Name: James J. Hancock Date of Degree: May 29, 1960

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Nature of Study: Many high school biology teachers find it necessary to use supplementary materials in presenting a unit on the cell and its life phenomena. This report deals with such items as: development of the cell theory; organization of the cell; cellular reproduction; chemical work of the cell; and malfunctions and abnormalities of cells. Illustrations of various processes of generalized cells are included.

Use of Study: It is desired that the concepts developed and the information presented in this report will be of value to secondary biology teachers in introducing or in summarizing the study of living organisms. Also, that some teachers who are not satisfied with the materials they currently employ may be assisted by the information and references presented.

ADVISER'S APPROVAL Jay U. Holt

A SYLLABUS FOR A UNIT ON THE CELL AND ITS LIFE PHENOMENA FOR SECONDARY BIOLOGY

By

JAMES J. HANCOCK

Bachelor of Science

Mississippi Southern College

Hattiesburg, Mississippi

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INTRODUCTION

The Problem Stated

It is evident that the key to every biological problem must finally be sought in the cell; for every living organism is, or at some time has been, a cell. The high school student should have a good understanding of the basic phenomena of the cell; however, most high school biology texts do not contain sufficient, and sometimes accurate information on this subject.

Because of these reasons the writer decided to prepare a syllabus for a unit on the cell and its life phenomena.

Purpose of this Study

The purpose of this study is three fold: (1) to provide the writer with a satisfactory knowledge of the cell and its life phenomena that may be easily communicated to the high school biology student; (2) to present a general guide which could serve as resource material for teachers in the teaching of the cell on the high school level, and (3) to build up a background of information about the cell and provide sufficient references for the teacher to proceed to further studies in specific areas of this topic, should he choose to do so.

Limitations of this Study

This study is limited by several factors. First, since there is an

abundance of literature on this subject, this study will contain selected references that the writer considers of most importance rather than an attempt to thoroughly investigate the entire field. Secondly, in order to adequately treat the basic concepts of the cell and its life phenomena, it has been necessary to select what the writer considers the most important topics out of many related and, probably equally important topics. Thirdly, since a complete understanding of the subject would necessitate a rigorous study of cytology, the writer has limited this study to the information on the elementary level of the general cell.

RESOURCE PROCEDURE

In searching for information, several high school biology textbooks were examined. All of these contained limited information on the topic.

The following categories of literature were studied to find additional information pertaining to the topic: recent textbooks on cytology; textbooks on college biology; other recent books considering various aspects of the topic; periodic literature; bulletins; and other research studies devoted to some specific area of the study of cells.

The first part of the study has been devoted to the historical background of knowledge about the cell. Consideration is given to the organization of the cell as a unit. The processes and functions of generalized cells are presented. The last part of this report involves the study of malfunctions and abnormalities of the cells.

Throughout the report, illustrations of typical cells have been used; frequently encountered exceptions have been explained in the body of the report.

HISTORICAL BACKGROUND

Since the cell is a very small structure, it is obvious that very little could be said about it until means were available for magnifying living objects to a sufficient extent.

The first attempt to describe the use of optics as an aid for seeing was recorded in studies made by Euclid in 590 B. C. Seneca, 65 A.D., reported that glass globules filled with water "will aid in seeing those difficult things that frequently escape the eye." Ptolemy, 127-151, investigated the problem of magnification by means of curved surfaces. The Janssen brothers, 1590, effectively combined two convex lenses within a tube, thus constructing the forerunner of the compound microscope. Leeuwenhoek, 1674, improved the art of polishing lenses of short focal length.[1]

Various techniques were applied to improve the microscope in an effort to do more detailed studies of the cell. The development of the electron microscope in 1932 was the climax to the concern of optics development for studying the cell.

The first definite accounts to formulate an explanation of the nature of life were largely speculation, with little, if any, support. Borel, 1656, accurately noted the regularity of movements of the red blood cells and investigated their microscopic structure.

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[1]Mordecai L. Gabriel and Seymour Fogel, Great Experiments in Biology (Englewood Cliffs, New Jersey, 1955), p. 1.

We shall consider the works of Robert Hooke as published in Micrographia, 1665, as the beginning of the subject. In this famous work, cellular texture is illustrated for the first time and the term "cell" is used in our sense of the word.[2]

In addition to his contributions on advanced techniques in optics, Leeuwenhoek discovered and described unicellular organisms. From time to time he had described his observation of blood, however, in 1674 he remarked that it consisted of small round globules driven through a crystalline humidity or water. Twenty-six years later he described the circulation of the blood in flat-fishes and gave accounts of the oval particles, or nuclei, in the blood of a salmon. This was the first reference to a nucleus.[3]

After studying the microscopic structure of plants and animals, Lamarck's, 1809, ideas were expressed as follows:

> "It has been recognized for a long time that the membranes which form envelopes of the brain, of the nerves, of vessels, of all kinds of glands, of viscera, of muscles and their fibers, and even the skin of the body are in general the productions of cellular tissues. But no one, so far as I know, has yet perceived that cellular tissue is the general matrix of all organizations and that without this tissue no living body would be able to exist, nor could it have been formed."[4]

Further advancement in the cell principle was projected when Dutrochet, 1824, observed that all tissues and organs are actually only

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[2]Arthur Hughes, A History of Cytology (New York, 1959), p. 3.

[3]Ibid., p. 32

[4]Mordecai L. Gabriel and Fogel, p. 2.

cellular tissues variously modified. The report by Meyen, 1830, of observations on algae, fungi, and higher plants contributed to the advancement of the cell principle.

A special study by Robert Brown, 1831, of the fertilization of dicotyledonous plants led him to conclude that the nucleus was a regular feature of plant-cells.[5] Observations of the process of cell division in algae was reported by Dumohtier in 1832; the same phenomena had been reported by Turpin six years before. Von Mohl, 1835-1839, carefully described some of the details of mitosis.

Among the milestones of modern scientific progress the cell theory of Schleiden and Schwann, enunciated in 1838-1839, stands forth as one of the commanding landmarks of the nineteenth century. Its advancement marked the turning point in the advance of biology, opening a new point of view for study of living organisms, and revealing the outlines of a fundamental common plan of organization that underlies their endless external diversity.[6]

In essence the cell theory states that all living organisms are made of cells, that all life phenomena and abilities are fundamentally cellular in nature. The history of this subject since Schleiden and Schwann can be divided into three periods.

The first, from 1840 to 1870 was the time of foundation, during which some of the fallacies were corrected. The principle of genetic continuity became more clearly defined. Only a few of the most important works are

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[5]Charles Singer, A History of Biology (Revised Edition, New York, 1959), p. 333.

[6]Edmond B. Wilson, The Cell in Development and Heredity, (3rd Edition, New York, 1934), p. 1.

considered in this report.

Carl Theodor Von Siebold, 1845, gave a formal expression in his textbook on comparative anatomy that protozoa were organisms consisting each of but a single cell. In 1861 he expressed the movement of cilia in the vertebrates as a form of cellular activity.

Albrecht Kolliker, 1844, applied Schwann's theory to the embryonic development of animals by treating the ovum as a single cell and the process of development as the results of cell division. He also gave an account of the cellular nature of the non-voluntary muscles and correctly demonstrated the structure of nerve-fibers. Among his innumerable interests were the problems of heredity and variation. Although he had not heard of Mendel's work and he preceded De Vries, he held that alterations in characters of races takes place by means of sudden and spontaneous changes.

