular and, later, multicellular organisms established themselves on our planet. Thus does science refute such religious figments as the spiritual source of life and the divine origin of living creatures.

The modern achievements of natural science, which reveal the laws governing the origin and development of life, deal crushing blows to idealism and metaphysics, to the entire reactionary ideology of imperialism.

Now that the internal organization of living creatures has been thoroughly investigated, we have every reason to believe that sooner or later we shall be able practically to demonstrate that life is nothing else but a special form of existence of matter. The successes scored recently by Soviet biology hold out the promise that the artificial creation of the simplest living beings is not only possible, but that it will be achieved in the not too distant future.

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