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A CONSIDERATION OF THE EVOLUTION OF THE NERVOUS SYSTEM

With Illustrations of Selected Mammalian Brains

by Thomas J. Heldt, M.D.*

This article is a philosophical discourse prepared at the invitation of the Publications Committee Chairman, because of the author's scholarly interest in problems of the nervous system. Most of the discussion deals with speculations concerning the origin out of primordial chaos of the inorganic, organic, and biological world.

The purpose of this presentation is to attempt a partial *longitudinal* description of the nervous system from its beginning to the present level of development. Cross sections there will be, but a *longitudinal perspective* is the goal.

Generally speaking, the nervous system is the guardian of life. How this has come about is a hazardous guess, but somehow it occurred between the beginning of all things and the present moment of existence. The more science uncovers, the greater the significance of the findings. Mystery fades with the unraveling of truth and fact.

Transmutation of Chemical Elements

Inasmuch as chemistry is basic in the interpretation of the physiology of living, it behooves us to give thought to the origin of chemicals and of life itself. The ancient Greeks held a mythical concept attributed to Orpheus, that the heavens and the earth were spun from chaos by the force of time[1]. If chaos be equated with the primordial status of the universe as we know it today, such myth is not excessively fantastic. Nothing in the preceding statements impugns the spiritual and no such implication is intended in any of the statements that follow.

Sir Isaac Newton (1642-1727)[2] said: "All these things being considered, it seems probable to me, that God in the Beginning formed Matter in solid, massy, hard, impenetrable, moveable Particles . . . ; no ordinary Power being able to divide what God himself made in the first Creation." Prophetically he further stated: "Now the smallest Particles of Matter may cohere by the strongest Attractions, and compose bigger Particles of weaker Virtue . . . "†

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†This reference is noteworthy not only for the words of Newton, but also for the pages of preliminary comment consisting of Preface by editor Cohen, Foreword by Albert Einstein, Introduction by Sir Edmund Whittaker and an Analytical Table of Contents by Duane H. D. Roller. To me, these pages are remarkable in content and as introductions to Newton's 406 pages of text.

Albert Einstein (1879-1955) in his writings in 1905 declared: "I shall never believe that God plays dice with the world."[3] He repeated words to the same effect in the time interval between 1940 and 1953: "I cannot believe that God plays dice with the cosmos, as the non-deterministic theory of relativity would seem to indicate."[4]

In the beginning, according to modern cosmogony, all was cold and dark. The primordial cosmic universe was a gigantic void occupied by a thin gas. In the matter of some 60,000 million years[5] gravitational forces and turbulence of motion brought about condensation and contractions of the gas into nebulae.[5] In more billions of years, stellar masses were formed and with the birth of stars radiant energy appeared. Interstellar space became populated, however thinly, with infinitesimal particles. These, in the light of present cosmogonical knowledge, were probably free protons, neutrons, and electrons with various cosmic rays and the elementary particles of cosmic dust. In the course of additional millions of years, some of the protons in mutation, by accident as it were, stuck together. Neutrons and electrons took part. Hydrogen was formed. Then came deuterium, tritium, and helium; and, with increasing

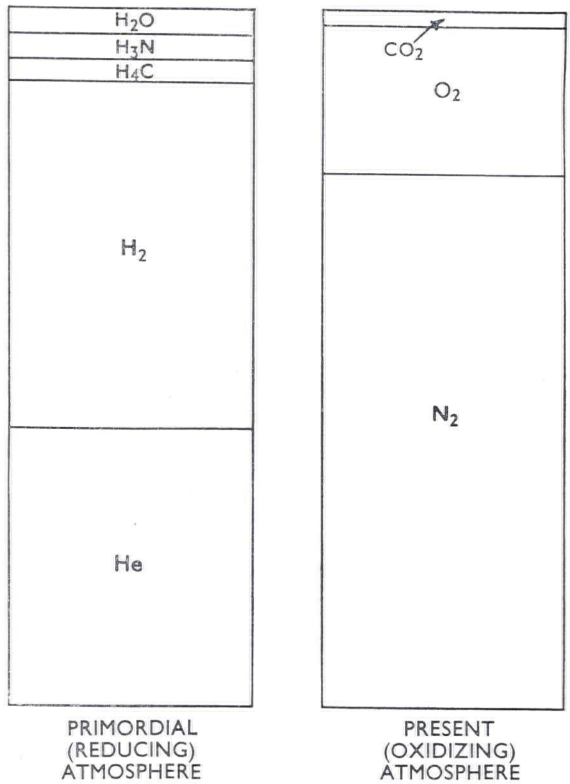

Figure 1

Difference between the constitution of the primordial and the present atmosphere of the earth. (After H. Urey,[11] p. 55, Permission Macmillan & Co., Ltd., London, W. C. 2.)

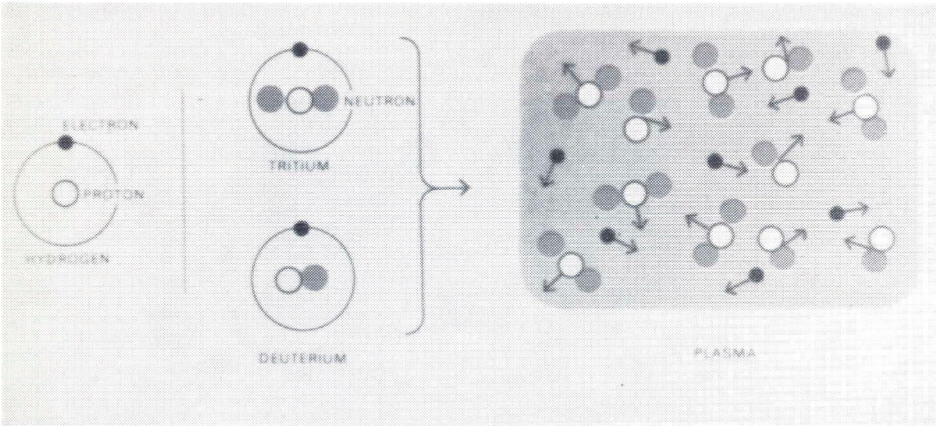

Figure 2

Plasma. A Fourth State of Matter: (After Papp and Editors of Life[13].) The ordinary hydrogen atom has one proton, one electron, and no neutrons. With two neutrons in its nucleus, it is known as tritium; with but one neutron, it is called deuterium. The gray-tinted rectangular illustration shows the chaotic movement of tritium and deuterium nuclei in the plasma state. Plasma, then, is a swarming mass of hot, electrically charged particles — free electrons carrying a negative charge, and positively charged ions, the whole being electrically neutral. Some substances require less heat than others to ionize, but the phenomenon usually does not begin until temperatures reach at least 5,000° F. or 6,000°, and it is not really going full blast until 100,000° F. Even then, the particles keep recombining spontaneously; thus, there are generally neutral atoms along with the charged particles of the plasma. (From Matters[13]. Courtesy Time-Life Books. (c) 1963 Time, Inc.)

stellar temperatures the fourth state of matter, plasma, was also formed. Then, since there is no stable nucleus with an atomic weight of 5, eons of time must have elapsed before the carbon cycle was established, again, probably as a mutation. The additional inorganic chemicals, carbon, oxygen, and nitrogen then joined in further chemical advances.

Astrophysicists now judge that, after many millions of years, stellar masses became formulated into two general types of stars, Population I and Population II. The latter contain the older and aging stars; the former, including our sun, are younger and were condensed from the remains of exploded old stars in the distant past. It is found that whereas stars of Population II contain minimal heavy elements, the stars of Population I show the carbon cycle. In more millions of years, and temperatures of many millions of degrees Fahrenheit, heavier chemical elements ensued, interstellar gases changed in concentration, and stellar radiations became more dominant.

At about 2.7 billion degrees Fahrenheit in the central core of a star: aluminum, silicon, sulphur, phosphorus, and other atoms should begin to form; and, at nearly 4 billion degrees these elements, in turn, should be transmuted into still heavier ones: titanium, chromium, manganese, iron, nickel, cobalt, copper and zinc.[6]

Thus, during millions upon millions of years the origin and the transmutation of the chemical elements are established. Some degree of conformation lies in the

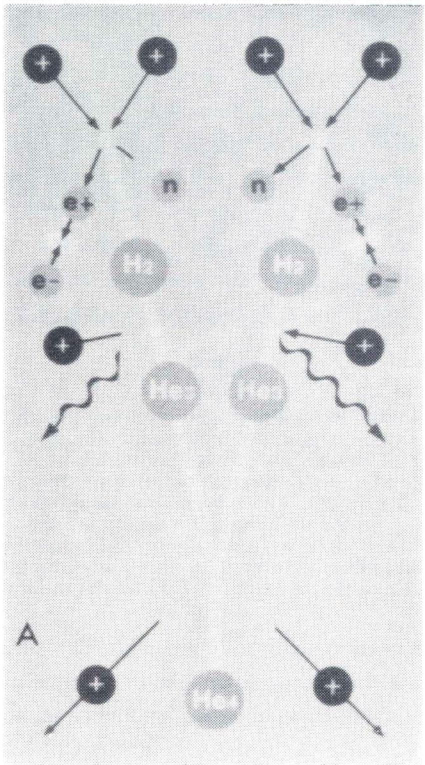

Figure 3a

Proton-Proton Cycle: (After Bergamini and Editors of Life[6].) The proton-proton cycle is the nuclear process which powers the sun. Key: +, proton, massive positive particle; e—, electron, tiny uncharged particle; o, nucleus, central core of an atom.

This cycle is confined to relatively cool stars, notably red giants, with central temperatures ranging between two million and 20 million degrees Fahrenheit. Hotter stars have different nuclear processes. In the proton-proton cycle, nuclei of hydrogen made unstable by heat and pressure are turned into stable helium and energy. The cycle would be fantastically slow if only a small number of atoms were involved, but there are so many of them in the sun that activity is continuous and on an enormous scale.

The cycle starts for any one proton when once in seven billion years, it collides with another proton. This collision produces a deuterium nucleus, a neutrino that shoots off into space and a positron which eventually annihilates a stray electron. After a few seconds, the deuterium nucleus is hit by another proton, producing a nucleus of helium-3 and a burst of gamma rays (wavy arrows). After some 400,000 years, the helium-3 nucleus hits another helium-3 nucleus, producing a nucleus of inert helium and two protons. These two protons are now free to start the proton-proton cycle over again. (From *The Universe*[6]. Courtesy Time-Life Books. (c) 1962, Time, Inc.)

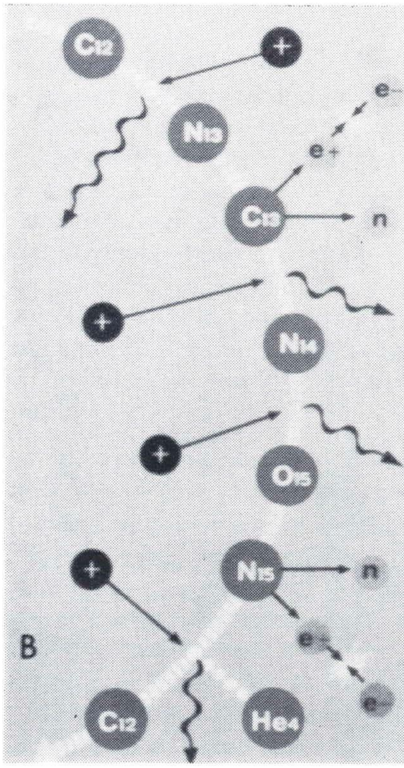

Figure 3b

Carbon-Nitrogen Cycle: (After Bergamini and Editors of Life[6].) The carbon-nitrogen cycle also results in the formation of helium and the eventual death of the star in which it takes place. It occurs in hot stars with central temperatures of at least 55 million degrees Fahrenheit. The process requires seven million years to complete, as compared to seven billion years for the cooler proton-proton cycle. After 2.5 million years a carbon nucleus (12) is hit by a proton, which it absorbs, changing into a nucleus of nitrogen-13, and giving off energy in the form of a gamma ray. The nitrogen-13 is unstable and quickly changes into carbon-13, releasing a neutrino, which shoots off into space, and one positron, which eventually meets a stray electron. The positron and the electron immediately neutralize each other. During the next 10 minutes the new carbon-13 is struck by a proton and changes into nitrogen-14, giving off a gamma ray in the process. After four million years, the nitrogen-14 is hit by another proton, changes into oxygen-15, and also releases a gamma ray. The unstable oxygen-15 becomes nitrogen-15 within a few minutes, simultaneously emitting one neutrino which is lost in space, and one positron, which again meets an electron and ends in mutual neutralization. After about 20 years, the nitrogen-15 is hit by a proton and splits into one nucleus of helium and a nucleus of carbon-12, the latter is left free to start the cycle over again. (From *The Universe*[6]. Courtesy Time-Life Books. (c) 1962 Time, Inc.)

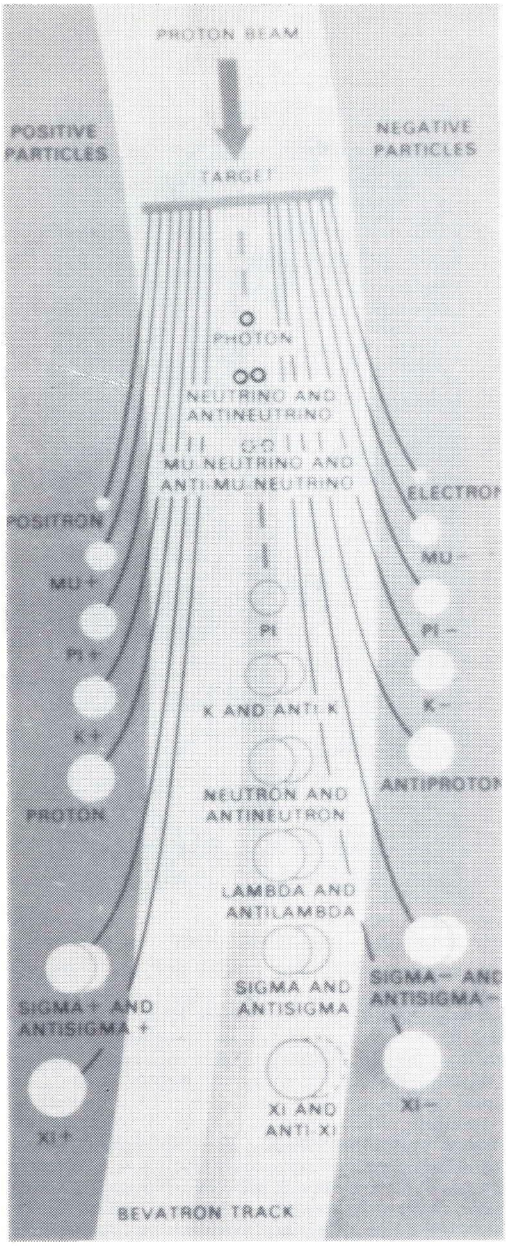

Figure 4

"Fundamental" Fragments of an Atom: (After Lapp and Editors of Life[13].) Atomic nuclei may release 32 "fundamental" particles when a high-energy beam of protons produced in a particle accelerator slams into a target. The eight fragments with positive charges are separated for study by a strong magnetic field which pulls them to the left. The lighter the particle, the more sharply its path is curved. The same magnet pushes the eight negative particles to the right. Physicists believe that there are 16 neutral particles, but have not yet conclusively proved the existence of the three shown in the figures as dotted circles — the mu-neutrino and anti-mu-neutrino, and the anti-xi-particle. Though most of these particles exist in free space for no more than a ten billionth

of a second, certain combinations of them known as "resonances" live for no longer than a hundred thousandth of a billion billionth of a second.
(From *Matter*.[13] Courtesy Time-Life Books. (c) 1963 Time, Inc.)

observed fact that the element californium was first discovered in the debris left behind by the explosion of the first man-made hydrogen bomb.[7]

Regarding the origin of the planets, Gamow[8] says: "Apparently the original ring around the Sun was about a hundred times heavier because of the overabundance of hydrogen and helium. Because of this much larger mass, gravitational forces acting between different parts of the ring were also much greater, and condensation of the ring material into planets could easily take place. But the original condensations, known as 'protoplanets', must have been much larger than the planets as we know them today, consisting mostly of a hydrogen-helium mixture with only about one percent of terrestrial elements. Soon after the protoplanets were formed, the original interstellar dust, consisting of the particles of iron oxides, silicates, etc., settled toward their central regions, forming solid cores surrounded by huge hydrogen-helium atmospheres . . . When millions of years later, the Sun became what it is now, the radiation pressure of the light emitted by it began to blow off the hydrogen-helium envelopes of the planets."

