The Integrated Basic Science Course at Kalamazoo Valley Community College

Dorothy Nichols Hackett

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THE INTEGRATED BASIC SCIENCE COURSE
AT KALAMAZOO VALLEY COMMUNITY COLLEGE

by
Dorothy Nichols Hackett

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
Degree of Doctor of Philosophy

Western Michigan University
Kalamazoo, Michigan
August, 1973
ACKNOWLEDGEMENTS

The writer would like to express her gratitude to the members of her Graduate Committee consisting of Dr. George G. Mallinson, Dr. John Josten, Dr. Jean Lawrence and Mr. Dean Tyndall for their time and effort in regard to this investigation.

A particular note of appreciation is extended to Dr. Mallinson and Dr. Josten for their patience, understanding, and confidence which greatly encouraged the author in the attainment of this degree.

A special thought is also extended to the administrative and instructional personnel of Kalamazoo Valley Community College for their cooperation in this effort.

And last, but by no means least, a warm recognition is extended to over 600 students who have participated in the development of the integrated basic science course and for whom it was designed.

Dorothy Nichols Hackett
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# TABLE OF CONTENTS

**LIST OF TABLES** .................................................. v

**CHAPTER**

I  THE COMMUNITY COLLEGE AND ALLIED HEALTH CAREERS .................. 1
   Introduction .................................................... 1
   Education and Training .......................................... 2
   Programs in Two-Year Colleges ................................. 3
   Investigational Objectives ..................................... 6

II ALLIED HEALTH CURRICULA AT KALAMAZOO VALLEY COMMUNITY COLLEGE .. 9
   Introduction ..................................................... 9
   Course Content .................................................. 14

III ANALYSIS OF STUDENT BACKGROUND DIVERSITY AT KALAMAZOO VALLEY COMMUNITY COLLEGE ........................................ 20
   Introduction ..................................................... 20
   Age ............................................................... 21
   Educational Background ......................................... 21
   Curriculum Designations ........................................ 24
   Implications ..................................................... 25

IV DEVELOPMENT OF AN INTEGRATED BASIC SCIENCE COURSE AND A MODULAR APPROACH TO THE CELL BIOLOGY PORTION OF THE COURSE ................. 26
   Introduction ..................................................... 26
   The Integrated Basic Science Course ........................... 28
   Development of the Cell Biology Modules ....................... 30
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>VALIDATIONS, CONCLUSIONS, AND RECOMMENDATIONS</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Validation of the Biological Concept</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Conclusions</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Recommendations</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>BIBLIOGRAPHY</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>APPENDIX A</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>APPENDIX B</td>
<td>48</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5</td>
</tr>
<tr>
<td>II</td>
<td>7</td>
</tr>
<tr>
<td>III</td>
<td>21</td>
</tr>
<tr>
<td>IV</td>
<td>22</td>
</tr>
<tr>
<td>V</td>
<td>23</td>
</tr>
<tr>
<td>VI</td>
<td>24</td>
</tr>
<tr>
<td>VII</td>
<td>24</td>
</tr>
<tr>
<td>VIII</td>
<td>35</td>
</tr>
<tr>
<td>IX</td>
<td>38</td>
</tr>
<tr>
<td>X</td>
<td>39</td>
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</tbody>
</table>

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CHAPTER I

THE COMMUNITY COLLEGE AND ALLIED HEALTH CAREERS

Introduction

The complexity of health care services in the United States has increased dramatically since the turn of the century. In the early 1900's, 97 percent of the 500,000 health care workers were either physicians or dentists, whereas in 1965 these two professions represented only 16 percent of the 2.8 million individuals providing some form of direct health care. The total number of health related workers had approached almost five million by 1970 and were employed under approximately four hundred health occupation titles (Dickinson, 1972). Today, approximately seventy-five billion dollars are spent annually for health care services and, in terms of manpower, this field is the third largest industry in the United States (Simonds, 1973). Reports issued within the last five years by the United States Department of Health, Education, and Welfare estimate that by 1975, there will be a shortage of 189,000 workers in the medical, dental, and environmental health areas and that by 1980, this shortage will have increased to a total of 256,000 (Egeberg, 1971).