Rudolf Virchow, in his great Cellular Pathologie, 1858, presented his main contribution to biology. His Omino Cellula e Cellula ('Every cell from a cell') is one of the three widest generalizations to which biology has yet attained, the other two being Omore Vivum ex ovo ('Every living thing from an egg; Siebold's reading of Harvey') and Omore Vivum e vivo ('Every living thing from a living thing; Pasteur).[7]

Max Shultze, 1861, described the cell as a lump of nucleated protoplasm. In 1863 he introduced the protoplasm concept as the physical basis of life.

The second period, from 1870 to 1900, included the development of information which gave more definite form to the ideas concerning heredity

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[7]Singer, p. 345.

and development. The combined efforts of Edward Strasburger and Walther Flemming, 1882, gave a clear description of mitosis. Both Strasburger and Flemming are resporsible for the nomenclature of mitosis. Van Beneden, 1883, and Hauser, 1884, gave final proof of the description given by Strasburger and Flemming on cell division.

The third period began in 1900 with the rediscovery of Mendal's laws of heredity and extends to the present. As the problem of heredity, of sex, of development, of the subordination of parts to the whole, of the essential nature of life, have all been reduced to cellular expressions, the main course of biological thought during the twentieth century has been concentrated on the cell.

Innumerable scientists have contributed to this field during the twentieth century; most of the individuals showed concern for a specific process or the behavior of a specific constituent. Several general contributions were of importance to all who studied the cell. The techniques developed by Harrison, 1907, for culturing and studying isolated cells or tissue fragments advanced the studies of various areas of the cell. The very convincing demonstrations by Wilson, 1907, of the high level of cell individuality in various cell phenomena added considerably to the vast knowledge of the cell and formulated the bases for advanced work in almost every area.

Within the scope of this report the writer cannot begin to mention all the many outstanding individuals who have contributed to the knowledge of the cell and its life phenomena.

ORGANIZATION OF THE CELL

Constituent Materials

There are many kinds of cells in plants and animals, which differ considerably in many ways; or all have certain basic features in common. Within a complex organism, various cells consist of different constituents. These structures may be readily recognized by the utilization of various staining techniques and the aid of magnifying instruments.

A living cell is conservative in that it probably retains no components that are of no functional importance. The physiological role in cell metabolism of some structures gives morphological evidence of their presence; however, their functions are more or less unsolved puzzles.[1]

A typical cell, or protoplast, consists of structures that are of two categories: (1) the protoplasmic components which are cytoplasm, centrosome, nucleus, plastids, mitochondria, and Golgi materials; and (2) the non-protoplasmic components which are vacuoles, cell walls, and ergastic bodies. Some of the components are sub-divided. An illustrative example of a generalized cell is given in Fig. 1.

Nature and Function of the Cell Constituents

Cytoplasm, or protoplasm, is located outside the nucleus and is the

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[1]Carl P. Swanson, Cytology and Cytogenetics (Englewood Cliffs, New Jersey, 1957), pp. 14-18.

seat of absorption, secretion, digestion, excretion, respiration and irritability. The outer perimeter of the cytoplasm is bound by the plasma membrane. This membrane is selectively permeable and structurally, it is of a double lipid-protein character.

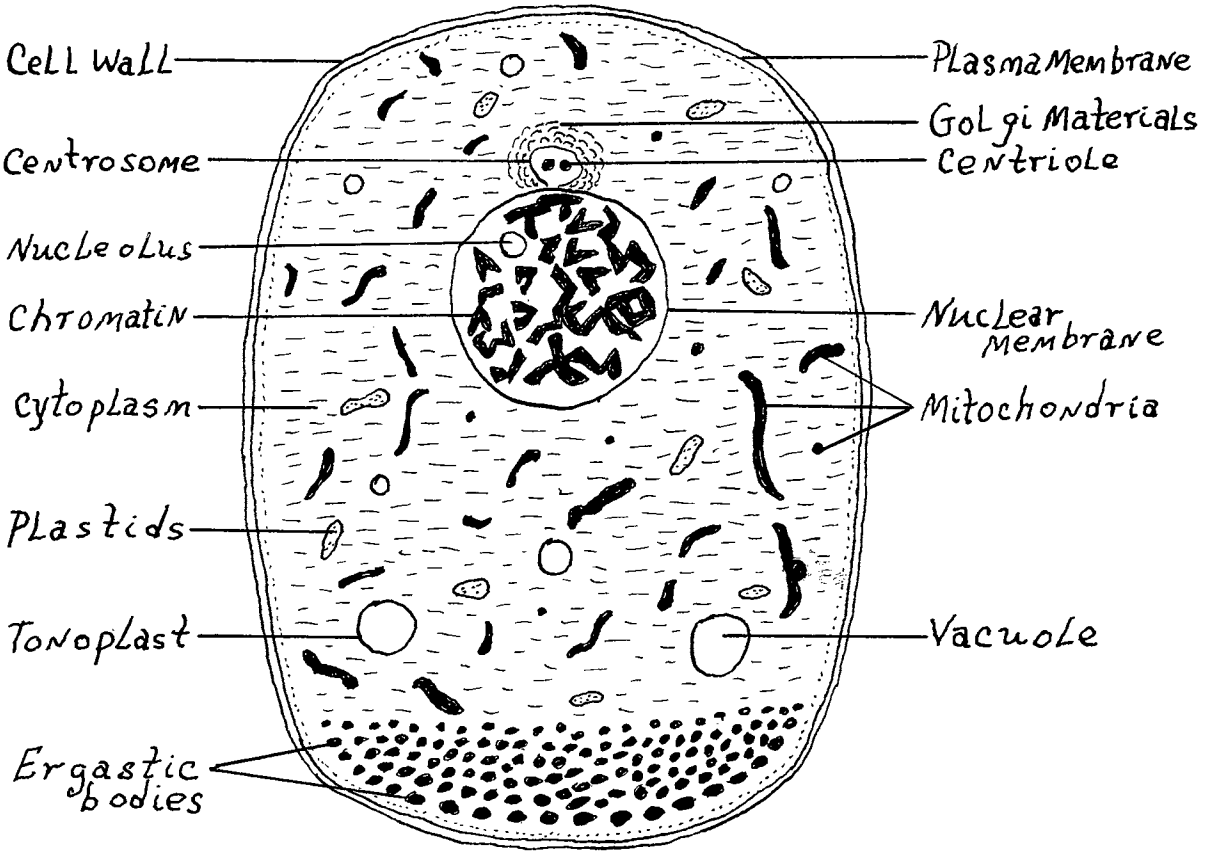

Fig. 1. Illustrative example of a generalized cell.

Without protoplasm there would be no life. This most important living substance is composed of very cheap materials. Water constitutes about seventy-five per cent of its contents; its salts are the most common varieties; mainly sodium chloride, and salts of potassium, magneseum, and calcium.[2] Morphologically, protoplasm, tends to assume a fibrillous

[2]L. V. Heilbrunn, "Calcium and Life," Scientific American, June, 1951, pp. 60-63.

structure.