To remain mindful of the significance of infinity and the extent of the universe it is wise to remember that present day astronomers judge that one out of every hundred stars must have a planetary system similar to that of our sun; and, since the Milky Way galaxy, of which our sun and its planets are a part, contains about 100,000,000,000 (10^{11}) stars we may conclude that there are within it about 1,000,000,000 (10^{9}) planetary systems not unlike our own.[9] Shapley, in writing the introduction to the volume *The Universe* in Life Nature Library, declares: "Some photographs record a million stars of our galaxy. Others, groping for the bounds of the universe, uncover thousands of other galaxies. Ten times as many galaxies inhabit our explorable space-time as there are men on this crowded planet. There are indeed galaxies enough for everybody!"[10]

Incidentally: Our Milky Way galaxy is 100,000 light years in diameter.[6] The sun rotates on its massive axis with a diameter of 864,000 miles, and moves around in its orbit about the hub of the Milky Way galaxy once every 200 million years. The galaxy also rotates and has its orbit.

"How big is the cosmos? . . . By the simplest interpretation — and that best backed by the facts — the universe is finite but unbounded. A light ray may travel infinitely far, going round and round in curved space, but it moves in a cosmos with a finite radius — a radius of about 13 billion light years."[6]

The density of matter in the universe as determined by the Dutch astronomer, J. H. Oort, is $3 \times 10^{-31} g/cm^3$ or 0.2 hydrogen atom per cubic meter, or one atom per 5 cubic meters.[11]

The age of the earth is upward of 5 billion years.[12]

". . . The sun pours forth 6 trillion quadrillion (6 followed by 27 zeros) calories of heat per minute to a candle's 1,600 and shines as if each square inch of its 'surface' were covered with 300,000 candles.[14] Even so, the sun possesses enough mass to continue to radiate at its present rate for 15 million million years (10^{12}).[5]

"In June, 1962, physicists at the 33-billion-electron-volt atom-smashing synchrotron at Brookhaven, Long Island, fired atomic particles through 42 feet of armor plate and discovered the existence of two different varieties of neutrino, a mysterious and elusive particle as close to nothing as anything can get and so penetrating that it can shoot through 100 trillion miles of lead like a bullet through a cloud."[13]

The two fusion reactions (proton-proton cycle and carbon cycle) transform an inconceivable 657 million tons of solar hydrogen into 652½ million tons of helium ash each and every second. The missing four and a half million tons of mass, converted into neutrinos and gamma rays, reflect a basic nuclear fact — namely, that a helium atom is only 99.29 percent as massive as four hydrogen atoms. The extra .71% of atomic weight has to be destroyed or the nuclear transformation cannot take place. This process of destruction obeys Einstein's famous law, $E=Mc^2$. ". . . It turns out that the sun is shining with a constant power of 380 million billion billion watts — which is equal to quite a lot of light bulbs."[6]

The origins of time, and space with its original inchoate gas, are still beyond our ken and the present eyes of research.

Inasmuch as many of the foregoing ideas are borrowed it is suggested that the interested reader seek confirmation and background from the additional references[13-19] for this chapter[20-27] of my thesis.

Evolutionary Growth of Biochemistry

Sequence there was in the chemistry of the primordial universe. With the origin of the initial atomic elements, the building blocks of molecules were at hand. Molecules of hydrogen and helium formed and with the influence of radiant energy carbon, oxygen, and nitrogen joined in. The age of molecular chemistry slowly formulated.

Of hydrogen there was an abundance, and with the advent of oxygen and carbon dioxide water could form. Encrusting of the earth led to an atmosphere with clouds of gases, water vapor, and suspended cosmic dust. Light with its myriad wave lengths, the constant solar rays, and awesome lightning in years of time brought about increasing chemical syntheses, including some amino acids. The crust and the mantle of the earth cooled as the water vapors of the atmosphere turned more and more to rain, and according to modern geophysicists, centuries of rain produced the seas.[1] These seas, rich in the chemicals washed into them by the rains, became the creative caldrons for more and more molecules. Frequent volcanic eruptions altered the rugged land surface and brought harsh waves into its oceans. In certain areas, the waters of the seas were literally churned into boiling solutions, while other areas were cooling, favorable for more and more molecular organizations. In this "primordial soup" inorganic chemical elements became mixed with organic compounds, and with the passage of time, the organic aggregates of molecules evoluted into biochemistry. The primitive forces of light, gravitation, condensation, as did chemotaxis and the many effects of electrical charges, magnetic forces, and cosmic ray relationships.

For many years in the past, and especially recently, scientists have sought artificially to duplicate the conditions in nature which caused various atoms and molecules to attract or repel each other. Of failures there have been many, but ever an increasing body of knowledge is obtained. Very noteworthy is the passage of electrical current through a planned natural mixtures of methane, ammonia, hydrogen, and water vapor with the production of some amino acids by Stanely L. Miller[30] in 1953. However, methane had been subjected to electric sparking by Austin in 1790 (cited by Carr) with the probable formation of hydrogen. Through aggressive interest in photosynthesis by engineer Charles F. Kettering, and grants from the Charles Kettering Research Foundation, the Ohio State University in its McPherson Chemical Laboratory under-took some very pertinent studies in 1948. This led to the presentation by the Ohio Academy of Science of a Symposium on Prebiological Chemistry,[31] under the chairmanship of Charles F. Kettering and William M. MacNevin, on April 25, 1953. Papers by MacNevin, Caley, Calvert, and Rubin of the Laboratory and two guest speakers focussed attention on helpful information. Evidence was given that porphyrins and chlorophyll are prebiological. Further studies and findings are recorded by Winifred Carr,[32] in her 1954 Ph. D. dissertation. She carried out experiments by electrically sparking methane, ammonia, and water vapor, singly and in varying mixtures of those gases. Products obtained included "cuprene" (probably polymerized acetylene, with formula of C_{54} H_{70} O_{16}), hydrogen cyanide, and ammonium cyanide. She concludes: "In general, the solids formed by the passage of high tension sparks through mixtures of certain simple gases were found to be highly complex organic compounds or mixtures of such compounds."

Miller[30] simulated the primitive conditions by adding molecular hydrogen to his experimental mixture and exposing it continuously to an electric current for a week. This was clearly a forward step over the Carr experiments. Fox[33] has corroborated Miller's deductions and with Harada[34] has proceeded to show that amino acids may be thermally synthesized in a simulated primitive atmosphere in the presence of various types of silica or of aluminum. These findings prompted Fox[35] to carry out experiments in thermal polymerization of amino acids and production of formed microparticles on isolated pieces of lava taken from the Kapolo field of the island of Hawaii. In this case the changes were wrought with a temperature of 170°. Previously, Miller and Urey[36] had judged higher temperatures were necessary. In September of 1964, Fox and Krampitz[37] reported that they found that the thermal condensation of the eighteen amino acids common to protein, (which condensation they designated protenoid) represents a synthesis by which protein moleclues can come into existence in a geological matrix. They concluded that, "The finding of catalytic activities for natural substrates and of integrated nutritive qualities in thermal protenoids entitles them to be considered both as synthetic general protein and as a model of primitive abiotic protein". Harada and Fox[38] detailed some of their studies of the findings at a conference in Wakulla Springs, Florida in October 1963. Their presentation with seven pages of published discussion by confreres is clarifying and very informative.

To the foregoing data it is well to add the studies of Weisskoff[39] in quantum theory and elementary particles. Acquaintance is gained with baryons, mesons, leptons, hadrons, and the ultra-elementary quarks. Note also the studies by Ponnamperuma and Mack[40] on nucleotide synthesis under possible primitive earth conditions..

Even this brief sketch of the evolutionary growth of biochemistry leaves little doubt that amino acids, certain organic acids, proteins, and even urea existed before the emergence of life.

Accession of Life

That amino acids will form in the presence of methane, ammonia, hydrogen, water vapor, and an adequate charge of electricity was experimentally confirmed by Miller in 1955[41] and 1957[42]. This abiogenetic synthesis of carbon compounds may be taken as the first step in the evolution of life.

When some of the chemotactic groups of molecules in the "primordial soup" attained the need of pattern arrangements to promote interrelationships, a "fencing in" of a kind was necessary. Through ionization, temperature changes, pressure, viscosity, and various rays of cosmic energy membrances formulated and cells of biochemical degree took shape. Cells were first so called by Robert Hooke (1635-1703).[43] Hooke's observations were organized and enlarged upon by biologists Schleiden and Schwann[43].

Concomitant with the formation of amino acids the saccharides probably also took form and likely some degree of fermentation soon followed. Through millenia of time and multiple mutations the elementary cells progressed into increased programs of biochemical activity. Syntheses of higher order occurred. The nucleic acids, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA); and, adenosine mono-, di-, and triphosphates (AMP, ADP, & ATP) developed into more and more reactions. Membranes surrounded cytoplasmic aggregates. Both the membranes and the cytoplasm became vital biochemical factories of ultra microscopic size but powerful in energy content. The amino acids of the DNA macromolecule encouraged increasing biochemical interrelationships. Genetic factors were promoted. Replication of cells was in progress.

Jeans[5] approximates the age of the universe at 60,000 million years. In such a span of time the age of earth estimated at five billion years is somewhat of a junior as can also be said of the solar system and the entire Milky Way galaxy. Just when in the five billion years life on earth made its first appearance is a matter of conjecture. Walcott[43] has found some fossilized blue-green algae in Canada and judges those fossils to be two billion years old.

Gamow[44] questions the time phosphorus, as a chemical element, was first added to the "primordial soup" in which life obviously had its beginnings. It seems reasonable to assume that the conditions necessary for the transmutation of phosphorus (Atomic wt. 31) were present very early in the earth's history. Radiant energy and the temperatures of the sun and the volcanoes of the earth, as well as of lightning, and mutations certainly produced provocative opportunities for its formation. Many organic chemical reactions must have been occurring in the hot waters of the seas. ADP and ATP were doing duty and proteins were probably being amalgamated.

It is of course conjecture, again, when viruses, bacteria, and bacteriophages put in their appearance, to say naught about the more recently discovered extra-small pleomorphic myoplasmataceae[45]. These forms are now being found among human pathogens. [46,47,48] To just what extent these organelle groups of multimolecules can be said to have life is open to question for they cannot reproduce themselves nor is there any replication without the intermediation of some host cell. The human white blood cell (polymorphic leucocyte) although it possesses locomotion of a kind in addition to being swept along by the blood current, and although it can ingest and digest microorganisms, cannot reproduce itself. It is produced by the hematopoietic organs of the human body, specifically for the granular polymorph, in the bone marrow. The malarial parasite reproduces itself but it must have intermediaries and

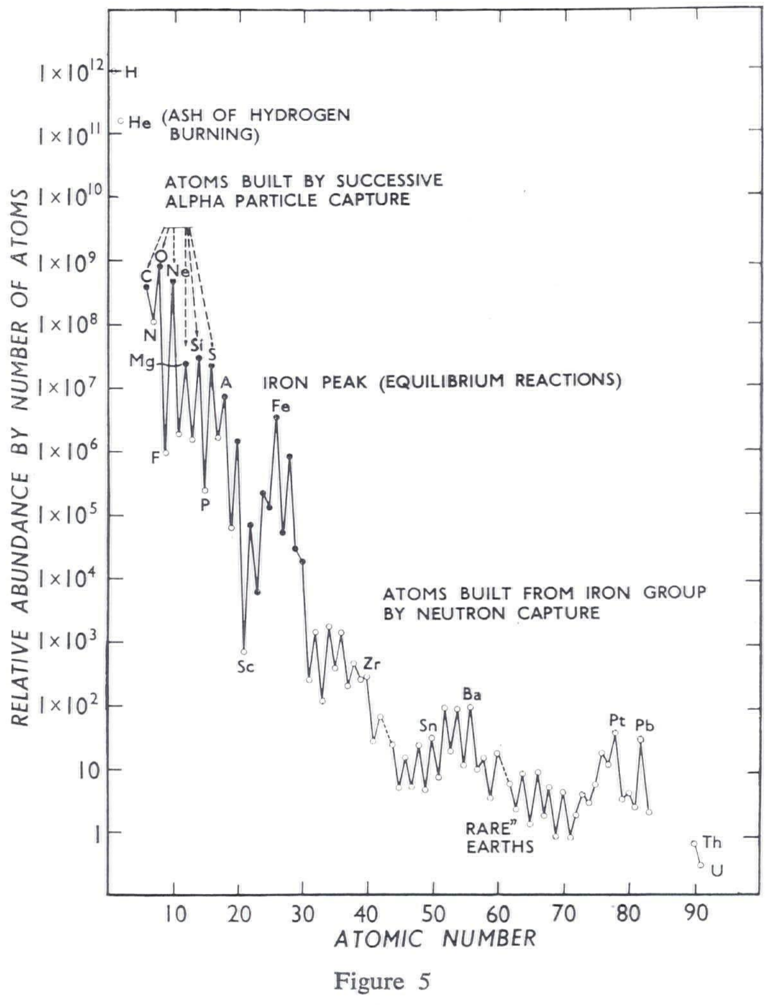

Figure 5

Relative abundances of atomic elements. (After L. H. Allen,[11] p. 70, Permission Macmillan & Co., Ltd., London, W. C. 2.) This abundance curve is normalized to hydrogen (one million million atoms). Note position of phosphorus (P).

does not come to full reproduction of its kind outside of an erythrocytic host. Many cells of the human body cannot reproduce themselves but are looked upon as having life because they are part of a living host. It remains, therefore, a moot question just when life steps in to honor the earliest biochemical specialized group of macromolecules. What and where is the first cell that can reproduce itself without the assistance of another cell?

Haldane, 25 years after his first studies in 1949,[49] in recording some of his suggestions in 1954[50] on the origin of life, wrote: "Life has no origin. Matter and life have always existed." And, again: "The critical event which may best be called the origin of life was the enclosure of several different self-producing polymers within a semipermeable membrane." In 1965,[51] in submitting his thoughts on the "Data Needed for a Blueprint of the First Organism", he says: ". . . the first organisms, by which I mean the first system capable of reproduction."

I like Ehrensvärd's[52] discussions and his generalization: "Life is what it is; and what it appears to be in simple outline, a cyclic procession of matter driven by daylight."