The underlying reasons for this rapid expansion of health care workers are numerous and include the lengthened life span, a decrease in infant mortality, an improved control and/or elimination of disease, expansion of private and public health insurance, and broadened public health educational program and the advances in technological knowledge.
These factors have contributed to the population increase by affecting one or more components of the growth rate formula: rate of population growth = birth rate - death rate + migration rate (Marshall, 1972).

The increase in the multiplicity of health care occupations is one of the direct results of the increased specialization caused by the division of labor and responsibilities involved with a team approach for providing total health care services as well as the expansion of technological support services that require trained personnel. The roles of the traditional health professionals, mainly the physicians, dentists, nurses and pharmacists, have changed greatly as responsibilities and functions have been delegated to an increasing number of support categories. This fractionation has resulted in a proliferation of job titles with many of the descriptions duplicating one another.

Over a hundred are presently identified as primary health careers and almost three hundred designated as secondary, or related health occupations (Egleston, 1972).

Education and Training

Traditionally, the hospital program has been the major, if not the only, method of training health personnel for jobs that did not require the baccalaureate degree. However, the increasing diversity and degree of sophistication now required in each of the various health fields has forced hospitals within the last decade to relinquish their dominant role to one of dual responsibility with outside educational institutions. A direct result of this action has been the accelerated development of university and two-year education programs (Macpherson, 1971).
In addition to the impetus mentioned above, another factor facilitating the involvement of academic agencies is the increasing economic burden of rising educational costs that medical centers are hesitant about passing on to the public in the form of patient costs (Light and Frey, 1973). There has, therefore, been a corollary increase in interest and emphasis concerning the educational programs involved with the continued expansion of allied health curricula, particularly as to where and how they will be implemented. This concern has been demonstrated at the national level in part over the past five years by the Allied Health Professions Personnel Training Act of 1966, the report of the Allied Health Professions Education subcommittee of the National Advisory Health Council in 1967, the formation of the Association of Schools of Allied Health Professions, the Report of the National Advisory Commission of Health Manpower in 1968, and the President's Committee on Health Education in 1971 (Volker, 1971).

A major trend noted within the above publications is an increase in the number of those health care careers available to individuals educated and trained with less than a baccalaureate degree. This has been supported by an increase in federal funding of disciplines at the Associate Degree level. The commitment of two-year colleges to the training of health personnel has grown by 165 percent between 1967 and 1970, whereas the senior college involvement increased by 38 percent, indicating the greater impact of the Associate Degree education as the major factor in the preparation of health care workers (Connelly, 1972).

Programs in Two-Year Colleges

An extensive directory of allied health programs in two-year educational institutions was compiled by the American Association of
of Junior Colleges for the Division of Allied Health Manpower, Bureau of Health Manpower Education, National Institutes of Health, Education, and Welfare, under the Contract No. NIH 70-4125 (DHEW, 1972). This endeavor encompassed the first coordinated attempt to provide a comprehensive compendium of programs involved with allied health education in operation at that time (1970-71) as well as an organization of predictive data on future programs then being planned and/or anticipated.

Information for the compendium was obtained by questionnaires sent to all of the 1,038 community colleges listed in the 1970 Junior College Directory and returned by 1,030. Seven hundred eight of the colleges that responded indicated that they offered one or more allied health occupation programs, or planned to initiate one or more new programs within a five-year period.

Table I, page 5 indicates the types and numbers of programs in operation during the 1970-71 school year and the additional programs expected to be in full operation by 1975. Because of the multiplicity of job titles and job descriptions of respondents, those compiling the compendium arbitrarily grouped them into fourteen categories (Appendix A) and excluded short term programs, mainly those with less than eight months duration, and aide-level education.

From the information contained within Table I, condensed by this author from the compendium, it can be seen that community colleges are planning to expand rapidly their curricula in the area of allied health education. There is an anticipated growth from 1591 programs to 2387 programs in five years. These figures, of course, do not take into...
consideration the formation of programs by schools not indicating a future involvement in 1970, or the establishment of new community colleges and any programs they may initiate before 1975.

TABLE I. The Type and Number of Allied Health Educational Programs Present in 1970 and Additional Programs Predicted for 1975.