The centrosome or central body, characteristic of a non-dividing cell, consists of a hyaline (glasslike) material, in the center of which are smaller granules, usually two, called centrioles. The dense cytoplasm that surrounds the centrosome is known as the centrosphere. The centrosome is very active and essential during mitosis, at which time it lies at the focus of the astral rays. During mitosis the centrioles separate and a spindle figure arises between them, which serves as a route for the chromosomes in the nucleus to move to each daughter cell. In the late phase of mitosis each centrosome will divide in preparation for the next mitotic division.

Observations of the nucleus usually shows four distinct components: a nuclear membrane; a nuclear frame-work, usually described as a fine network, or recticulum; a colorless fluid called the nuclear sap, or karyolymph; and one or more dark round bodies called nucleoli.

The nuclear membrane is a delicate but well-defined film which separates the nucleus from the cytoplasm of the protoplast. It is semipermeable, elastic and in some cases very tough. This membrane permits the exchange of materials between the nucleus and the cytoplasm. During mitosis it ruptures and is reconstructed during the later stages of the process.

The fine network, or recticulum, consists of the hereditary material known as chromatin and the linin network of fine fibers which serve as a foundation for the chromatin. Aggregates of the chromatin granules called chromomeres combine with the linin to form the chromosomes. These chromosomes are constant in number for the diploid or haploid cells of a given species.

Karyolymph is a colorless fluid that is slightly firmer in consistency than water. It has its ground substance made up of nucleolymph, or nuclear sap.

A stained nucleus reveals nucleoli which are rich in histones and ribosenucleic acid. The nucleoli are attached to specific regions of the chromatin, these regions act as organizers for the nucleolar material.

Most cells have one or more nuclei which vary in size and shape for various species. Basically the nuclei play a major function in the process of cell division; controlling and governing various cellular activities; and aiding in the secretion of enzymes.

Plastids are bodies, especially characteristic of the cells of plants, capable of self-perpetuation. They represent conspicuous structures of the cell of great importance for continuation of organic existence. Among the most common plastids are: chloroplasts which are intimately concerned with photosynthesis; leucoplasts from which other plastids arrise during its embryonic development; amyloplasts which serve to condense glucose into solid starch-grains; and elaioplasts which act as centers of fat-formation. Fundamentally, plastids may represent stored food, waste material, or definite areas of chemical activity.

The mitochondrion, powerhouse of the cell, is a small body which appears to play a central role in the oxidation of foodstuff. These bodies are the most plastic of cell structures and occur in nearly all kind of living cells. Variations occur in size, form, and position of the mitochondria. Within the mitochondria are tiny bodies whose contents and function are entirely unknown. The ceaseless motion of the mitochondria in living cells is one of their most striking features; they not only change size and shape but, also appear to divide and recombine. These

changes may be related to the changes in their chemical activity. The activity of the mitochondrion in regulating activities in other parts of the cell indicates that it may be not only a servant of the cell, but also, one of its controls.[3] Chemically the mitochondria contain lipids, nucleotides, flavins, nucleic acid and numerous important enzymes.

Another conspicuous structure present in the cell is the Golgi material. This material is chemically lipo-protein in structure. Vitamin C is found associated in fairly high concentrations within the Golgi material. By electron microscopy it has been shown that the Golgi material consists of membranes, ground substances, and granules.

Vacuoles are cavities in the cytoplasm bounded by a delicate membrane, the tonoplast, and filled with cell sap. Basically there are two kinds of vacuoles; food vacuoles for the purpose of digestion and assimilation, and waste or contractile vacuoles are very small or even absent in the dividing cell, but once the cell has passed into a state of differentiation the vacuoles enlarge.

Each cell is limited by a boundary; for plants it is a cell wall and for animals, a cell membrane. The cell wall is a secretion product of the cytoplasm; the same is true for the cell-membrane of animals. More commonly, the cell membrane is referred to as the interstitial substance. Three distinct regions of the cell wall are recognizable; the middle lamella which is usually shared by an adjoining cell and functions as a cement; the primary wall which is the first deposition of the protoplast; and the secondary wall which provides the chief supporting structure for

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[3]Philip Siekevitz, "Powerhouse of the Cell," Scientific American, July, 1957, pp. 131-140.

plants. In animal cells there is only a secretion product of the cytoplasm which serves to bind the cell together.

The ergastic bodies are secondary products of protoplasmic activity and are commonly characterized by a great variety of granules. In general these bodies are temporarily stored products, destined sooner or later to disintegrate or dissolve.[4]

From the preceeding discussion it is evident that differences between cell organization varies as different organisms are considered. A typical protoplast has been considered in this presentation; however, it must be remembered that some constituents not considered here are found in some specialized cells.

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[4]Wilson, p. 38.

CELLULAR REPRODUCTION

The reproduction of cells is essential for the continuation of a species from one generation to another. This process is the remarkable phenomena usually referred to as cell division.

Consideration of two types of cell division shall be given: mitosis, or somatic cell division, the process by which units of living matter duplicate themselves, and meiosis, or germ-cell division, a special kind of cell division which reduces the number of chromosomes to one half or the gametic number.

Mitosis

Of all the activities that can be seen in the cell, mitosis is the most complicated, and its machinery is about the most elaborate that a cell can manufacture.[1]

Mitosis in a number of ways varies widely from one species to another but the essential processes and consequences are similar for all organisms: it provides a means for an increase in the number of cells or organisms. This process has been divided into five stages: interphase, prophase, metaphase, anaphase, and telophase as shown in Fig. 2. Although the various stages are readily indentifiable by certain appearances, cell division is a dynamic and a continous process, each stage passing almost

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[1]Daniel Mazia, "Cell Division," Scientific American, August, 1953, pp. 53-63.

inpreceptibly into the next.[2]