It is rather tenuous to agree with Thales (640-546, B.C.) that magnets have life because they attract iron, but probably somewhat less to think that production and reproduction occur in atoms and molecules. When in the illimitable range of time and space a proton meets an electron, a hydrogen atom is formed. In a next step, H_2, the molecule, is produced. In the entire process the photon, or gamma ray, is the probable initiator.

Barnett[53] in "The Morning of Life" gives an epitomized account of many of the steps leading to the accession of life, abiogenic to vertebrates.

Morgulis, in 1952, in his "Introduction to the Second English Edition" (republication of Oparin's 1938 edition of The Origin of Life) succinctly records his then impressions as to how life might come into being. Some of his statements are worthy of repetition:[54]

"The origination of life was a transition from organic to biological chemistry, from lifeless to living matter, from the inanimate to the animate realm of Nature. But what is Life? . . . living systems must have appeared in highly complex protein macromolecules antedating the appearance of cellular organisms . . . Neither viruses nor genes, both of which represent nucleoprotein systems, can duplicate or replicate themselves unless they are incorporated within a suitable cell or nucleus. Considered simply from the point of view of capacity to reproduce, are these nucleoproteins living or non-living systems? . . . in reality life is a manifestation of catalysis by means of enzymes which are proteins. Chemical reactions in plant and animal organisms proceed at very high velocities. Without catalysis there could be no life. In fact, the bulk of protoplasm is filled with enzymatically specific active proteins. Yet enzymes are not living matter . . . But we know that the protein catalysts (enzymes) had already been operating at the very dawn of the appearance of plant and animal life . . . Evolution has flowered from the Bryozoa (and probably long before them) to the vertebrates, but the heavy metal electron transfer enzyme system has persisted through all these hundreds of millions of years as the basic design of cellular respiration . . . biochemical unity suggests that the coenzymes became part of a basic metabolic plan laid down even before evolution, acting through natural selection, had created a highly diversified flora and fauna.

"The only known means for storing, transforming and mobilizing energy for the metabolism in living organisms is the system of high energy phosphate bond; namely, Adenylic Acid $\leftrightharpoons$ Adenosinediphosphate $\leftrightharpoons$ Adenosinetriphosphate . . . If life is a manifestation of the existence of proteins, or more correctly a manifestation of catalysis by means of protein enzymes, the origin of life must have coincided with the origin of proteins if not actually preceded by them. Did protein precede the enzymes or did enzymes the proteins? . . .

"Whether the ultimate particles of life have been found and identified is very doubtful, some of the units themselves being highly organized entities, but the concept of a cell as the unit of life has been thrown out of the window together with the atom . . . In all probability it (DNA) supplies the cytoplasm with ribonucleic acid (RNA), and their interrelationship should be described as symbiotic . . . A few random examples of biological symbiosis may serve to emphasize the profound significance of this phenomenon as the pattern which might have been operative not only at the cellular or particulate level but even at the macromolecular level in the transformation of non-living to living matter.

"Hemoglobin, the red blood pigment, has been usually regarded as a strictly animal product. In recent years it was discovered that hemoglobin is formed in the root nodules of legumes harboring nitrogen fixing bacteria. The far-reaching significance of this biological observation lies in the fact that neither the root nodules nor the microorganisms, by themselves, are capable of effecting this synthesis. Only in the infected nodule is hemoglobin being synthesized. . . .

"Another pertinent story can be told about chlorophyll, a green pigment closely related chemically to hemoglobin. This pigment is found in plants in special organelles, the chloroplasts. Chlorophyll absorbs light waves in the purple and red range of the spectrum and thus traps radiant energy . . . It is interesting to note that chlorophyll itself is unable to accomplish the photosynthetic reaction except as a component of a chloroplast. Chloroplasts are small green bodies enclosed in the cytoplasm of high plants and of green algae. The reaction sequence of photosynthesis begins and ends within the chloroplast. . . .

"A concluding word should be added about viruses. Both the virus and the gene represent the simplest substances known to be autoreproducible. Both are largely or entirely nucleoprotein macromolecules. Plant viruses contain only ribonucleic acid (RNA) and animal viruses contain both RNA and DNA, whereas genes contain desoxyribonucleic acid (DNA). Nevertheless, viruses and genes have some things in common. Thus, neither can reproduce itself except within a suitable type of cell. However, if the gene (nucleus) and cytoplasm fit each other (i.e., belong to the same or closely related species) their symbiotic relationship culminates in normal development; if the virus and host cell fit each other, the virus usually multiplies and in doing so destroys the host (parasitic relationship). The discarded virus, unless it can invade another cell, reverts to the status of non-living matter."

Oparin, an early student of the origin of life, published his first thoughts on the matter in 1924 (some references also give the year as 1923) in a booklet entitled: Proiskhozhdenie Zhizni (The Origin of Life), Moscow, Russia, Izd. Moskovskil Rabochil, 1924.*

Oparin's ideations, interpretations, and graphic illustrations of chemical formulations and experimental presentations of coacervates add much to our body of knowledge regarding the abiogenic origins and their relation to the biogenic. The progressive development of his studies are well recorded in his translated books, 1938 to 1964.[55-59] He suggests from present (1964) information: "Life is a special and very complicated form of the motion of matter.[59] In his article: "The Pathways of the Primary Development of Metabolism and Artificial Modeling of the Development in Coacervate Drops", he helpfully details the process of coacervation.[60]

In the early chemical studies of evolution, Mora[66] records reflections on: "The Folly of Probability". The recorded refutative and amplifying discussion of colleague scientists enlighteningly covers as many pages as does Mora's well-ordered article.

*This writer has been unable to locate this booklet in any of the libraries in the U. S. A. He is hoping to procure a copy, or a photostat of it, from the Lenin State Memorial Library of Russia, but he will probably not obtain it before this presentation goes to press.

Should the reader desire additional details and critiques, references [61-67] are suggested.

Fungi live in symbiosis with algae.[68,69,70] Symbiosis is a necessity for most of the earliest forms which can be said to have life. The golden orange lichen of the Arctic (Caloplaca elegans, also called Xanthoria elegans) is dependent on its symbiont alga of the genus protococcus.[71,72] Yet even man himself is not without his symbioses and commensal relationships in his environment.

With algae living two billion years ago,[43] precisely when life can be said to have made its advent is still decidedly a controversial matter.

The Emergence of the Nervous System

The amoeba is said to be without a nervous system. It has been studied for years and its locomotion to this day has been declared to be free from the assistance of any type of nervous mechanisms. Amoeboid movement is still receiving much research attention but it appears clear that the plasmalemma is composed of two layers although this does not go without challenge by some investigators. To me it appears that the outer layer is not unlike the tread of a caterpillar tractor. It makes all connections with substrata. The inner layer is organized in relation to the cytoplasm of the animalcule.

Different researchers have different thoughts regarding the first evidence of nervous function and whether it is primarily dependent upon hormonal chemicals and possibly on neurosecretory substances. Ions, atoms, and molecules with their electrons, primitively, were probably influential in one way or another; but, at what level were they first organized into an organelle or neurosecretory cell? Demand for rapid influence beyond the cell called for some conductive system. How and when was this first accomplished? When was insulation first produced in order to confine the driving impulse? What in this regard is the significance of unmyelinated and myelinated nerve fibers, and how is the speed of impulse related to diameter of nerve fiber, for example, as seen in the giant nerve fibers of the squid?

Some biologists judge that the paramecium, diplodinium, and euplotes are the first forms with evidence of nervous function. Euglenoids certainly are among the first and some of the coelenterata present ample evidence.

When in the chemical history of organisms did RNA (ribonucleic acid) and DNA (deoxyribonucleic acid) put in their first appearance? It is said that their appearance and function were necessary before life could be said to have occurred. They are the substances by which genetics are judged. No cells, organelles, or tissues can exist without their genes. Plants and animals alike have them. Whether it be plant or animal, the slime mold is among the first to reproduce its kind within its own sphere of activity. Mycoplasms, viruses, and bacteria must have the help of host cells.

In the expression of life the plant cell demands eminent attention. A helpful close-up of the plant cell is given by Dainty:[73]

"The plant cell would appear to be more complicated than a typical animal cell. It has a cell wall composed principally, but not entirely, of polycaccharides of various kinds; within this cell wall and pressed up against it, perhaps even intimately penetrating it, there is usually a thin layer of protoplasm, and this in turn surrounds in mature cells, a large central vacuole. It is usually assumed, though not wholly accepted, that the protoplast is bounded by two membranes; the outer one has come to be called the plasmalemma, and the inner, bounding the vacuole, the tonoplast. The central vacuole is an aqueous solution of salts, in higher plants often salts of organic acids such as malic acid. The protoplast contains the usual organelles, nucleus, mitochondria, endoplasmic reticulum, etc. — together with chloroplasts in green cells, and the whole cell clearly has a much more complex structure than do most animal cells and is, therefore, correspondingly difficult to work with."

With algae living remotely far prior to the Pre-Cambrian age, two thousand million years ago, the giant unicellular alga acetabularia of the family Dasycladaceae native to the warm seas can tell us much about plant life, but for the purpose of this article let us advance to the slime-molds. We shall also pass by the yeast cells, diatoms, and sea anemones.

The slime molds (Myxomycetes) are also called slime algae because the taxonomists have not decided whether they are plants or animals. Being on this important borderline, these peculiar organisms are said to be without membranes and to consist of naked protoplasm which very slowly creeps over the surface to ingest food. At times, these masses or plasmodia come to rest and on the release of a chemotactic substance called acrasin give rise to peculiar bodies known as myxamoebae which lead to production of more plasmodia. Lonert[74] gives interesting details as does Went.[75] Reinhardt[76] recently recorded a helpful study of the cellular slime molds, or "social amebae", the Acrasiales.

The amoeba, especially amoeba proteus, has been the object of many studies for years on end. After celestial motion, Brownian movement, and motility generally, amoeboid movement, the most primitive form of animal movement, has claimed much attention. Mast[77-80] and many other researchers are now reasonably certain that its nature is that of "streaming" character. In recent years, the limiting membrane of the amoeba, its plasmalemma,[81-85] also, has claimed much thought, especially since about 1935 with the advent of the electron microscope. That the plasmalemma is a double membrane seems now reliably confirmed.

Went[86] graphically presents the "First Organized Living Things" as the Archaic Bacteria and the "First Oxygen Producing Plants" as the "Uralgae" (blue-green algae), ascribing the time as "Pre-Cambrian — about 2 billion years".

The archaic bacteria probably include some 50 species, among them the nitrifying bacteria and the iron and sulphur bacteria. Breed[87] in Bergey's Manual of Determinative Bacteriology asserts: "It is necessary to assume that living protoplasm, with its complex enzymatic systems, existed before primordial bacteria which utilized inorganic materials as food. In other words, complex proteins had to be in existence before either the chemoautotrophic and photoautotropic bacteria of the type now found on earth could exist."

It is well to give thought, also, to the microtatobiotes (smallest living things) of Philip.[88] Recall here, Rickettsia quintana of trench fever as an example of extra-cellular growth in its host, the body louse. Further, confer for additional details in bacteriology and virology to Zinsser's "Microbiology",[89] and to a 1963 symposium report[90] on viruses, nucleic acids, and cancer.

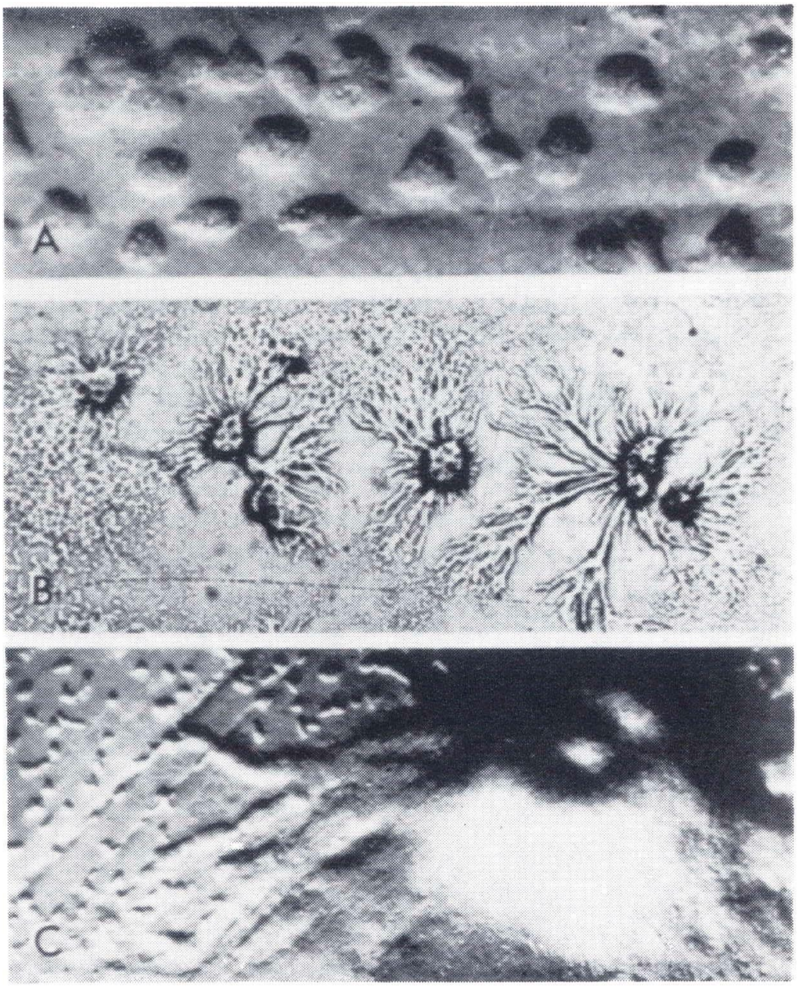

Figure 6a

Stages in Fructification of Slime Mold (Dictyostelium discoideum) (After Lonert,[74] Courtesy of General Biological Supply House.) A. Wandering myxamoebae, x 400, prior to fructification. B. Convergence of myxamoebae into centers of aggregation, x 15, early stage of fructification. C. Growth of aggregation, x 100. D. Cores of myxamoebae, x 45. E. Completed fructification, the sorocarp, x 30. F. Portion of a crushed sorocarp, x 230. G. Freshly hatched myxamoebae 78 hours after onset of fructification, x 400.