<table>
<thead>
<tr>
<th>Categories*</th>
<th>Programs in 1970</th>
<th>Additional by 1975</th>
<th>Percent Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative Services</td>
<td>12</td>
<td>17</td>
<td>140</td>
</tr>
<tr>
<td>Biomedical Engineering and Instrumentation</td>
<td>6</td>
<td>17</td>
<td>283</td>
</tr>
<tr>
<td>Dental Services</td>
<td>210</td>
<td>98</td>
<td>41</td>
</tr>
<tr>
<td>Environmental Control</td>
<td>24</td>
<td>56</td>
<td>230</td>
</tr>
<tr>
<td>Emergency Services</td>
<td>1</td>
<td>6</td>
<td>600</td>
</tr>
<tr>
<td>Laboratory Services</td>
<td>123</td>
<td>79</td>
<td>64</td>
</tr>
<tr>
<td>Medical Records and Office Services</td>
<td>247</td>
<td>94</td>
<td>38</td>
</tr>
<tr>
<td>Mental Health and Psychiatric Services</td>
<td>64</td>
<td>54</td>
<td>84</td>
</tr>
<tr>
<td>Medical Care Assistants</td>
<td>92</td>
<td>73</td>
<td>79</td>
</tr>
<tr>
<td>Miscellaneous Services</td>
<td>14</td>
<td>23</td>
<td>164</td>
</tr>
<tr>
<td>Nursing Services</td>
<td>661</td>
<td>139</td>
<td>21</td>
</tr>
<tr>
<td>Optical and Visual Care</td>
<td>10</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>Radiological Services</td>
<td>105</td>
<td>64</td>
<td>60</td>
</tr>
<tr>
<td>Rehabilitation Services</td>
<td>46</td>
<td>63</td>
<td>137</td>
</tr>
<tr>
<td>Totals</td>
<td>1591</td>
<td>796</td>
<td></td>
</tr>
</tbody>
</table>

*For detailed explanation of categories, See Appendix A.
Estimates of the number of graduates in 1975 are not available. However, Table II (page 7) indicates a dramatic increase in the number of personnel trained at the community college level within one year. By combining the inferences of the increasing number and types of programs offered by community colleges with the rising number of graduates from these programs, it is obvious that the two-year educational institutions are going to continue to exert a major influence in the training of those individuals entering the health care occupations.

It is common knowledge that the two-year institutions have a unique contribution to make in that they basically have more understanding of, and are far more interested in, the teaching of occupation-related skills than do four-year institutions. Also, they are aware of the emphasis needed to use methods of instruction by which employable skills can be taught easily and effectively to a large number of students. The community colleges have thus assumed a dual responsibility by enlisting the support of health professionals and cooperation of hospital staffs to provide career opportunities for students entering the health care professions.

Investigational Objectives

Multiple problems arise from the rapid expansion of community college health care curricula even though they are better equipped than the traditional hospital programs, both physically and philosophically, to handle the diversity of educational techniques. A major element contributing to one of these problems, instructional difficulties, is the adherence of public supported two-year colleges to an educational
TABLE II. The Number of Graduates in 1970 and the Estimated Number of Graduates for Each Category for 1971.

<table>
<thead>
<tr>
<th>Categories*</th>
<th>Graduates 1970</th>
<th>Estimated 1971</th>
<th>Percent Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative Services</td>
<td>5</td>
<td>90</td>
<td>1800</td>
</tr>
<tr>
<td>Biomedical Engineering and Instrumentation</td>
<td>21</td>
<td>28</td>
<td>133</td>
</tr>
<tr>
<td>Dental Services</td>
<td>2,957</td>
<td>4,144</td>
<td>140</td>
</tr>
<tr>
<td>Environmental Control</td>
<td>6</td>
<td>8</td>
<td>133</td>
</tr>
<tr>
<td>Emergency Services</td>
<td>62</td>
<td>193</td>
<td>311</td>
</tr>
<tr>
<td>Laboratory Services</td>
<td>918</td>
<td>1,366</td>
<td>149</td>
</tr>
<tr>
<td>Medical Records and Office Services</td>
<td>348</td>
<td>790</td>
<td>228</td>
</tr>
<tr>
<td>Mental Health and Psychiatric Services</td>
<td>2,140</td>
<td>2,773</td>
<td>129</td>
</tr>
<tr>
<td>Medical Care Assistants</td>
<td>367</td>
<td>872</td>
<td>237</td>
</tr>
<tr>
<td>Miscellaneous Services</td>
<td>123</td>
<td>154</td>
<td>125</td>
</tr>
<tr>
<td>Nursing Services</td>
<td>17,512</td>
<td>22,746</td>
<td>130</td>
</tr>
<tr>
<td>Optical and Visual Care</td>
<td>85</td>
<td>91</td>
<td>107</td>
</tr>
<tr>
<td>Radiological services</td>
<td>508</td>
<td>1,011</td>
<td>200</td>
</tr>
<tr>
<td>Rehabilitation Services</td>
<td>260</td>
<td>484</td>
<td>186</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>23,312</strong></td>
<td><strong>34,750</strong></td>
<td></td>
</tr>
</tbody>
</table>