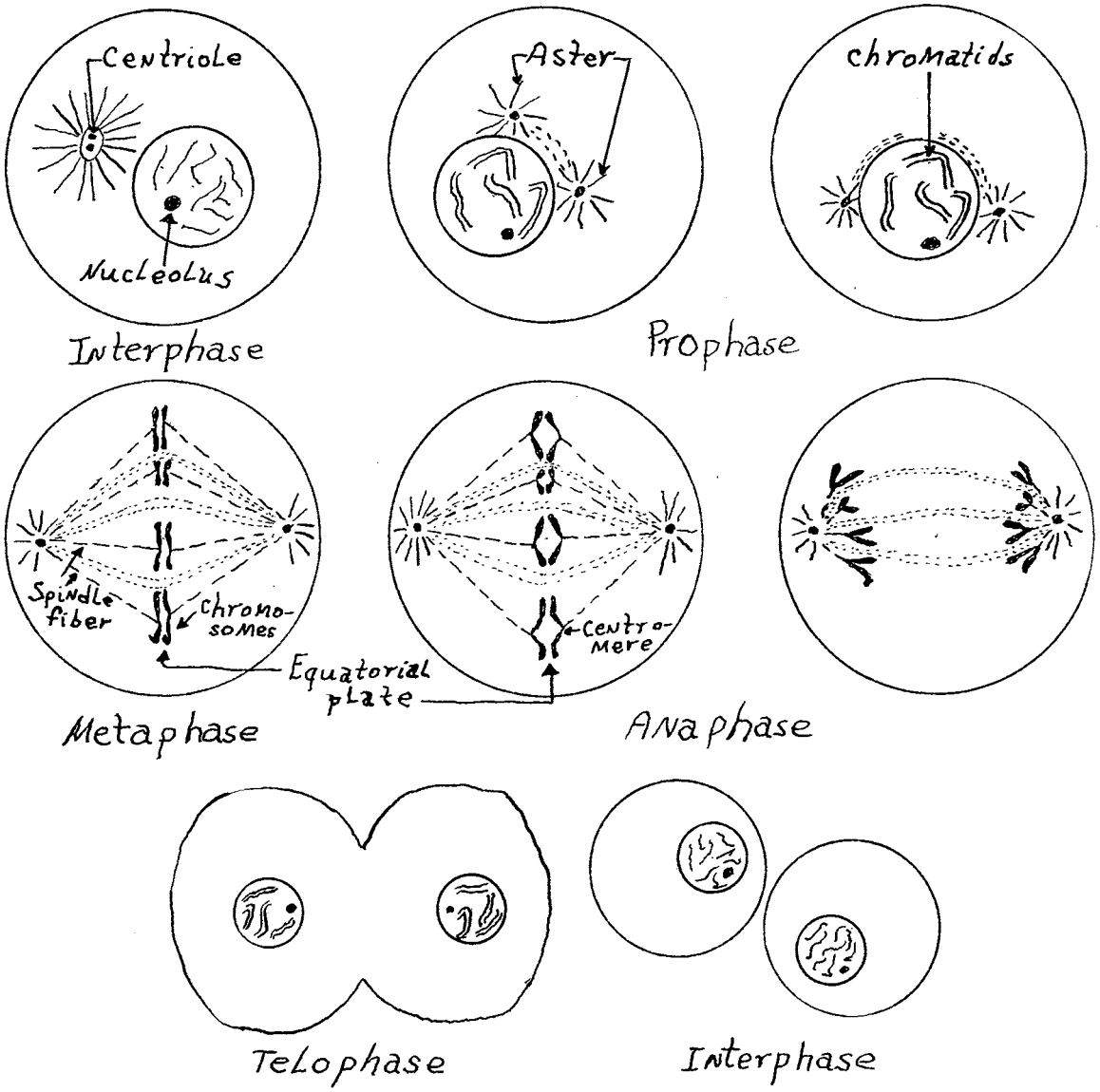

Fig. 2. Diagrammatic illustration of mitosis.

Cells in interphase, or so-called "resting stage," are very busy in other ways but have not gone through the process of giving birth to two daughter cells. This stage is characterized by the nucleus that shows

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[2]Swanson, p. 47.

little or no definable structure, except for the nucleoli and prochromosomes. There is no evidence of a mitotic apparatus, except that in favorable cases the centriole may be detected near the surface of the nucleus.

Prophase begins when the chromosomes become visibly distinct. Prior to the chromosomes becoming visible the nucleus becomes enlarged by the uptake of water. The chromosomes become shortened and thicker in their diameters. Chromosomes are longitudinally doubled from their earliest appearance. As prophase progresses the chromosomes become shorter, thicker and more distinct. In animal cells these shortened chromosomes migrate to the nuclear membrane, whereas, in plant cells they remain at random. If one or more nucleoli are present, they can be observed to diminish in size, usually disappearing before the onset of metaphase.

Another characteristic of prophase is the formation of the mitotic apparatus. The centriole, if present within the centrosome, becomes duplicated at this time, with each new sphere containing one centriole. Each of the new centrosomes migrates away from the other until they are about 180 degrees apart along the nuclear membrane. During the migration the centrioles form astral rays in the cytoplasm.

The metaphase is initiated by the disappearance of the nuclear membrane. The astral rays, at the time of membrane dissolution, overlap and coaleace to form continous fibers, or spindles. These spindles connect the two centrioles and serve to bring the chromosomes onto the equatorial plate. Only the region known as the centromere, or kinetochore, of the chromosomes need be in association with the spindle for the process to occur. With the chromosomes on the equatorial plate the mitotic apparatus is completely formed.

Metaphase passes into anaphase at the time the centromere divides

and the chromosomes begin to move toward the poles, or centrioles with their mechanisms. The mitotic apparatus functions to pull the chromosomes to their respective poles by contractile fibers attached to the centromeres. In late anaphase the cytoplasmic division, or cytokinesis, is initiated.

Telophase is characterized by the regrouping of the chromosomes into a nuclear structure within a membrane and the completion of cytokinesis. In general, the nuclei of the cells now return to an appearance identical with that of the interphase period.

Since cytokinesis differs considerably in plants and animals, a separate consideration of each is warranted. In plants the equatorial region of the spindles widen into the phragmoplast. It increases in diameter until it reaches the lateral walls, where it disappears. Before its disappearance a thin line of droplets, pectic substances, forms across the center of the equatorial plate, this widens in area as the phragmoplast migrates, and eventually forms the new wall which separates the two new cells. This membrane is sometimes referred to as the cell plate. The two daughter cells now form a plasma membrane around each protoplast, and the cell walls are thickened by the deposition of hemi cellulosic materials secreted by the cytoplasm.

In animals cytokinesis is completed by a process known as furrowing, which originates at the point of constriction of the outer membrane near the position of the equatorial plate. This constriction moves inward to cleave the cell into two daughter cells. In various species exceptions exist in the method by which cytokinesis proceeds.[3]

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[3]Ibid, pp. 56-59.

There are two general phases a student should understand after a study of mitosis. First, the formation of the mitotic apparatus which deals with the nuclear division. The centrioles divide, separate, and as they separate, throw out a radiating system of fibers, or asters. These appear to find their way to opposite poles of the cell and to be connected by spindles running from one centriole to the other. Meanwhile, the chromosomes become more evident and the nucleus fades away. The chromosomes migrate to the equator of the spindle; this completes the formation of the apparatus. At some point along the way it is possible to observe chromosome duplication.

Second, the mechanism of the mitotic apparatus, which perhaps is the most dynamic stage of mitosis. One complete set of chromosomes is moved to each pole. Coordinated with this is the division of the whole cell such that each set of chromosomes goes to the daughter cells. The action of the mitotic apparatus may cause the cell to become distorted; however, it also controls the location of the cell plate or furrow.

As previously stated, cell division provides a means of an increase in the number of cells present in an organism. A very likely question at this point is: What phenomenon causes the formation of various cells within an organism? Cells arise only from pre-existing cells by cell division, consequently all cells should be alike.

The process by which various cells mature and specialize is called differentiation. The controlling mechanism of this process is the nucleic acids of the fertilized egg-cell. Apparently the giant nucleic acid molecules contain blueprints for the manufacturing of protein molecules, which include the enzymes that catalyze the multi-various chemical reactions of living matter. The blueprints are distributed to each daughter

cell, which in turn bequeath an identical set to each of its descendants. Due to the polarity of the cells and their locations, various blueprints are followed as a result of the different stimuli received from the cytoplasm.[4] The results are specialized cells grouped together as an organ.

Meiosis

In the somatic cells of an individual the chromosomes are grouped into pairs. The germ cells will produce only one-half the number of chromosomes as contained in the somatic cells, or one chromosome each of the different kinds. This condition is brought about through the process known as meiosis. Essentially the process consists of two successive cell divisions including chromosomal duplication. A reduction in the number of chromosomes occurs in the first division. See Fig. 3.