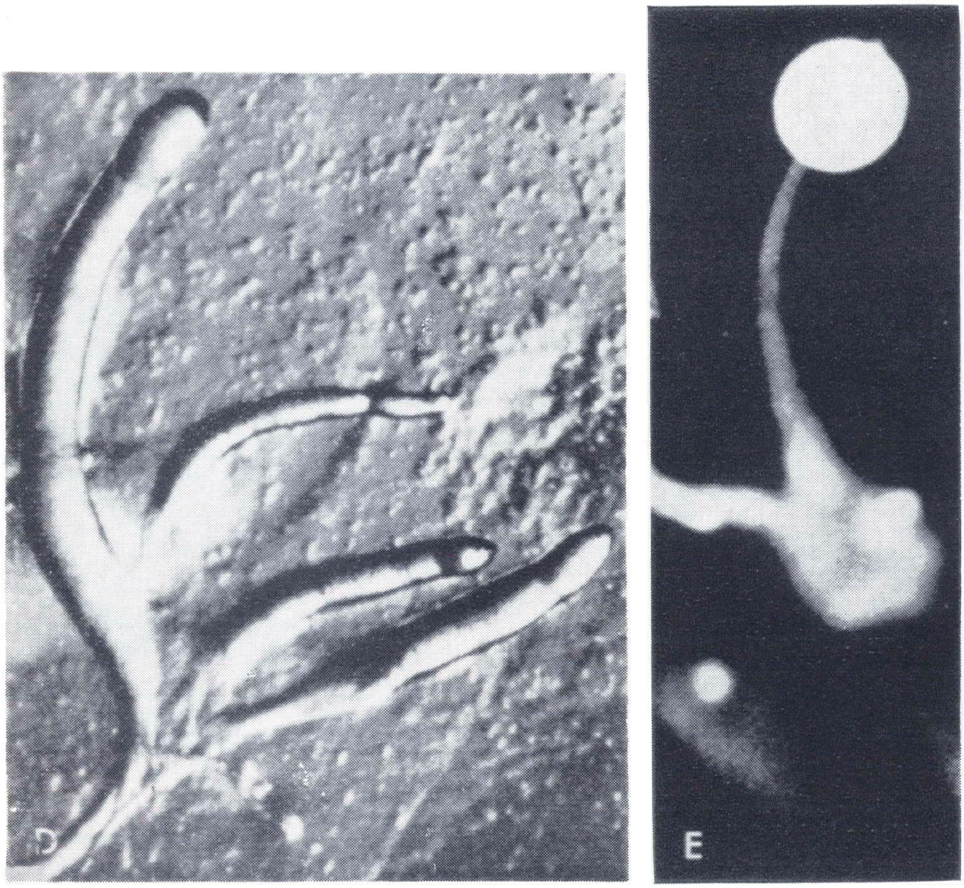

Figure 6b

Since the beginning days of microscopy, the walls of plant and animal cells have claimed attention, but it is not until recent years that their importance has been fully appreciated. Not only do they confine the cytoplasm and its organelles, but also, they take part in cellular metabolism[91] and reproduction. In the determination of the chemical constituents of cell walls, Salton[92] finds that the complexity of cell-wall composition is greater in gram-negative organisms than in gram-positive bacteria. The basic chemical compounds are of the class of mucopeptides and mucopolysaccharides. Pertinently Salton[93] says: "It is perhaps fortunate for mankind that nature saw fit to encase bacteria in a wall containing amino sugar and amino acid structures not normally encountered in higher organisms, for this undoubtedly accounted for the great selective toxicity of the antibiotic penicillin and probably some of the subsequent antibacterial agents."

Obvious it is that cell membranes and walls are in themselves important organelle systems in the life of living protoplasm.

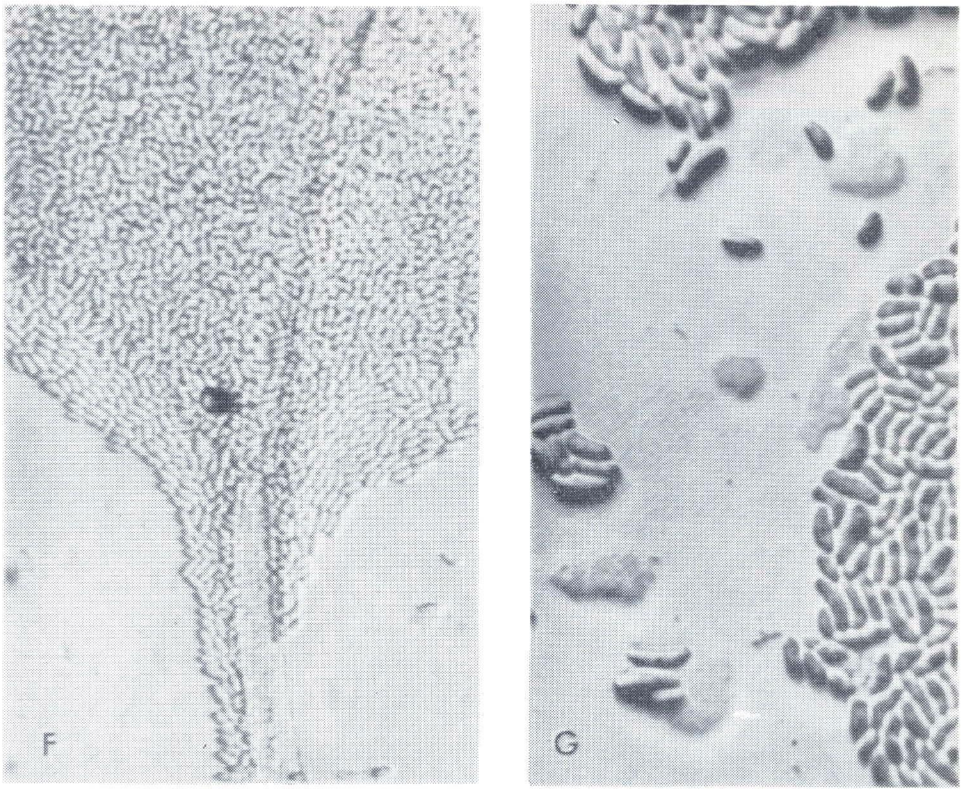

Figure 6c

Forbes[94] helpfully suggested in January of 1964 that the first evidences of a nervous system in animals might be found 'for protozoans in the neuromuscular apparatus or fibrils of paramoecium and diplodinium, or for the metazoans in the diffused net of nerves in the coelenterates, in the hydra for example.'

It seems reasonable to expect some coordinating force in control of flagella and cilia of those unicellular organisms which depend on them for motion and the obtaining of sustenance. However, this directive influence is judged to be other than the neuron function seen in the metazoans. Although referred to as "neuromotor" and even "neuromuscular", neither neuron nor muscle as such are present Hyman[95] appropriately asserted in December 1963, that primitive nerve cells cannot be histologically differentiated from other cells. Such deduction regarding evolutionary pre-nerve cells may explain much of the difference of opinion of many of the researchers into the origin of nervous function. Parke,[96,97] Tuzet,[98] and Pavans de Ceccatty[99] insist that certain cells of sponges (porifera) are neurons whereas Bullock and others are equally sure they are not. Bullock[100] declares: "Whether the protozoans have some kind of specialized system that conducts excitation is . . . that the answer for the moment is 'no', but only on balance of evidence; its unequivocal demonstration is not yet attained. . . . Unquestionably there is a great deal yet to be

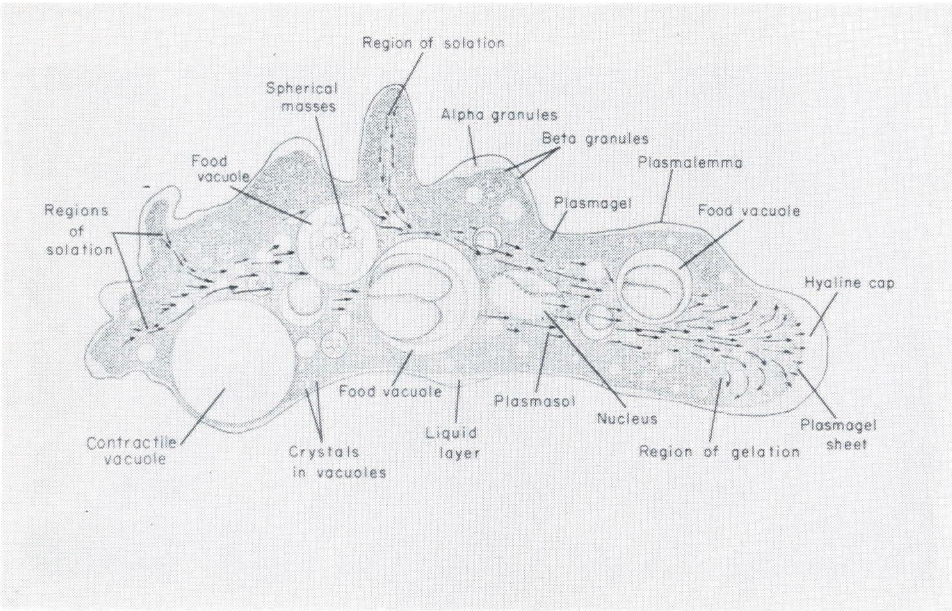

Figure 7

Camera sketch of horizontal optical section of Amoeba Proteus. (After Mast,[78] Courtesy of Wistar Institute.)

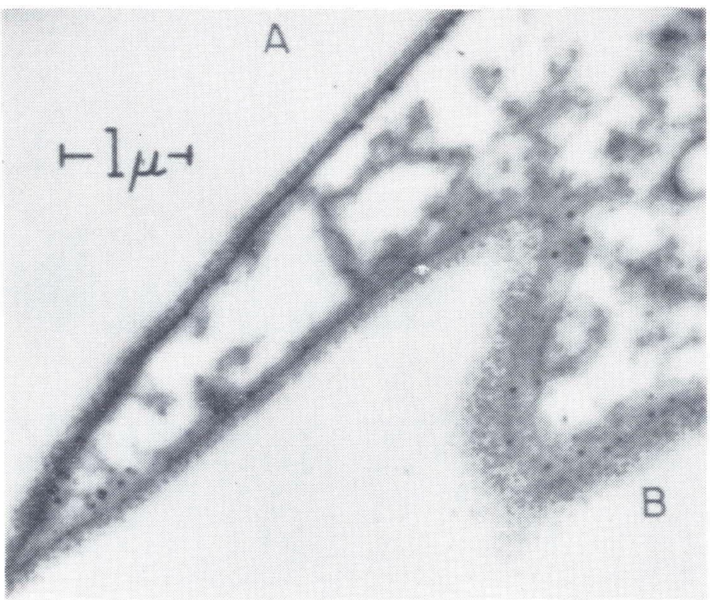

Figure 8

Electron micrograph of a section of the plasmalemma of Amoeba Proteus. (After Pappas,[81] Courtesy of New York Academy of Sciences.) The plasmalemma is seen in cross section at A, and is cut tangentially at B; its two layers are evident. x 21,000.

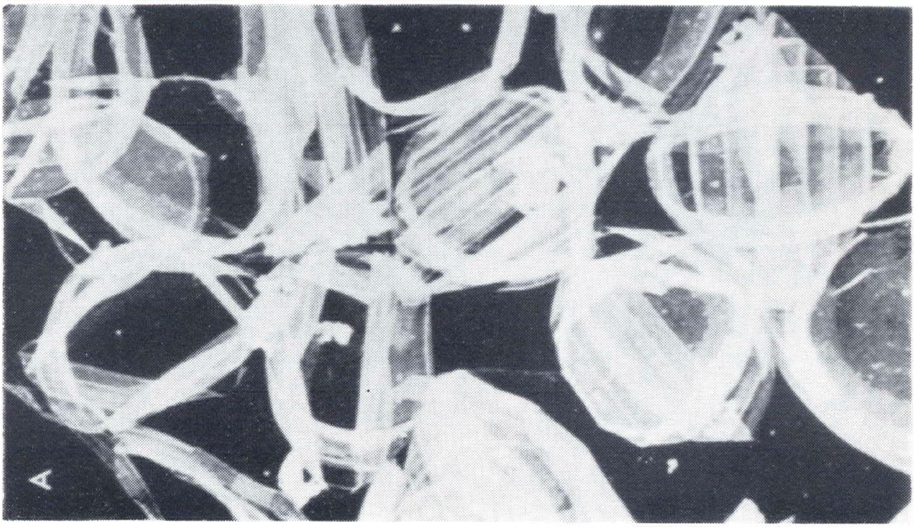

Figure 9a

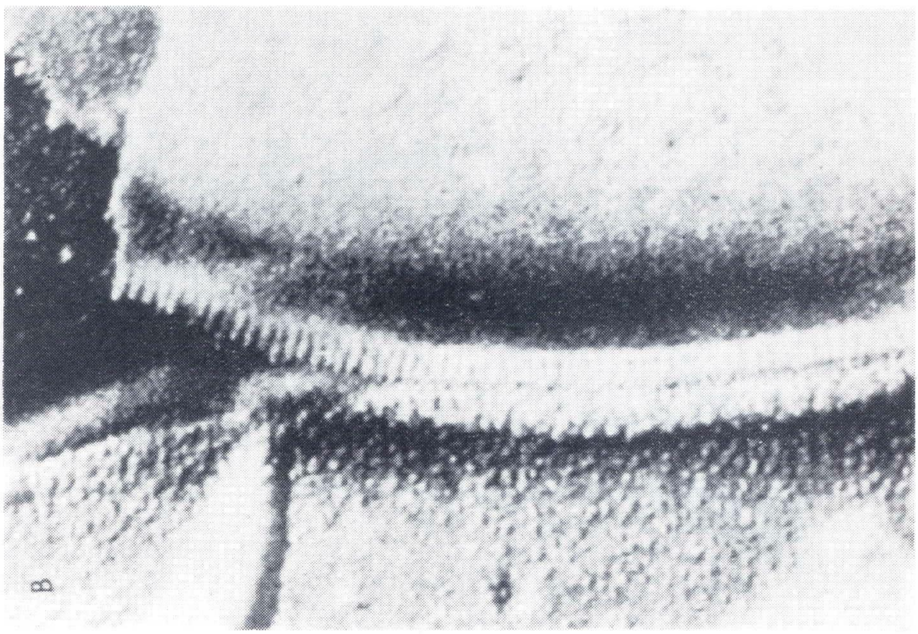

Figure 9b

Cell walls of the blue-green alga, (Phormidium uncinatum). A. Isolated cell-walls, x 5,350. B. Cell pores and cell-wall septa, x 42,750. (After Salton.[93] Courtesy Elsevier Publishing Co.)

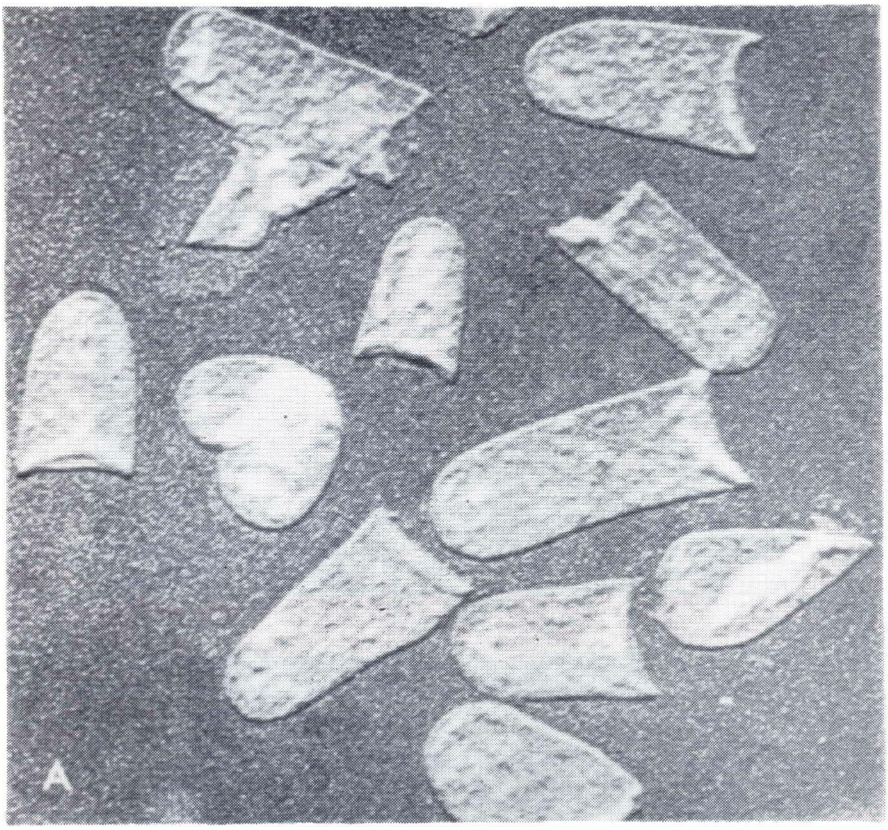

Figure 10a

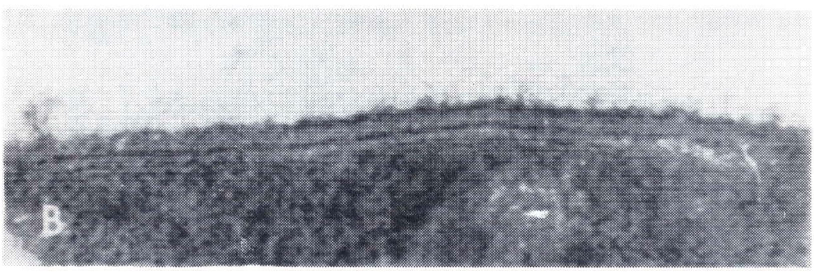

Figure 10b

A. Cell walls of Mycobacterium tuberculosis (BCG), x 32,500 isolated from cells disrupted in the pressure cell used by Ribi, et al, 1959. B. Thin section of Mycobacterium, strain Jucho, showing the multilayered appearance of the wall together with the underlying membrane x 120,000. (After Salton.[93] Courtesy Elsevier Pub. Co.)