An obvious function of meiosis is the maintenance of a constant chromosome number in the species, for without it as a consequence of syngamy, there would be a doubling of the chromosome sets in each generation. A second function of meiosis is to serve as a physical mechanism for the segregation, assortment, and recombination of the genes, or hereditary determiners.

A complete discussion of the process of meiosis will not be given in this report because this information is obtainable from almost all the references used. It is the belief of the writer that simplified methods

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[4]S. Meryl Rose, "Feedback in the Differentiation of Cells," Scientific American, December, 1959, pp. 36-41.

of presenting this material to high school students would be of more value.

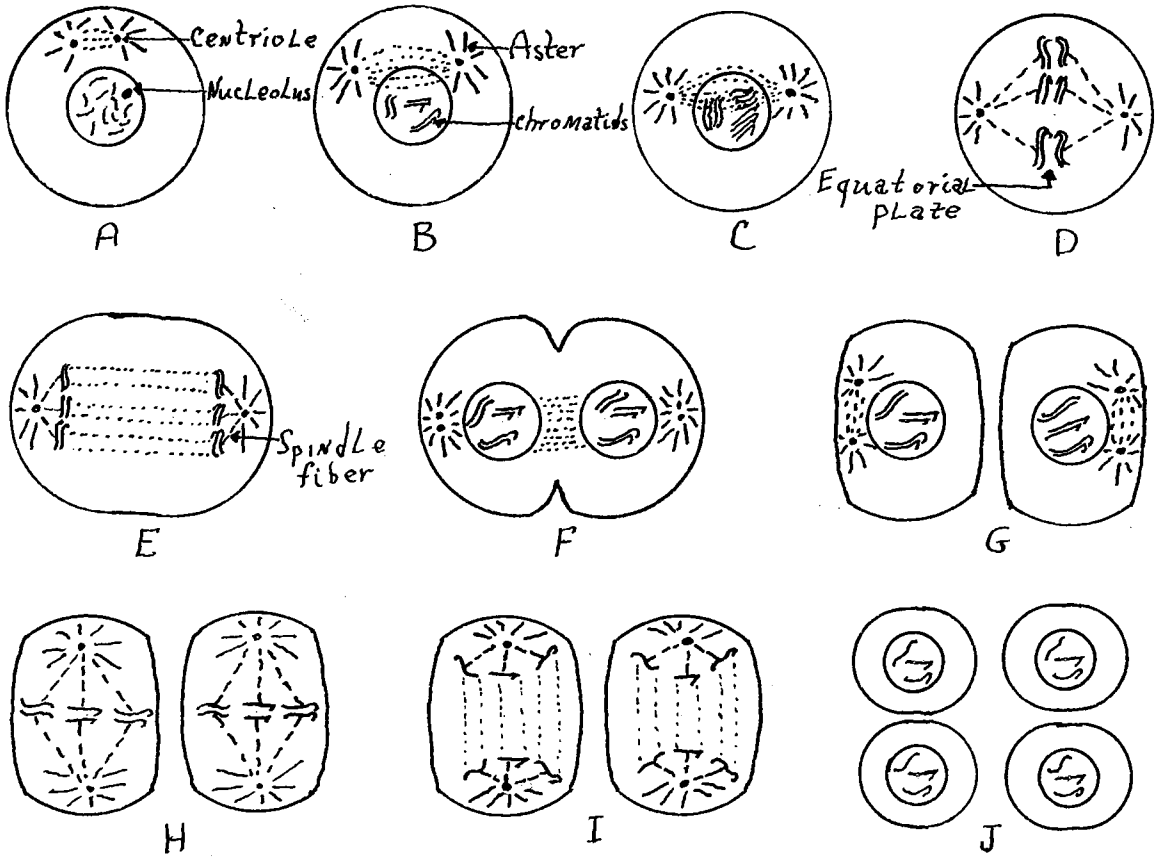

Fig. 3. Diagrammatic illustration of meiosis. A, Early prophase of the first meiotic division: B, Synapsis. C, Chromosome duplication. D, Metaphase of the first meiotic division. E, Anaphase of the first meiotic division. F, Telophase of the first meiotic division. G, Prophase of the second meiotic division. H, Metaphase of the second meiotic division. I, Anaphase of the second meiotic division. J, Mature gametes.

To aid the student in understanding what happens to the chromosomes during the mitotic division to produce the germ cells, a model consisting of several strings of poly-ethylene pop-beads may be used to represent the chromosomes.

Assuming the model of the cell to possess four chromosomes; two long and two short. Use a long string of red beads to represent one long chromosome and a long string of green beads to represent the other long chromosome. Use a short blue string and a short yellow string of beads to represent the pair of short chromosomes.

Fig. 4. The four chromosomes

The first significant thing that occurs during meiosis is synapse or the formation of partnerships. The two chromosomes come together and the two short chromosomes come together as shown in Fig. 5.

Fig. 5. The partnership

The next thing that happens is duplication, however, this does not involve the centromeres, the small bodies shown in the center of the chromosomes. This process may be illustrated by the selection of four additional strings of beads identical to those already in use. The pairs are joined at their centers as shown in Fig. 6.

Fig. 6. The chromosomes duplicated

Separation of the partner chromosomes is the first division in meiosis.

The original red chromosome and its duplicate separate from the original green chromosome and its duplicate. The yellow chromosomes and the blue chromosomes separate in a similar manner. This separation results in two pairs of chromosomes in each of the two cells, one long pair and one short pair as shown in Fig. 7.

Fig. 7. First division in meiosis

The pairing of the chromosomes is random or by chance. That is to say, it is not known if the red chromosomes will be present with the yellow or blue chromosomes in a cell, however, in this discussion assumption has been made that the red and yellow are present in one cell while the green and blue are present in the other cell.

In the second division in meiosis the centromeres split; thus one of the long red chromosomes and one of the short yellow chromosomes go into one cell. The other long red and short yellow chromosomes go into a second cell. Precisely the same thing occurs in the cell containing the long green and short blue chromosomes. There are now four cells and each one has two chromosomes, one-half the number present in the cells from which they developed.[5] See Fig. 8.

Meiosis would always occur like this if it were not for the fact that the individual strands that make up the chromosomes become intertwined and entangled. This is referred to as crossing over, or the exchange of

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[5]N. B. Abraham et al., Laboratory and Field Studies in Biology, (Washington, D. C., 1957), pp. 671-673.

equivalent portions by homologous chromosomes.

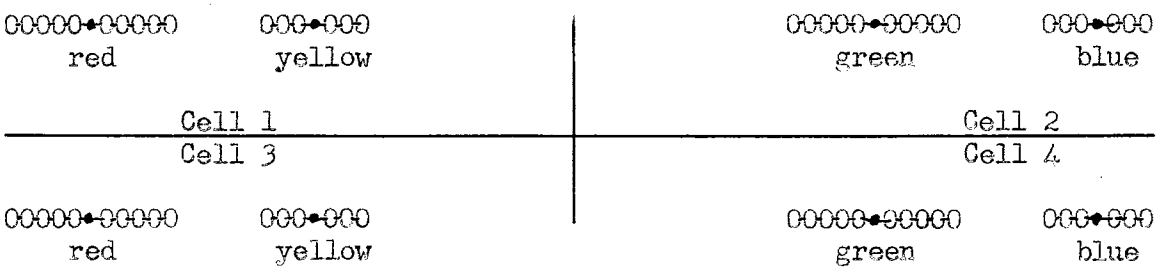

Fig. 8. Second division in meiosis

Maturation of the male sex cell is known as spermatogenesis; maturation of the female sex cells is known as oogenesis. Four spermatozoa results from the maturation of one spermatogonium. The results of the two maturation division in the female is one large cell, the ovum, and three small, nonfunctional cells, the polar bodies.

When conception occurs the sperm fuses with the egg cell and the resulting zygote is diploid with respect to the number of chromosomes present. The zygote now undergoes mitotic cell division in the developmental process which results in a new individual.

A very likely question that might be asked at this point is: What is there in living organisms that causes the developemnt of different characteristics in a species? What is inherited is nothing more than a very small quanity of cytoplasm and some chromosomes.

There is "something" in the chromosomes that determines these characteristics called genes. A gene is a molecule or part of a molecule located in a specific position (locus) in a chromosome and is responsible for controlling certain chemical changes in the cytoplasm, thus determineing different characteristics in different individuals.

There are several points a student should understand after a study of meiosis. First, the chromosomes are passed on from parent to offspring. Second, the chromosome number is reduced by one-half when the gametes are formed. Third, the chromosome number is restored at the time of fertilization. Fourth, chance operates in reduction division and fertilization. Fifth, each parent contributes one-half of the chromosomes present in the offspring and one of each homologous pair. Sixth, in the offspring there is a "mixing" and some chromosomes present in the parents and grandparents may be absent.

CHEMICAL WORK OF THE CELL

Modern physiology readily accepts the fundamental conclusion that all vital energies are traceable to the chemical energy of the food-stuff that have been incorporated into the cell constituents and are there set free by oxidation and other destructive chemical processes of metabolism. Thus the cell may be regarded, physiologically as a "chemical machine".[1]

Experiencing normal conditions, the activities of every cell are of a specific type. This specificity of each kind of cells depends essentially upon its organization. Considerations shall be given to the most common processes of generalized cells.

Protein Synthesis

Proteins are giant molecules that consist of many different amino acid residues, linked primarily through peptide bonds to form long polypeptide chains. Each kind of protein has a unique number and sequence of side groups of amino acids which give it a particular size and chemical idenity. Any living organism synthesizes many hundreds of specific proteins.

Protein synthesis is dependent upon a collection of suitable supplements by the cell. The essential supplements are a complete array of amino acids, together with adenosine triphosphate (ATP) or an ATP-

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[1]Wilson, p. 635.

generating system and nucleic acids; in some cases purines and pyrimidines are required. Some sub-cellular systems which consist of microsomes, are capable of making proteins.[2]

Evidences are that the nucleic acid, known as DNA, is responsible for the sequence determination of the amino acids in protein synthesis. Once a full sequence of amino acids have been lined up, an enzyme may then bind the units together and peel off the newly formed protein, leaving the DNA available to organize another. Since the storehouse of genetic information is the DNA, the ultimate potentiality of a cell to synthesize a specific protein must be conferred by its DNA.[3]

Protein synthesis is measured by several methods. One of the most accurate and convenient methods is to measure the enzyme activity and correlate this with the quanity of proteins being synthesized. Analysis of the products of a cell's activity is another way of estimating the rate of protein synthesis.

Most of the proteins made by an organism are enzymes, which must be produced in a balanced array to permit the correct integration of biochemical functions.

Enzyme and their Activities

Enzymes are compounds which cause chemical reactions to proceed at higher rates than would be the case if they were absent. It may be shown that enzymes are unchanged in amount and properties during a chemical

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[2]J. B. Neilands and Paul K. Stupf, Outlines of Enzyme Chemistry (2nd Edition, New York, 1958) p. 371.

[3]Ernest F. Gale, "Experiments in Protein Synthesis," Scientific American, March, 1956, pp. 42-46.

reaction in which they may participate. Thus enzymes are catalysts: special catalysts that occur only within or as secretions of living organisms. Enzymes are proteins (simple or conjugated).

Studies on the synthesis of enzymes have revealed two general groups of enzymes: inducible enzymes, which are formed in the cells in response to a specific externally supplied inducers, and constitutive enzyme, which need no inducers to cause their formation.

Practically all the enzymes known may be grouped into four classes. The classes are: (1) enzymes which catalyze the addition or removal of waters; (2) enzymes which catalyze the transfer of electrons; (3) enzymes which transfer a radical from one molecule to another; and (4) enzymes which split or form C-C bonds without group transfer.

Enzymes occur in every living cell. However, they are not uniformly distributed. Many of the enzymes are associated with the various constituent particles of the cell. Previous mention has been made of the enzymes associated with the mitochondria that are responsible for the oxidation of food-stuffs. Other enzymes are associated with other cell structures such as chromosomes, nuclei, and the surface of the cell.

Enzyme synthesis occurs in the cells and is dependent upon the presence of a particular gene and the required proteins. Several factors control the rate of enzymatic formation. One, which has already been mentioned, is specific inducers. A secord control mechanism is the specific suppression of enzyme synthesis. A third control mechanism is the hormonal regulation of enzyme synthesis.

It has become evident that the function of any enzyme is to catalyze metabolic reactions involved in the maintenance, growth, and reproduction of the living organism. Metabolism is a composite of two sensitively

balanced processes: namely, anabolism, or the utilization of energy and materials for chemical synthesis; and catabolism, or the breakdown of substrates with the relcase of available energy for work. Each step of these complex sequences of reaction is controlled by a specific enzyme system.

Antibodies and their Activities

In the simpliest terms an antibody can be described as a modified soluble protein with properties that make it stick to the type of molecule or micro-organism against which it was developed. They are produced in the cells which produce the blood protein gamma globulin. The cells change the pattern of the gamma globulin in such a way that the molecule attaches itself to the foreign material, the process is analogous to a lock and key combination.

The very same cells, scavenger cells, that are responsible for the dealing of removal of damaged or worn-out cells. The specific question now is: How do the scavenger cells distinguish between the body's own proteins and the foreign proteins? A plausible hypothesis that has been proposed after extensive experimentation is: during early embryonic life an individual may accept foreign proteins and develop a lasting tolerance to them; the cells ability to recognize the difference between self and not-self occurs some time before birth. This occurs because of certain structures which are called "recognition units" located in the scavenger cells. These units can recognize, up to the critical point of formation, "self markers," that is, molecular configurations typical of the expendable cells of the body, and any pattern that may be present due to the infection or accident. Once the critical point has been passed, the

scavenger cells will react differently to any new patterns that may become present, that is, an antigen.[4]

It has been observed that antigens resemble self-markers closely enough to react with the recognition units. In this reaction the units are distorted and reshaped. These new recognition units multiply, reproducing their new specific pattern. Some of the multiplying units enter into certain cells known as stem cells where they may persist, for life, though in most instances there seems to be a slow drift back to the original pattern. When an acute stimulus to antibody production occurs the stem cells give rise to specialized cells which produce and liberate large quanities of antibody molecules into the blood. When the stimulus of infection ceases, antibody production drops to a lower level. Like all blood proteins, antibody is in a constant state of flux.