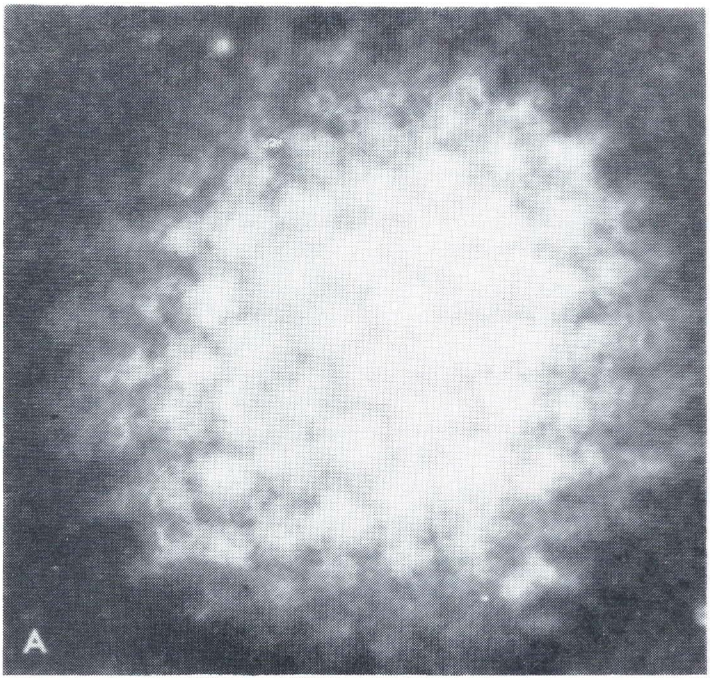

Figure 11a

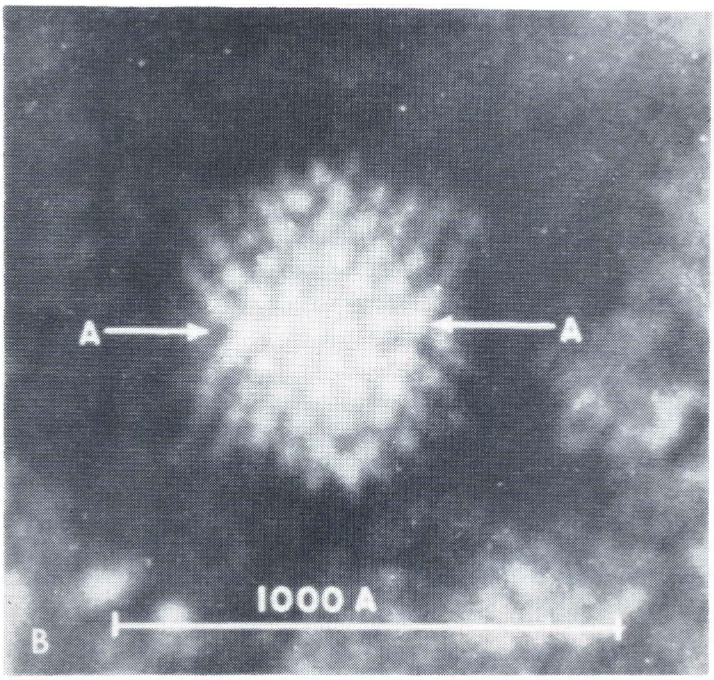

Figure 11b

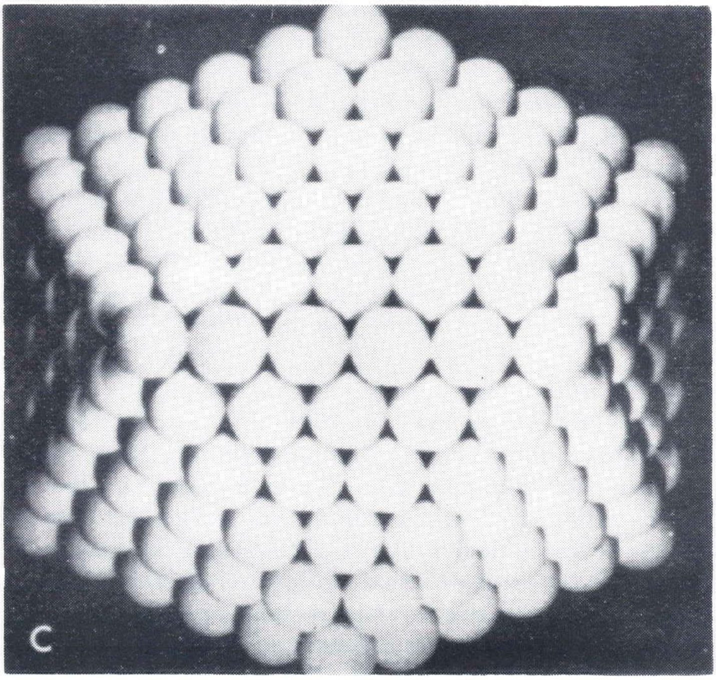

Figure 11c

A. A single infectious canine hepatitis virus in phosphotungstic acid preparation, capsomeres are aligned in equilateral triangular faces, six to an edge. x 550,000 (0.1 = 5.5 cm.). (After Victor J. Cabasso.[165] Courtesy New York Academy of Sciences.) B. Electron micrograph of a single particle of adenovirus. The arrangements and symmetry of the surface structure can be clearly seen. Negative staining. C. A model constructed from 252 spheres forming an icosahedron photographed in the same orientation as the virus particle shown in B. (After R. W. Horne.[166] Courtesy New York Academy of Sciences.)

learned by careful study of the electrical activity of protozoans, relevant to the physiology of the metazoan nerve cell, whether they have differentiated conducting organelles or not." Bullock[100] gives, in his two volume study, 1719 pages and 9,900 references, a very detailed and informative review of present day conceptions. Regarding the Porifera (sponges) he specifically states: "However, owing to the inherent limitations of the methods and the animals used, it must be concluded that the identification of nerve cells in sponges is premature on the standards acknowledged for other metazoa."

Supportive and as background for Bullock's[100] extensive studies, published in February, 1965, time and thought must be given to the earlier five volume record by Hyman[101] studies of the invertebrates. Her observations constitute a veritable encyclopedia of taxonomic descriptions. At the close of volume five, her Retrospect of 58 pages is a classical masterpiece of retrospective condensation and pithy deductions. Also, not to be neglected are the thorough studies of Hanström,[102] those of Hadzi,[103] and yet others.[104,105,106]

The first unequivocal evidence of nerve cells and fibers is to be found in the coelenterata of which the hydra is probably one of the simplest forms. The nerve net of the multicellular hydra is a network of nerve cells extending through the entire animal and coordination of its activities is one of its functions. Bullock[100] mentions that the relations of the sense cells to the nerve net probably represent ". . . the first nervous integration in evolution." He adds that interaction between conducting systems as seen in the marginal ganglia or ring nerves of medusae" . . . represents the first integrating concentrations of nervous tissue in the animal kingdom." Furthermore, the hydra gives, ". . . a clear confirmation of the Hertwig hypothesis of the phylogeny of ganglion cells, since there is a clear series of transitions between sensory neurons and typical ganglion cells."

Barnett[53] frankly states, "In succession up the evolutionary ladder there must have appeared forms like the sponge . . . like the gutless flatworm with the first nervous system and the first brain . . ." The platyhelminths are the lowest group of the bilaterally symmetrical metazoans. It is not precisely clear how they come to have a well-developed nervous system consisting of a brain and a set of longitudinal medullary cords connected by commissures. The acoels are the most primitive of the order, and with them the nervous system becomes progressively more complex in the higher forms. The planarians have even gained newspaper headlines. James V. McConnell[107,103,109] is credited with finding evidence that trained flatworms can pass on to untrained worms some of their education through the process of cannibalism, i.e., having the uneducated worms eat the trained ones. This suggests that the acquired training responses are chemically transmitted and strongly implies that memory can be linked to ribonucleic acid (RNA). This deduction is also supported by experiments with rats by Hyden [103] and by Glasky & Simon.[103] Burger[110] gives thought-provoking details.

Structure and Function

In the evolutionary scale from unicellular to bilayered, to trilayered, and to multilayered organisms, there was more and more demand for coordination and integration. Scheer[111] reviews this at some length and Bern and Hagadorn[112] give details. Neurosecretory systems, neurohemal organs, neurosecretions, neurohumors, and neurohormones receive much consideration. Since first brought to the fore by Ernest Scharrer[113] in 1928, neurosecretion has received considerable attention, and it is conceded that neurosecretory neurons occur in the supraoptic and paraventricular nuclei of the human brain. Axon transport is admitted, but the full function of the portal vessels of the hypophysis and its stalk, however, remains unknown. Regarding these vessels, the gentle admonition by Bullock[100] expressed in parentheses in his Preface rightly applies: "A comprehensive and critical survey of the comparative physiology as well as anatomy of the nervous systems in vertebrates is much needed, and would stimulate new research." Attention was first called to the portal vessels in man by Popa and Fielding[114,115,116] in 1930. Wislocki[117] gave a thoroughgoing description in 1936, and mentioned their occurence in whales.[118] Finley in 1937[120] and again in 1939[119] found no portal vessels in the eminence of the tuber cinereum. Baker[121] makes helpful review in 1962, and refers for his deduction regarding portal circulation to Xuereb.[122,123] Scheer[111] makes pertinent reference to these portal vessels. Howell[124] in his textbook of physiology gives speculative uncertainties regarding their significance, but even Kaplan and Ford[125] in their recently published text fail to give full clarification of their structure and function.* In this regard, one wonders also, not only as to the origin and the presence of many blood-borne hormones, but also as to the possible influence of chemotaxis in the relationships of ions, atoms, and molecules. May there not be an avid affinity of one chemical for another not unlike that of the thirsty anhydrous $CaCl_2$ for H_2O, all with cellular volume and transport change? Regarding such transport changes, Tosteson[126] remarks: "It would appear reasonable to conclude that volume regulation is the most fundamental and primitive cellular function of active Na & K transport. Without it, we would all be at best, mute dryads of the trees imprisoned in cellulose walls."

The full details of the olfactory sense in evolutionary growth, structure, and function with some of its retrogressions, also, remain elusive despite many studies. Response to tactile stimuli probably originally preceded the senses of smell and vision. Vision seems thoroughly documented in an extensive literature, but smell leaves much to be desired. At the moment, there comes to mind the loosely attached intranasal organ of the Alaskan moose. What are its sensory receptors and their central connections? Are there an organ of Jacobson and a nervus terminalis? Are they autonomic or nonvegetative? Is there any myelination? Crosby, Humphrey, and Lauer[127] say, "The vomeronasal organ (Jacobson's organ) is not present in adult man but can be demonstrated in the human embryo." The nervus terminalis, however, has been traced in the human embryo and the adult. Many understatements beset the rhinencephalon and its evolutionary structure and functions. Herrick (1868-1960)[128,129] provocatively gives valuable data in his studies of the brain of the necturus, and even defines the "hypophysial nerve". Herrick[130] most creditably presents some 50 years of study of the nervous system of amphibians in a masterpiece, "The Brain of the Tiger Salamander (Ambystoma tigrinum)." Phylogenetic morphogenesis receives special consideration. Among his many provocative statements occurs: "In the olfactory bulbs of Necturus and Amblystoma we find an interesting series of transitional cells between apparently primitive nonpolarized elements and typical neurons." In his volume,[131] "Evolution of Human Nature", Herrick records his lifetime of opinions and deductions. The observations of Janet[132] on the brains of ants, and especially olfactory details, are very informative. His exhaustive studies[133,134,135] give pertinent background to Wheeler's fine volume on ants.[136] The studies of Turner (1867-1923)[137,138] and of Ziegler[139] give additional background. Let it be emphasized that the olfactory receptor capacity of the antennae is of great utility to the ant. Although the vision of most ants is very poor, their ability to lay down a screen of odor at their rear permits orderly following of any formicarian leader.

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*I was very much impressed in May 1964, by the numerous vessels and their extent while removing the brain of an adult moose. There seemed to be too many, too long, double back on themselves, and looping about the hypophysis and its stalk.
I am sure the structure and function of the moose can tell us much more. Strangely, in the Classified Bibliography (Vol. III) of Walker's *Mammals of the World,* (Ref. 222) there occur 187 references to articles on the moose. In that number of references there is only one on the physiology of the animal, and that on its thermoregulation, a study done in Moscow.