Photosynthesis

The basic process on which all life depends is the utilization of solar energy for the elaboration of complex molecules. This process now occurs almost entirely in the photosynthetic apparatus of plants.

Chlorophyll, a green pigment, present in the chloroplast is the basic enzyme of the photosynthetic apparatus. These structures act as energy transformers, and are very efficient, for the conversion of light into chemical energy.

The primary action of the chloroplast is to split water into two fragments or radicals, H and OH. The oxygen is eventually liberated from

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[4]Sir Macfarlane Burnet, "How Antibodies are Made", Scientific American, November, 1954, pp. 74-78.

the OH, while the hydrogen atoms are available for energy transfer. The hydrogen atoms will combine with any suitable hydrogen acceptor, in plants they are used chiefly to combine with hydrogenated diphosphopridine nucleotide which is used to transfer the hydrogen to form energy-rich compounds.[5]

In the process of photosynthesis, carbohydrates are synthesized from carbon dioxide and water by the chloroplasts of living plant cells in the presence of light, oxygen being released. By using radioactive carbon atoms to label the carbon dioxide, it has been found that the carbon dioxide enters into a complicated cycle of changes. The intermediate compounds of this complex cycle are used by the organism to carry out many other necessary reactions.

The process of photosynthesis as outlined in Fig. 9 presents evidences of two distinct phases, the light and dark reactions. The light reaction produces unstable intermediates; the dark reaction stablizes them by conversion into the final products, oxygen and carbohydrates.[6]

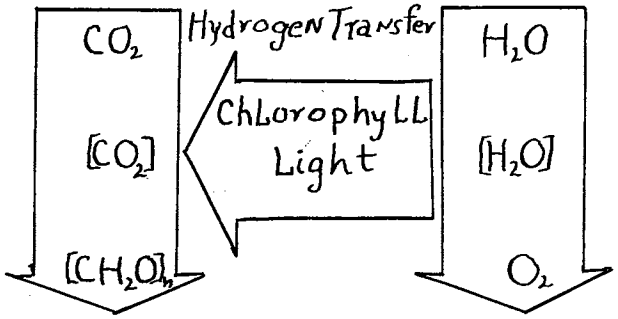

Fig. 9. Outline of Photosynthesis.

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[5]J. A. V. Butler, Inside Living Cells (New York, 1959), pp. 106-109.

[6]Eugene I. Rabinowitch, "Photosynthesis," Scientific American, August, 1948, pp. 25-35.

Energy Production

The cell's energy is a product of the oxidation of carbohydrates, fats and proteins. The complex series of reactions to form carbon dioxide and water and thereby, release energy is known as the citric acid cycle. The fuels for this cycle is pyruvic acid, fatty acids and amino acids.

The pyruvic acid is formed from carbohydrates, which have fermented or split into two molecules of lactic acid and each having lost two electrons and two hydrogen atoms, and from amino acids which have oxidized to form, in addition to pyruvic acid, oxaloacetic acid and I-ketoglutoric acid. Fatty acids are broken down into C-C units which correspond to acetic acid.

The fuels enter the cycle at various steps as indicated in Fig. 10. It is evident that both pyruvic acid, a C_3 unit, and acetic acid, a C_2 unit, enters the cycle at the same place. The pyruvic acid combines with a C_4 unit to form a C_7 unit which immediately burns a carbon atom to produce carbon dioxide and a C_6 unit which is identical to the C_6 unit formed by acetic acid combining with a C_4 unit. Now the C_6 unit is degraded, carbon atom by carbon atom until it is reduced to the original C_4 unit. This C_4 unit will again combine with another C_2 unit or C_3 unit, and so the process continues until all the C_2 and C_3 units are burned. The "C splinter", split off at each step, is carbon dioxide.

The energy produced by the citric acid cycle is captured by parallel reactions which convert inorganic phosphates to organic phosphates of high-energy content. The energy is stored in the bonds that attach the phosphate groups to the ATP, adenosine, triphosphate, molecule. The ATP system acts as a storage battery or transformer, in that it contains the

high-energy phosphate bonds and shuttles the energy to the system involved in biochemical reactions.

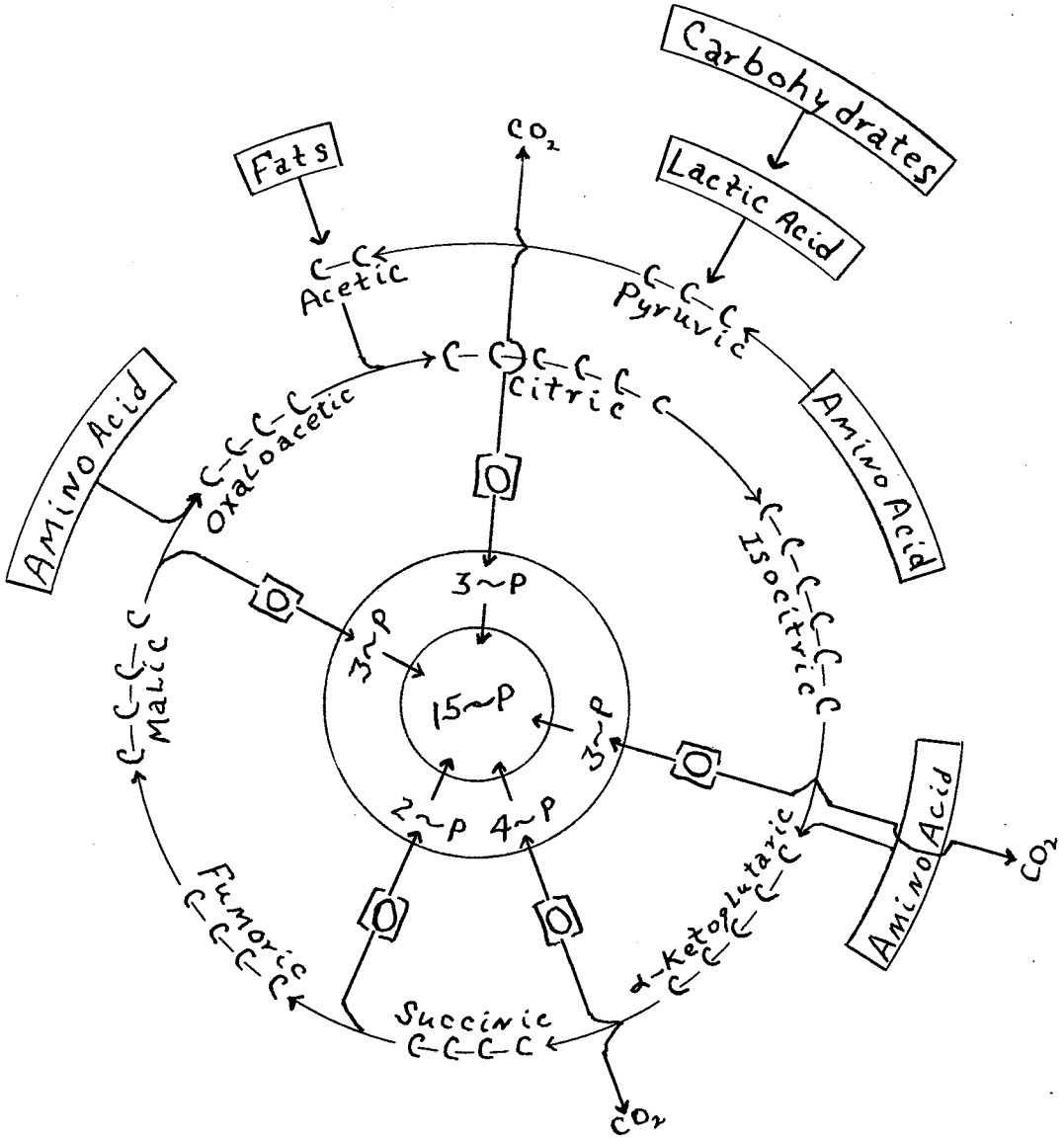

Fig. 10. Citric Acid Cycle

Each complete turn of the cycle produces fifteen high-energy phosphate bonds as indicated by the center of Fig. 10. The energy production is profoundly influenced by (1) the enzymatic constitution of the cells (2) the hormonal balances and (3) the electrolyte pattern in the extracellular and intracellular fluids.

MALFUNCTION AND ABNORMALITIES OF CELLS

As previously stated, cells vary in structure according to their functional activities and morphological differences characterizes "resting" and dividing cells. These changes are the expressions of the normal range of physiological functioning. Other modifications of cell structure are the results of alterations of humoral enviroment or a consequence of infection. The latter constitutes the malfunction and abnormalities of cellular structures.

Regressive Changes

When pathological conditions exist the most frequent results is cellular degeneration. Morphological changes can be observed in the mitochondria, cytoplasm, centrosphere, Golgi apparatus, and nucleus.

With the advent of adverse conditions the mitochondria will begin to collect around the nucleus, usually becoming heaped up around the centrosome. As degeneration continues, the mitochondria will be reduced to fine granules and finally they disintegrate completely. The mitochondria of nerve cells seem to resist most pathological conditions.

The cytoplasm can be observed to possess a few granules, when stained with neutral red or basic dyes, under normal conditions. Pathological conditions bring about an increase in these granules, that is, degeneration granules; there also may be considerable vacuolation of the cytoplasm and the formation of fat droplets.

The "degeneration granules" accumulate in the area of the centrosome, as does the filamentous mitochondria. The centrosphere enlarges in an effort to avoid the penetration of either the "degeneration granules" or the mitochondria.

The Golgi apparatus will break up into granules in degenerating cells. The fragmented particles give rise to fat droplets. Due to its sensitivity to a variety of pathological conditions, fragmentation of the Golgi apparatus has been described.

Interaction Between Cells and Micro-organisms

The present day knowledge of cell reactions to bacterial infection is very incomplete. Observations have revealed that most bacteria grow intercellularly in the body fluids, giving rise to toxins which have a generally injurious action, while others exert their action more particularly on specific tissues.

Following injections of bacteria or bacterial toxins into an organism, degenerative changes in cells have been observed. In general, the degenerative changes involved reduction in size of mitochondria, diminution in number, and finally their disappearance.

Another type of association exists between certain mycobacteria and cells. These are relatively large acid-fast bacteria, and includes the causative organisms responsible for tuberculosis and leprosy. When the bacillus becomes lodged in the tissues it brings about an accumulation of cells around it, within which it is said to proliferate. A collection of such cells, known as epithelioid cells, constitute the characteristic

lesions of the disease.[1]

Many pathogenic conditions result from viruses, which are nucleoproteins of varing size and shape. They are described as ultramicroscopic and filter-passing organisms. Viruses lack the ability to extract from raw materials the food needed to maintain life and make enzymes and proteins; however, they do make use of the apparatus, essential for this ability, which is provided by their host cells.

The infectivity is usually highly specific in that a strain of the virus will only live and multiply in one particular host species, sometimes the virus can multiply only in some strains of a species. Cells infected with viruses react in various ways. In fact, the changes produced in cells by the action of a virus is characteristic of the disease it produces.

Various experiments have revealed that viruses can be stripped of their proteirs and the remanent nucleic acid portion is capable of causing the disease characteristic of the virus.

During short periods of observations of viruses, changes in their behavior are often noticed and new strains appear. Apparently their successful maintenance may depend on this ability to change and so keep one step ahead of defensive mechanisms which the host may also develop.

Cancer

It is obvious that the growth of an organism is very accurately controlled. The control mechanism, whatever it is, often breaks down so that

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[1]G. H. Bourne, Cytology and Cell Physiology (2nd Edition, Oxford, 1951) pp. 384-389.

some cells, or malignant cells, escape the control of the organism and just continue to multiply without stopping. These malignant cells form cancers. They not only escape control of the organism, but often infilterate through tissues and find their way into the blood stream or lymph and are then carried to other tissues. Usually death of the organism results from these cells interfering with the work of various tissues or by consuming the available nourishment and so starving the remaining cells.

Numerous theories of the origin of cancer have been proposed, all of which present some facts and observations that give evidence of each theory's validity. These theories may be grouped into three types.

One, the mutation theory which holds that mutations of cells occurs within an organism, and occasionally a new type of cell is formed that escapes the control mechanism of the organism. This new type of cell will invade and replace other tissues of the organism by its continous reproductive ability. These mutations are the results of some chemical substances or radiations.

Two, the virus theory suggests that healthy cells harbour viruses, but it is only when the cell becomes weakened or diseased that the virus can act effectively to produce cancer. It has been suggested that carcinogenic chemicals act in reducing the resistance of the cell, so that the virus already present becomes an effective agent of malfunction.

Third, the metabolic theory holds that the carcinogenic agents are poisons which interfere with the normal mode of life of the cell and permanent alterations are made by the cell in order that it may survive. The change is from the normal to that of cancer and one result of this effort is that cell division is stimulated to an abnormal rate.

Some cancerous growths are due to the interference with flow of oxygen and food materials, others may be caused by continual irritation or the preventions of a wound from healing.

Obviously, the subject of cancer is a large and very complex one and there are many different facets to the whole problem. It is quite possible that cancer is not one phenomenon but many, that different types of cancer have distinct origins. However, it may be that there is a single pattern, the nature of which is still unknown, which underlies the different manifestations.

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VITA

James J. Hancock

Candidate for the Degree of

Master of Science

Report: A SYLLABUS FOR A UNIT ON THE CELL AND ITS LIFE PHENOMENA FOR SECONDARY BIOLOGY

Major Field: Natural Science

Biographical:

Personal Data: Born at Summit, Mississippi, September 5, 1933, the son of Julius and Melba Hancock.

Education: Attended grade school in Meadville and Smithdale, Mississippi; graduated from Mars Hill High School, a rural school in Amite County, Mississippi, in 1950; received the Bachelor of Science degree from Mississippi Southern College, Hattiesburg, Mississippi, with a major in Chemistry, in June, 1955; did graduate work at Louisiana State University during the summer of 1958 and at Mississippi Southern College during the summer of 1959; attended Oklahoma State University during the academic year of 1959-1960; completed requirements for the Masters of Science degree in May, 1960.

Professional experience: Taught general mathematics and algebra in Pike County, Mississippi, 1955-1956; taught general mathematics, algebra, and geometry at Port Gibson, Mississippi, 1956-1957; taught general science, biology, chemistry, and physics at Port Gibson, Mississippi, 1957-1959.

Professional organizations: Member of the National Education Association; Mississippi Education Association; Mississippi Academy of Sciences.