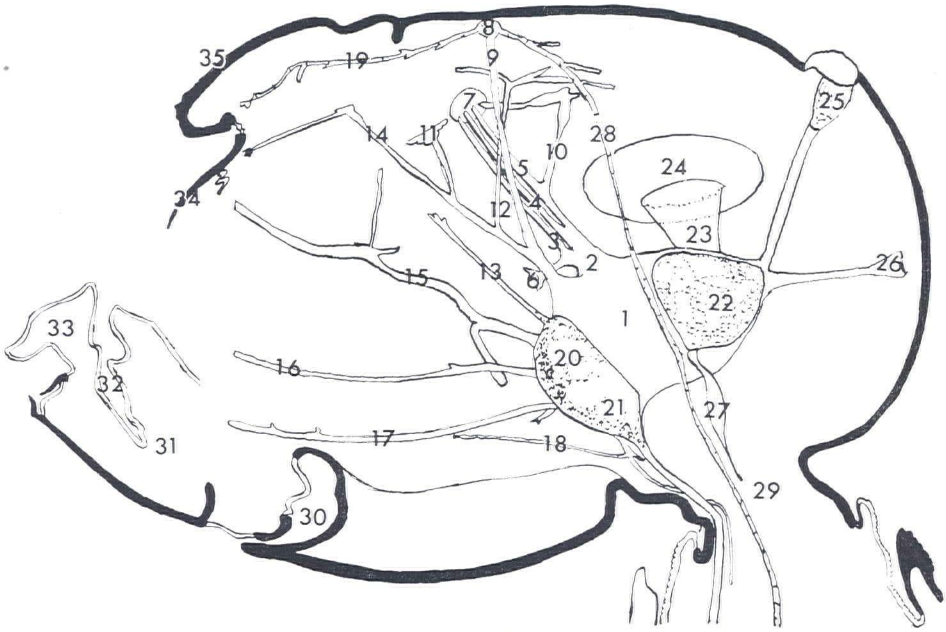

Figure 12

Schematic Sagittal Section of Head of Queen Black Ant (Lasius niger), showing Brain and some of its Nerves (After Janet[133]). 1 Brain; 2 Nerve tract of antenna; 3 Antennary motor nerve; 4 Antennary sensory nerve; 5 Antennary sensory nerve; 6 Antennary motor nerve of scape; 7 Antennary articulation; 8 Frontal ganglion; 9 Nerve connecting ganglion and brain; 10 Antennary chordotonal nerve; 11 Pharyngeal sensory ganglion; 12 Motor nerve of labrum; 13 Inferior dilator nerve of pharynx; 14 Sensory nerve of labrum; 15 Mandibular nerve; 16 Maxillary nerve; 17 Nerve of lower lip; 18 Nerve of labial glands; 19 Motor nerve of clypeus and pharyngeal muscles; 20 Optic ganglion or lobe of brain; 21 Maxillary ganglion or lobe of brain; 22 Optic ganglion or lobe of brain; 23 Optic nerve; 24 Lateral eye area; 25 Median ocellus; 26 Lateral ocellus; 27 Post-cerebral ganglion; 28 Recurrent nerve from frontal ganglion; 29 Neck; 30 Recess for lip glands; 31 Lower lip; 32 Recess for lip gland; 33 Tongue; 34 Labrum; 35 Clypeus.

A cursory glance at the olfactory lobes of various animals stresses a rich field for correlative inquiries, both morphologically and physiologically.

This writer has probably not reviewed the literature sufficiently to be adequately informed regarding the significance and the importance of the size and the caliber of nerve fibers from the giant axons of the squid to the finest fibrils of autonomic synapses. He remains speculative and uncertain regarding this and the full meaning of myelination and nonmyelination. Grundfest[140] informs us: ". . . the smaller the diameter of the fiber the higher is the longitudinal resistance of the axoplasm and the radial resistance of the membrane. The rate of spread of excitation or the conduction velocity is thus a function of the diameter and a 10μ unmyelinated invertebrate fiber has a conduction velocity of about one meter per second or less. Giant axons, produced by the fusion of small fibers, attain diameters of 100 to 1000μ and are capable of conducting at rates up to about 30 meters per second." Prosser[141] says, "Velocity increases as some function of fiber size. In medullated fibers the velocity is proportional to diameter, in nonmyelinated fibers (e.g. squid giant fibers, polychaete giant fibers) the increase in speed is as some power of the diameter. . . . A sheath of

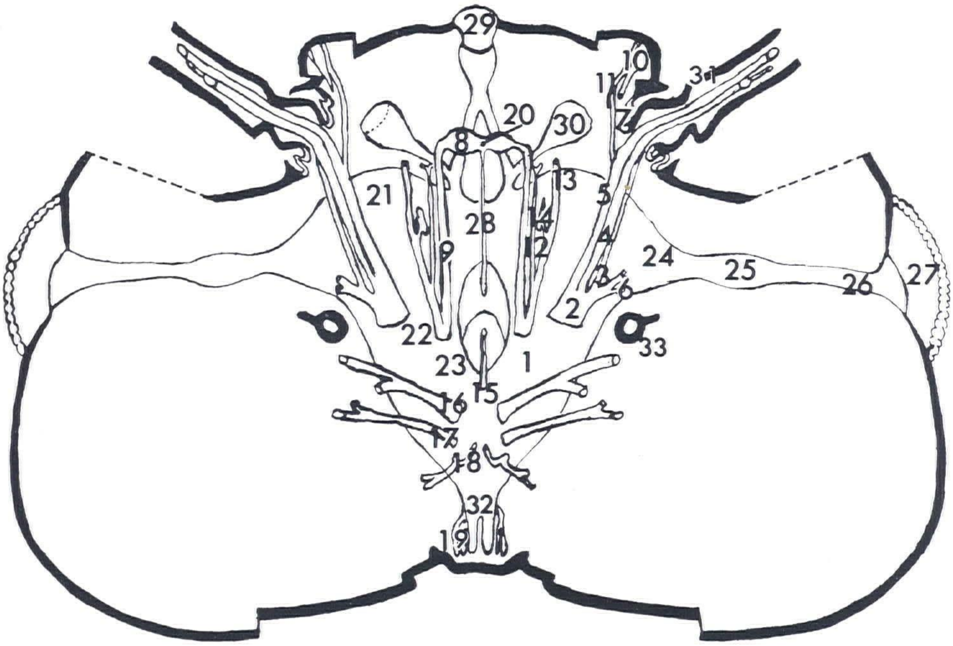

Figure 13

Schematic Cross-Section of Head of Queen Black Ant (Lasius niger), showing Brain and some of its Nerves (After Janet[133]). 1 Brain; 2 Nerve tract of antenna; 3 Antennary motor nerve; 4 Antennary sensory nerve; 5 Antennary sensory nerve; 6 Antennary motor nerve of scape; 7 Antennary articulation; 8 Frontal ganglion; 9 Nerve connecting ganglion and brain; 10 Chordotonal ganglion; 11 Antennary chordotonal nerve; 12 Motor nerve of labrum; 13 Sensory nerve of labrum; 14 Sensory nerve of labrum and pharynx; 15 Inferior dilator nerve of pharynx; 16 Mandibular nerve; 17 Maxillary nerve; 18 Nerve of lower lip; 19 Nerve to labial glands; 20 Motor nerve of clypeus and pharyngeal muscles; 21 Protocerebrum; 22 Deutocerebrum; 23 Tritocerebrum; 24 Optic lobe; 25 Optic ganglion; 26 Optic nerve; 27 Lateral eye; 28 Recurrent nerve from frontal ganglion; 29 Median ocellus; 30 Lateral ocellus; 31 Antenna; 32 Connecting nerve tract; 33 Tentorium.

myelin favors speed, hence a small well-myelinated fiber may conduct faster than a large thinly myelinated one. An 8μ cat fiber with nearly half its diameter as sheath conducts at the same speed as a 650μ squid giant axon with only 1% of its diameter as sheath." Hodgkin[142] contributes, ". . . . it is roughly true to say that there are separate fibers for each class of sensation. . . . There is no doubt at all about the proposition that the impulse does not change with the nature or strength of the stimulus . . . The auditory nerve may sometime fire at 1000/sec. but other mammalian sense organs or motor neurons rarely send off impulses at rates greater than 200/sec. The normal working range in the body is 5-100 impulses/sec." The electric organ of one (stenarchus albifrons) of the electric fishes of South America can emit electric discharges at the rate of 1600/sec. If such a fish in its lifetime of three years were continuously to emit discharges even at 1000/sec. its nerve fibres and electroplates must carry 10^{11} impulses. It is said that Volta in 1800 compared his electric battery to the stack of plates in an electric fish.[142]

In general orientation in neurophysiology the Ruch[143] and Patton volume is helpful, as is volume 3 of Progress in Brain Research.[144] For the rhinencephalon Lauer[145,146,147] presents gross findings, and Valverde's recent monograph, "The Periform Lobe,"[148] gives informative documentation. Also, the recently issued Volume XXX[149] of the Cold Spring Harbor Symposia on Quantitative Biology submits stimulating data for further research studies on sensory receptors.

In the mind of this writer, heredity, instinct, and unconciousness ("canned" memory) all find their origin in the chemistry of genetics,[150,151] The ribonucleic acids, RNA and DNA[152,153] have recently yielded some of their secrets. This is emphatically attested to by Jacob, Wolff, and Monod. Nobel Prize winners in medicine in 1965, in their observations of a new type of regulatory gene having the capacity to help other genes to survive.[154] Heredity is the biology which the genes of our ancestors have given us.

Wald[155] in 1941 in speaking of the biology of instincts remarked, ". . . the study of instincts is yet to come." Of their psychological aspects he added, ". . . the more we learn about instinctive tendencies the more apparent it becomes that the situations from which they proceed are meaningful, but we need not suppose that the organism is necessarily aware of the meaning." Tinbergin[156] in closing his discussion of instincts remarks: "Subjective experiences, however, are not directly observable in animals and cannot therefore be used for comparison . . . This is perhaps the main reason why a strictly scientific comparison of the behavior of animals and man has not yet proceeded very far." The muddauber wasp (sceliphron cementarium) correctly places a sting in spider or caterpillar to paralyse it as long-term living food for its larvae. The ephialtes wasp deposits its egg in the larva of the wood wasp carefully hidden beneath bark and wood. It does so by drilling its needle-sharp ovipositor through the bark and wood to the soft prey larva.[157] The African fly (stomoxys ochrossoma) in flying drops its larva in front of an unladen worker ant in a column of army ants. The ant dutifully carries the fly's larva to the ant's nest for rearing.[158] Do these insects know what they are doing? What stimulus in their living triggers the reactions mentioned, and what is its molecular technology?

Healy and Bronner[159] say: "The unconscious is that vast quantity of mental life which never was in consciousness, or, previously in consciousness, has been repressed."

Of unconsciousness, Dorsey[160] states: "In the fundamental respect, my self-unconsciousness is more helpful to me than my self-consciousness, for there is vastly more of me that is unconscious than conscious. Without it, I could not survive . . . It is the motive power of my physiology."

To this author, the unconscious is that part of the mind which is not in the immediate focus of attention or its area of awareness. The unconscious holds the life history of all our experiences with or without our full knowledge. It is the storehouse of our memories, past, present, and future of our daily living. And it is judged that its full record is kept in the spiral shelves of the DNA and RNA molecules and their modifiers.

This writer, as he waded in and about the voluminous literature of his subject, has been impressed with the probability that homo sapiens is highly self-centered. There is a superfluity of studies in ontogeny and a relative paucity in phylogeny. If the mesenchyme cell of the hydra could be isolated and grown in axenic cultures; if the biochemistry of the sea anemone were better known; if the phylogenetic chemistry of actin and myosin of contractile organelles and tissues were determined;[161] and, if— so on and so on, *ad infinitum,* man might become better acquainted with himself. Also, this author is convinced that many scholars and researchers are remiss in not exploring more than they do the recorded literature of the past. Regarding the subject at hand, this writer stood back in mute respect on reviewing the studies of neuroanatomist Stilling[162] for 1859, and naturalist and scientist Thomas Say[193] for 1824. Such reviews always add something to the knowledge and the *élan vital* one already has.

Are anatomical anomalies forward steps or backward steps in the scale of evolution? Possibly they are instances of "trial and error" in the course of Nature. Since 95% of the animal kingdom are invertebrates and only 5% vertebrates, it behooves us vertebrates to evaluate more fully the morphology and the physiology of our assets and our liabilities.

Retrogression as an inevitable part of evolution is only partly understood and too little documented. Retrogressive changes have long been going on in human olfaction. How long and to what extent is a matter of conjecture. Some degree may be deduced from Figure 14. A striking example of evolutionary reduction in the plant kingdom is to be seen in the shoestring fern as reported by Wagner & Sharp.[164]

In February of 1962, the writer collected the brain of a swamp jaguar in the wet coastal area of the state of Nayarit, near the village of Mexcallitan, Mexico. It has been found that the brain of that animal shows a developmentally defective corpus callosum. Despite its agenesically impaired callosum, no changes were obserevd in its behavior during the time of the hunt. Lauer[165] cites nine authors who have reported on some degree of congenital agenesis of the human corpus callosum. He pertinently remarks: "Because section of the corpus callosum gives no recognizable mental defect does not signify that it has no functions."

Birds see eight times better than humans, a real advantage of being "up in the air". It is generally believed that carrion-eating birds, such as buzzards, vultures, and the like, locate their carrion by their sense of smell. No, such is not the case.[157] Cover the carrion even with a cloth and they do not find it. Possibly those birds ars so poor on smell that they be not embarrassed by the stench of the carrion on which they feed.

Teleologically speaking, what is the phylogeny of the functions of the tongue of a snake? Why does it repeatedly stick out its tongue? It is not because it hates humans.

We talk much about converting matter to energy. Can we convert energy to matter? Lapp[13] says we can. Associated details are, however, outside the scope of this presentation.

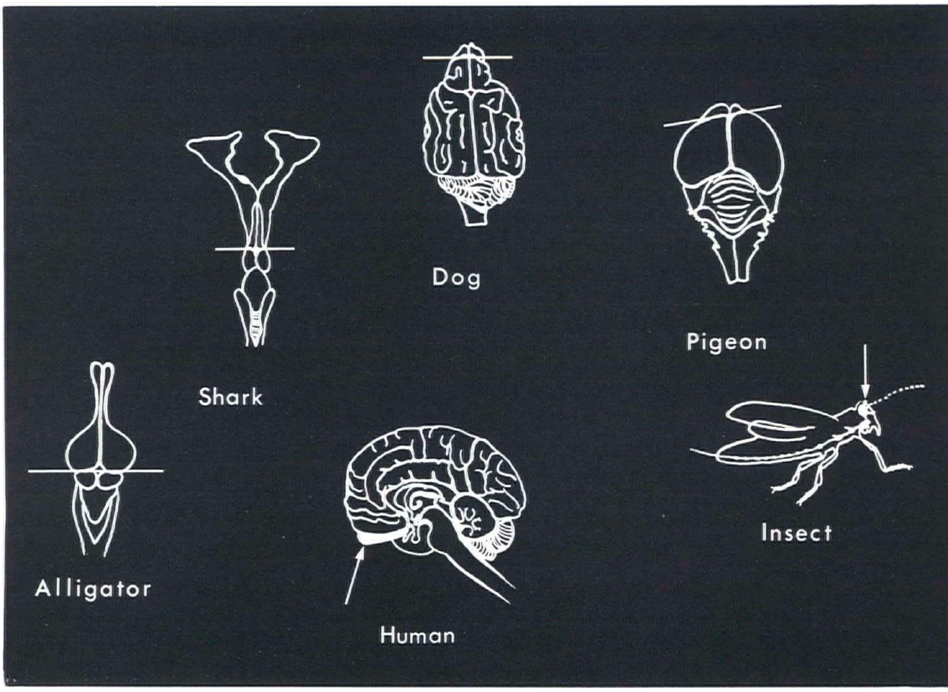

Figure 14

Sketches of six different animal brains to show grossly and comparatively the proportion of the olfactory lobes to the other portions of the brain. Observe the parts anterior to white line drawn across four of the brains. Arrows point to olfactory areas in other two. Note large size of olfactory lobes in shark and alligator and small size in pigeon. Although only a small portion of the olfactory lobes is visible in the sketch of the dog's brain, a truly considerable part is now visible because the frontal lobes overlie them. In the insect the arrow points to the chordotonal ganglion and brain with olfactory nerves projected into the antennae, the ganglionated nerve cord extends throughout the lower portion of the animal's body. The heavy white area to which the arrow points in the human brain is a much proportionally enlarged representation of the olfactory lobe and tract.

All animals used in this study, unless otherwise stated, were wild animals personally collected in their native habitat. This was done to secure the most reliable brain specimens of the selected genus and species. All animals were healthy and full grown.

The vast accumulation of almost isolated data about animal structure and behavior are still too often essentially valueless because there is inadequate effort at correlation and coordination at basic levels, not only of phylogeny but ontogeny as well. The symposia conferences,[19,28,51] in various fields of endeavor[91,167,168] in the past 15 years are commendable and are serving helpfully in correlating newly acquired knowledge.

It is somewhat of a task to obtain continuity for a *longitudinal* thread from the beginning of a well-founded observation to its present day application. Hence, many "runner-up" references[169-179] had to be consulted before coordination was established. Adroitly detailed cross-section studies are numerous; but unfortunately, most are devoid of desirable correlation with that which precedes and that which follows. A crucial observation is often lost in a maze of minutiae insufficiently interrelated; insufficient even to the point where it might be said that there are more and more words about less and less; could be, of course, what Dewar[180] calls the "cacophony of erudition". Increased studies of biological integration[181-189] are needed to avoid nebulosity in a plethora of keenly made observations. It is hoped this author obtained at least partial orientation from the bibliography[190-197] he has consulted and hopes his readers will liberally consult the selected references[198-204] of the many more he reviewed. Most of his citations[205-212] were selected on the basis of a meaningful title,[213-222] and in his opinion this has offered him helpful documentation. Some of our science writers are doing better at integration than our science investigators.

It is hoped that the selection of figures and their legends will clarify rather than obfuscate the subject matter the author has attempted to present.

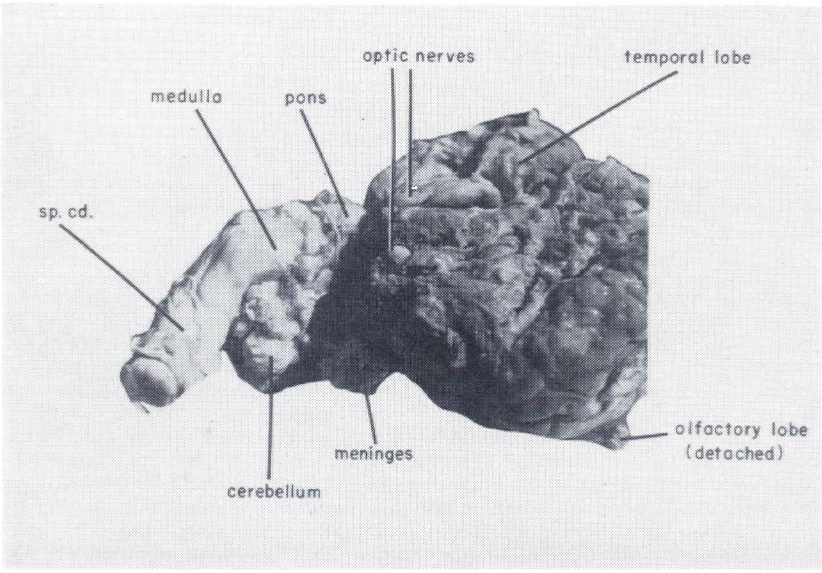

Figure 15

Brain of the wild feral water-buffalo (Bos bubalus bubalis, Male) under side, and turned slightly toward the viewer. The olfactory lobe was accidentally detached during the removal of the brain. Connected to the brain by its olfactory tract, it lay just outside the skull proper in a recess of the ethmoid bone, x Ca 1/3.

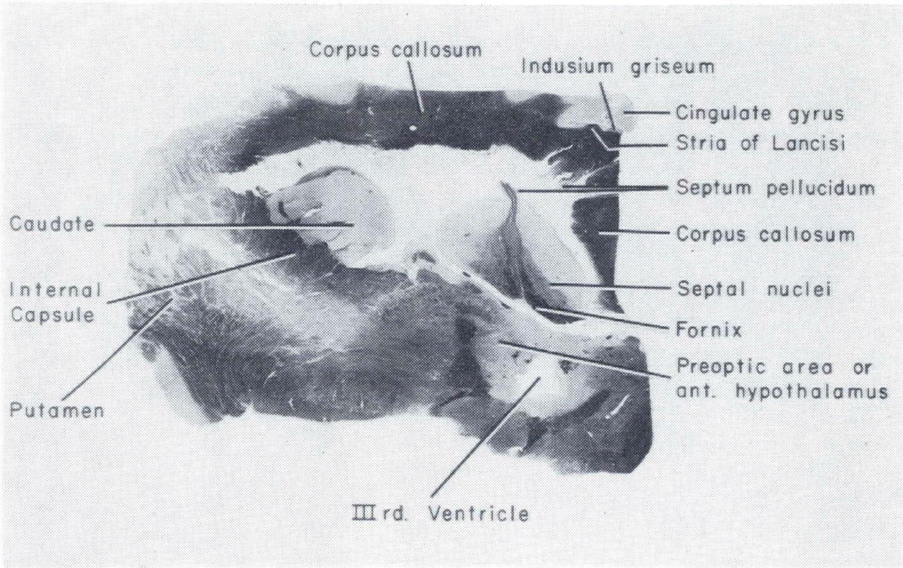

Figure 16

Wild feral water-buffalo. Microphotograph, coronal section through diencephalon. Series 669, Slide 476. 10% formalin fixation, Weil stain, x 3.8. Due to difficulties in removing brain from skull and transportation irregularities, specimen is somewhat distorted, as is obvious from torn and displaced septum pellucidum and related structures.

Water-buffalo*. This animal was personally dispatched, April 4, 1958, with a high-powered rifle in the jungle-swamp of Marejó Island, 15 miles south of the equator and 20 miles from the Atlantic Ocean. The Marejó Island is the largest of the several islands which make up the delta of the Amazon River. It is some 200 miles long by 125 wide. The wild water-buffalo of this island is a native of Indochina where the animal has been domesticated since ancient times. Such animals of Indochina were transported to the Barbados Islands, then to French Guiana, and next transferred by the Portugese to Brazil in 1534. During domestication, some of these water-buffalo stray and thus become the feral founders of roving colonies. Over the centuries, these feral animals have become more outlawed and increasingly regarded as game animals. Mr. Lobato, prominent rancher of some 15,000 acres of island jungle and marshland, insisted that the feral buffalo colony of which this animal was a member had existed for more than 400 years. This mammoth wild bull was indeed a patriarch. Lobato and his herdsmen estimated his age at 25 years and his weight at 800 kilos (1750 lbs.). His age was liberally attested to by gray-haired patches on his face, neck, and brisket. The hair of his body generally was too sparse and too soiled to disclose the color with certainty. His odor was strongly porcine rather than ox-like. The abundant hair on the inside of his large ears was completely white. Evidence of age was confirmed when removal of his brain was undertaken. With much effort, the lower jaw was disjointed, all muscles were cut from the skull. The bone-cutting instruments the writer had with him were of no avail in his attack on the skull-bones. The large butcher's bone-cutting saw of rancher Lobato, also, merely whined as it was drawn back and forth across the calvarium. The ranch foreman judged that a heavy axe set in position and then struck with a six pound sledge was the best approach. This proved to be the case, albeit with much jarring of the skull contents. The flinty bone was literally split off in pieces of varying size. The hardness of the bone surpassed any with which the writer had had experience. Ever since this incident he has wondered to what extent

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*I am greatly indebted to Laurence S. Fallis, Surgeon in Chief, emeritus, Henry Ford Hospital, Detroit, for assistance in negotiating my trip to South America for the acquisition of the brain of this animal, the capybara, and several other specimens. I am also indebted to Brazilian authorities, American Consulate, merchant Manoel Albuquerque, rancher Irval Lobato, and doctor Armando Morelli for much help at Belem, Brazil.

apatite or hydroxyapatite were a part of the mineral-like hardness. The apatite content of the context of the femur of an adult human is 67%; of the enamel of teeth it is 97%. Hence, it is judged that the mineralization of this animal's skull bones lies somewhere near 80 to 85%, possibly more†§.

Incidentally, the natives used machetes for the flesh and axes and sledges for the bones in cutting up the animal. Despite the age of the animal, the native cooks prepared his flesh in savory manner.

Airplane transportation probably can be blamed for additionally fracturing the friable brain tissue. The weight of the animal's brain, as determined by a reliable scales at the ranch, was 825 grams.

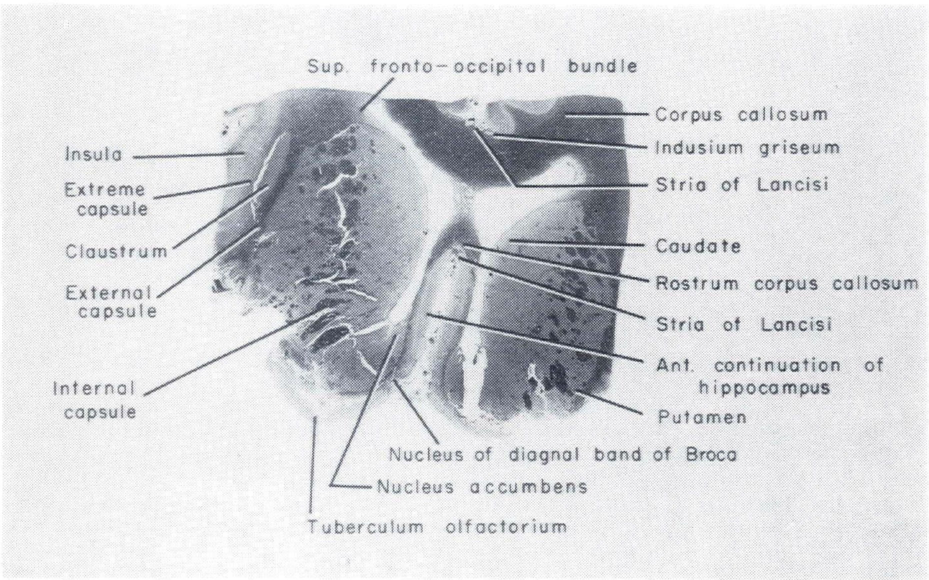

Figure 17

Musk ox (Ovibos Moschatus Male). Microphotograph, coronal section through diencephalon. Series 668, Slide 82, Anterior to slide 214. 10% formalin fixation, Weil stain, x 4.5.

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†I am grateful to Dr. F. A. Henny, oral surgeon; Dr. H. M. Frost, orthopedist, of Henry Ford Hospital; and to Dr. D. W. Armstrong, biochemist, University of Minnesota, in arriving at these percentage deductions.

§Stuman, Termine, and Posner[169] give infra-red spectra for hydroxy-, floura-, and chlorapatite.

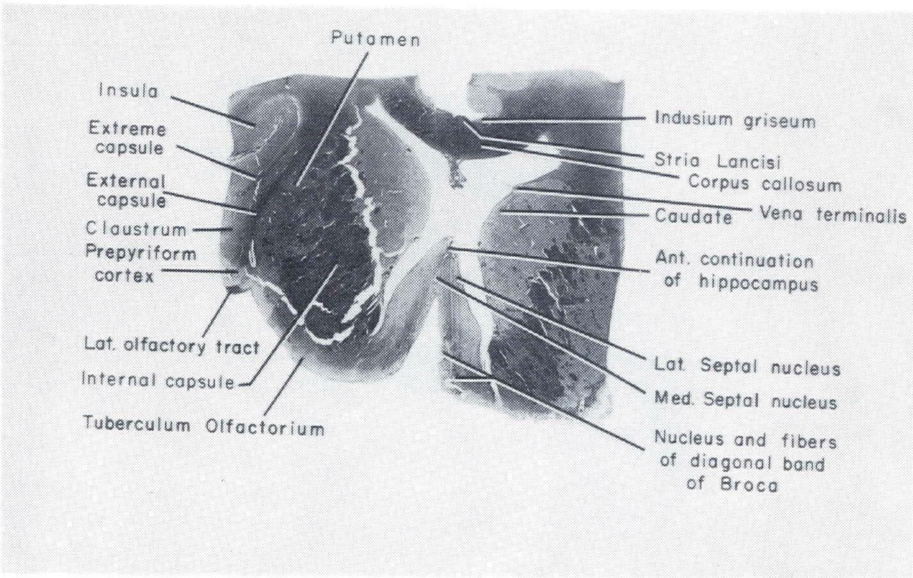

Figure 18

Musk ox (Ovibus Moscatus, Male). Microphotograph, coronal section through diencephalon, posterior to that of Slide 82, Series 668, Slide 214. 10% formalin fixation, Weil stain, x 4.5.

Musk ox: The writer was personally present at the taking of this animal on February 16, 1960, on Nunivak Island in the Bering Sea off the cost of Alaska. Arrangements for his collection were made through the U. S. Department of the Interior. Federal direction declared that the animal to be taken must be a lone outlawed bull, and he was an outcast from a herd of some 70 animals. The musk-oxen of Nunivak Island are descendants of the Greenland Musk-oxen purchased and transferred by the U. S. Government in 1934. Except for his brains, he became a museum specimen in the Jonas Brothers Museum in Anchorage, Alaska. The author succeeded with little difficulty, in satisfactorily removing the brains of the animal by manually using special "key-hole" saw blades cut and tempered to saw iron and steel. It was judged that the brain was properly transported to the anatomical laboratories of the University of Michigan. However, sectioning of the brain showed that some fractures had occurred in the brain substance during airplane transportation. Bush planes piloted to Nunivak Island and return, of course, were not pressurized.

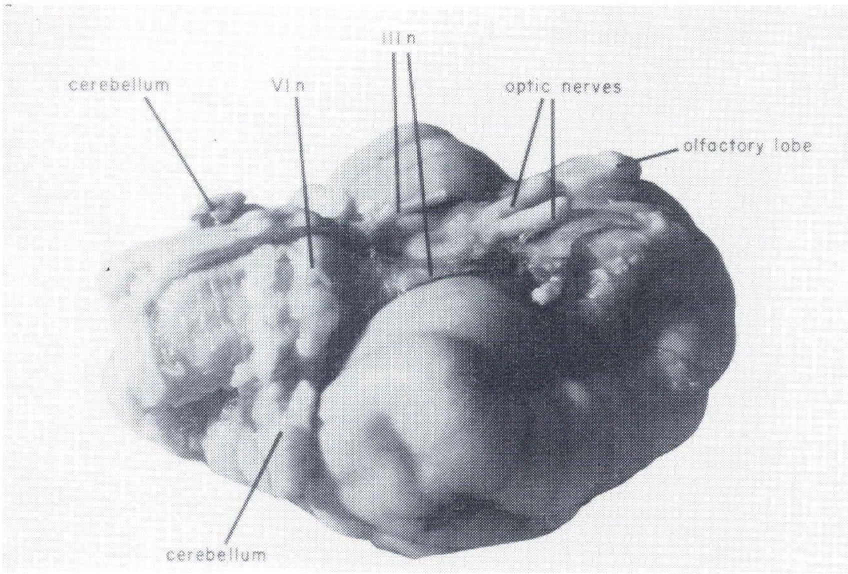

Figure 19

Under surface of the Brain of Capybara (Hydrochoerus capybara, Male), turned slightly toward viewer. Note shallow sulci. x ca 3/4.

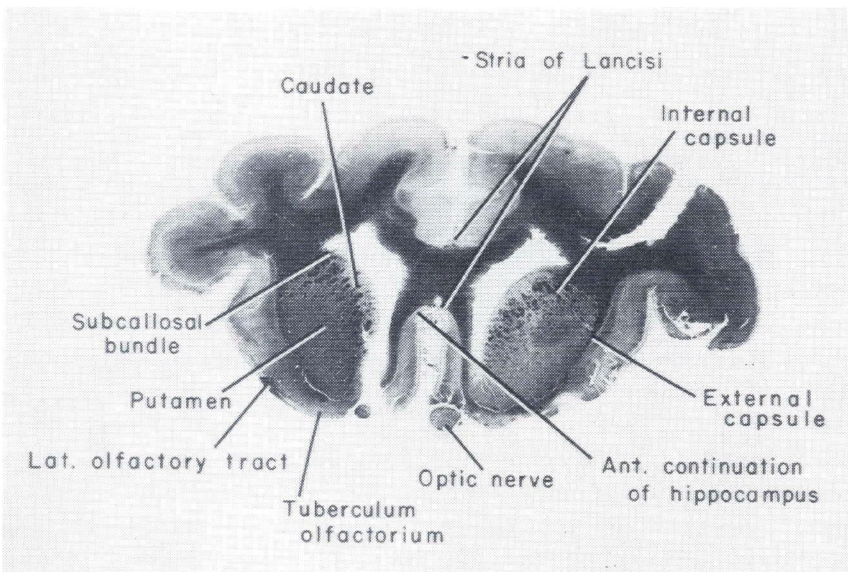

Figure 20

Capybara (Hydrochoerus capybara, Male). Microphotograph, coronal section through diencephalon. Series 661, Slide 294. 10% formalin fixation, Weil stain, x 4.

Capybara: This interesting animal is the world's largest rodent. A weight of 200 pounds has been recorded. The animal whose brain is sectioned here weighed 84 pounds. With the exception of his tail, this animal reminded the writer more of a beaver than of any other aquatic animal. In the water, he is a most skillful submarine, speedy, and evasive. Seen from a low-flying plane at the edges of marsh ponds, he seemed gentle, harmless, and trustworthy in his habits. Some biological works give him webbed toes, but of this specimen this was not true.

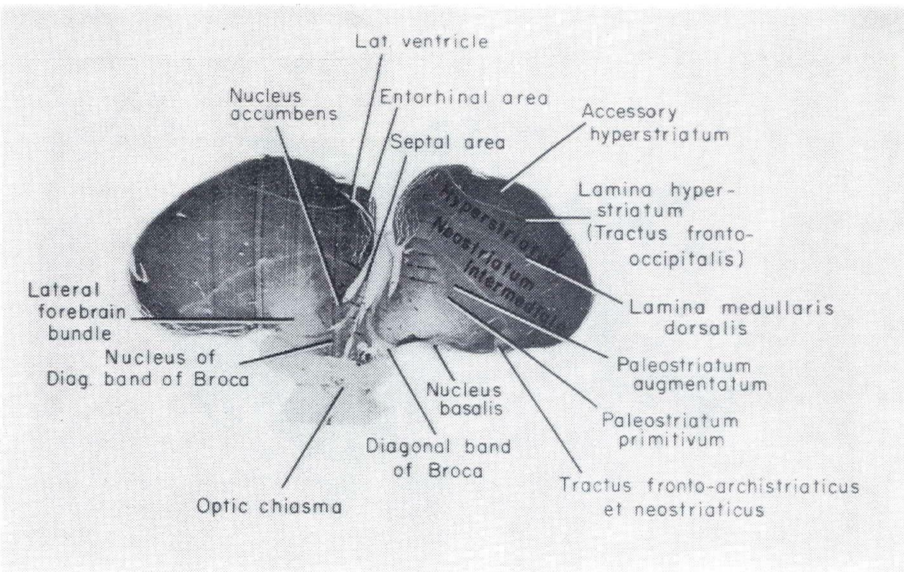

Figure 21

Wild turkey (Meleagris gallopavo Merriami, Male). Microphotograph, coronal section through diencephalon. Series 676, Slide 55. 10% formalin fixation, thionin stain, x 5.2.

Wild Turkey: This large bird of early United States history was collected in the woods of a ranch near Folsom, New Mexico. This collector thought he probably was fortunate to take the majestic bird; partly because the bird, though by heritage exceedingly crafty and elusive, had only one winter to his credit, certainly not more than two. His weight was a liberal 19 pounds. In obtaining this avian brain, it was highly desirable to have a truly wild turkey, for inbreeding is not uncommon where domesticated turkeys are to be found, which the collector was assured was not the case in this instance. The rancher told me there were no tame turkeys for miles around and had not been for some years. In terms of his experience, the rancher* declared the turkey measured up to being a full-blooded Merriam.

In summary manner, it is probably not presumptuous to say: In the beginning there was a void of time, space, and darkness, thin inchoate gas, motion, and cosmic ray; electrogenesis, turbulence, and gravity; condensation, heat, and weight. Cosmic dust, atoms, and magnetism; chemotaxis, micromolecules, and organization followed; macromolecules, polymers, microspheres, and coacervate drops; membranes, photosynthesis, permeability variations, and volume exchanges came in order. Inorganic to organic chemistry, and prebiological configurations added increasingly to greater assemblies of function and structure. Formulation of RNA and DNA led to increased replication of molecules and their aggregates. Cells with their membranes came into being with their myriads of function. Metabolism of divers kinds, with its catalysts, enzymes, and coenzymes became established in evolutionary chemistry and selectivity. Volume changes and transport services of cell membranes promoted multicellular units of varying identities to the long postponed demand for taxonomical classification; hence, our plant and animal kingdoms with their phyla, classes, orders, families, genera, and species.

*I acknowledge with gratitude the thoughtful planning of rancher Edward Bray of the Bray Hereford Ranch, Folsom, New Mexico, in connection with the taking of this wary bird.

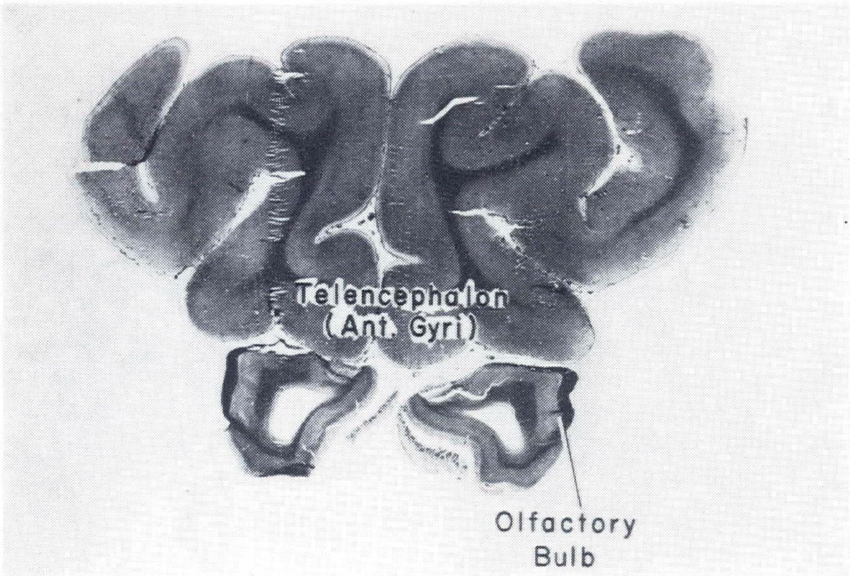

Figure 22

Deer (Odocoileus virginianus, Male) of Michigan. Microphotograph, coronal section through forebrain. Series 689, Slide 53. 10% formalin, Weil stain, x 3.5.

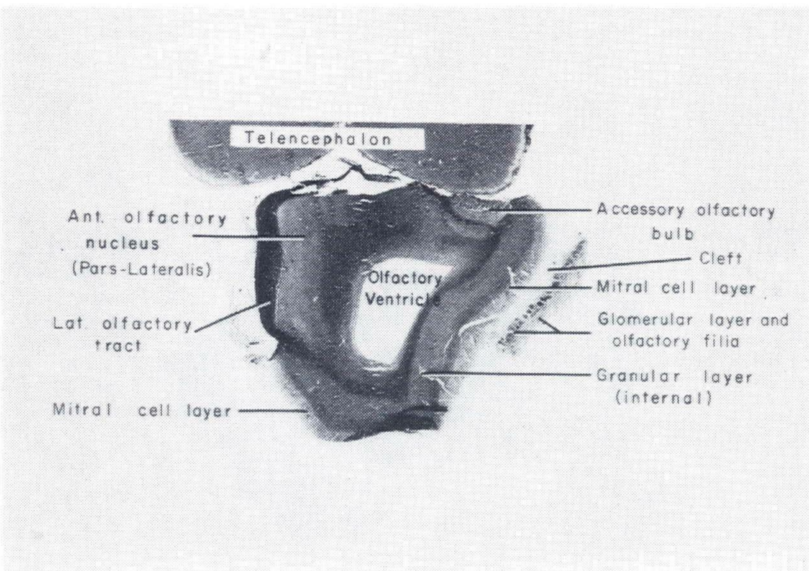

Figure 23

Deer (Odocoileus virginianus, Male) of Michigan. Microphotograph, coronal section through forebrain, at same level as Fig. 22. Series 689, Slide 53. 10% formalin, Weil stain, x 20.

The tissue preparations for microphotographs of brains of water-buffalo, musk-ox, capybara, wild turkey, and deer were all prepared in the Anatomical Laboratories, under supervision of Dr. Edward Lauer, School of Medicine, University of Michigan, Ann Arbor.

Figure 24

Wolverine of Alaska (Gulo gulo luscus, Female), predaceous rover of the Arctic, 21 pounds in its winter coat. Stood 18 inches at the shoulder and measured 30 inches from tip of nose to root of tail. Selected state animal of Michigan. Its basic color is a dark brown. In the photograph the lighter areas are a yellowish light brown, especially the side patterns. Its head and face have a liberal supply of grey hair, at throat and front of neck white spots occur. Estimated age, 5-6 years.

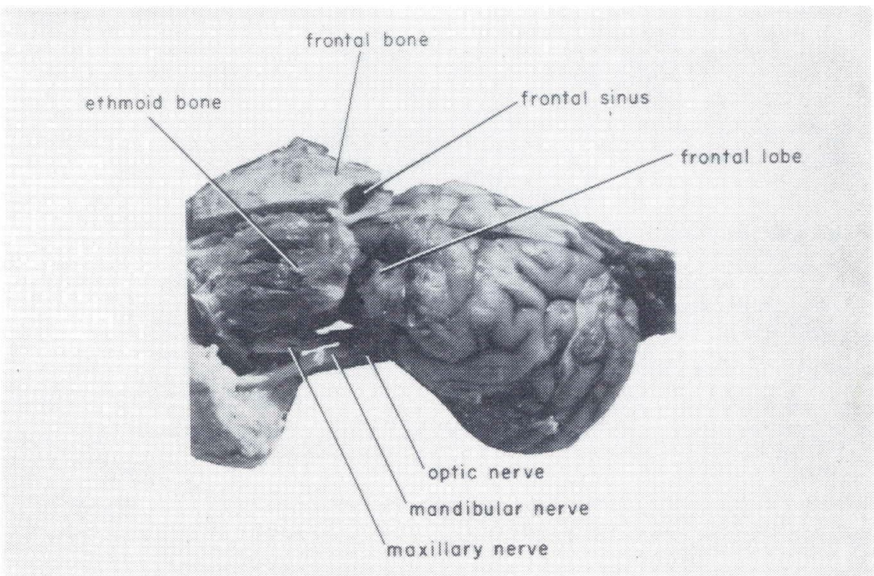

Figure 25

Brain of Alaskan Wolverine* (Gulo gulo luscus, Female) in profile to show frontal area relationships. x ca 1/3.

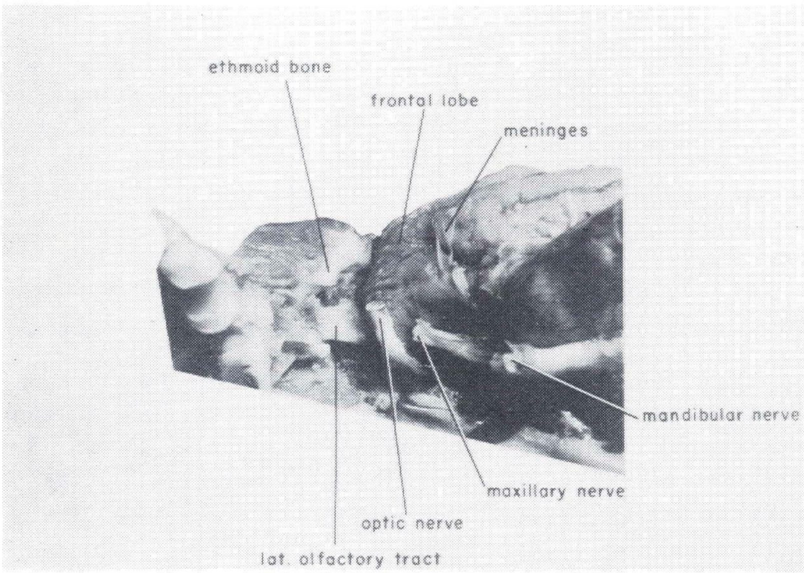

Figure 26

Brain of Alaskan Wolverine* (Gulo gulo luscus, Female) in profile to show frontal area relationships.

In his studies over the years the author has had occasion to remove and to observe in the gross, and home histologically, the brains of the following wild animals: deer, coyote, wildcat, racoon, opposum, skunk, rabbit, weasel, black, grizzly and kodiak bears, mountain-lion, wildcat, pronghorn, American bison, peccary, cacomistle, badger, marmot (groundhog), wild turkey, alligator, snakes, Alaskan moose, caribou, Arctic wolf, stone sheep, lynx, and wolverine; water buffalo, capybarra, crocodile (cayman), iguana, and several birds of South America; and the wild boar and red stag of France. Also, these domesticated animals: horse, cow, pig, sheep, rabbit, cat, dog, and different rodents.

*I am indebted to Dr. Robert L. Rausch and his staff of the Arctic Health Research Center (U.S. Health, Education & Welfare), Anchorage, Alaska, for this specimen. Its collection and transportation is no small task when it is realized that the brain must at no time be exposed to freezing and must be in fixative within 20 hours after death of the animal.

In biopoiesis the emergence of a nervous system was compulsory in the evolutionary scale, and its many capacities will continue to exact compelling studies. This is especially true for the basic chemical matrix of the instincts and the multilateral nature of their expression. The etiology of the instincts and the ethology of their behavior remain enigmatical. If details of the metabolism of nervous tissue can be determined, great advances in understanding its functions will be attained. Despite all research, the precise formulation of life, its modus operandi, and the quintessence of reason still escape us.

This presentation lacks much of the completeness the author had hoped for; hence, treat his attainments a little kindly and his shortcomings a little blindly. No attempt has been made to prove anything, but just to throw a few lights and shadows on things we already know. The present day progress of molecular biology is so fast that some of this author's thinking is already far in arrears.

Acknowledgement is due to editors and publishers for courtesies extended to me; also, to David H. Johnson, mammalogist, and his colleagues of the Smithsonian Institution; and to many obliging correspondents.

At the Henry Ford Hospital, I am especially grateful to John J. Kroll, photographer; John Mohr, medical artist; and librarians, formerly Mary McNamara and now Helen Feltovic. I am deeply indebted to my secretaries Florence Lyon and Elizabeth Crosby, as well as many other thoughtful colleagues, but any errors of omission and commission are strictly on the shoulders of the author.

Bibliography will be supplied on application to the author—

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