*For detailed explanation of categories, see Appendix A.

philosophy that incorporates the concept of open admission to any educable individual who is eighteen years of age regardless of previous educational attainment (Clark, 1968).
If all educable students are to be admitted, a means must be developed to handle efficiently the varied backgrounds of those entering the allied health fields. The challenge to both the institution and the individual instructor is one of jointly delivering a combination of learning situations that will increase student competencies without lowering educational and training standards while allowing the flexibility of advanced placement when necessary. Two-year institutions are therefore energetically seeking more effective methods by which varied employable skills can be taught to a large number of students with diverse backgrounds.

The aim of the investigation reported here is to demonstrate the rationale leading to, and the development of, a modular approach in a basic integrated science course as one possible answer to the challenge of preparing health care workers at one two-year institution, that of Kalamazoo Valley Community College located in Kalamazoo, Michigan. This paper will, therefore, concentrate on several aspects of the total problem including (1) the diversity of backgrounds found in students entering any one of the four allied health curricula offered at the college; (2) the rationale and design of the integrated basic science course; (3) the writing of twelve core modules complete with learning objectives, text, glossary and programmed self-test to eliminate any, or several, student incompetencies in the area of cell biology; and (4) the validation of the twelve core concepts with respect to their relevance in future course work.
CHAPTER II

ALLIED HEALTH CURRICULA AT KALAMAZOO VALLEY COMMUNITY COLLEGE

Introduction

Kalamazoo Valley Community College was organized by a vote of the Kalamazoo Valley Intermediate School District in August of 1966 and opened its doors to the first class of 1,500 students in September of 1968. Two years later, the college became involved in the preparation of allied health care workers when it initiated the Associate Degree in both nursing and dental hygiene programs. The latter received final accreditation in 1973, whereas the former will be reviewed for accreditation in 1974. A third area of involvement with health care curricula involved a program that was initiated in 1971 for training medical office assistants. Inhalation Therapy training has just recently been added to the health curricula under the title of Respiratory Therapy following the completion of agreements with respect to academic training at the college and clinical training at the two local clinical facilities, Borgess Hospital and Bronson Methodist Hospital.

The nursing program was expanded during the 1972-73 school year to include the training of licensed practical nurses, an educational function formerly fulfilled by the Kalamazoo Public School system. A unique idea of career ladder education has been incorporated into the planning of the related nursing fields by the arrangement of course requirements. A one year licensed practical nurse would no longer lose credits when registering for the second year of study leading to the Associate Degree of Nursing.
A fifth allied health related area is presently being contemplated by Kalamazoo Valley Community College involving the training of medical laboratory technicians. This program would not only prepare individuals for immediate job procurement in a supervised laboratory situation, but would also be designed to facilitate transfer status at the baccalaureate level without loss of credits, to a four-year university in a program leading to a degree in Medical Technology.

The course requirements for each allied health area now offered at Kalamazoo Valley Community College will be described in order to enhance understanding of the rationale for developing an integrated basic science course and incorporating it into each of the programs as a core prerequisite. Only those courses that are directly related to a science discipline and/or to the technical allied health education will be included in the following survey.

Dental Hygiene

The overall purpose of this program is to educate men and women to provide dental health care services to the public. These students are trained to provide such services in private dental offices, civil service positions, school programs, and various public health fields. Upon completion of formal training, the graduates must pass a State Board Examination for licensure as registered dental hygienists. The curriculum includes the following science related and technical courses.

Related Courses:

- Chemistry 100: Foundations of Chemistry
- Biology 105: Microbiology
- Biology 106: Anatomy and Physiology
- Biology 107: Head and Neck Anatomy
- Food Service 102: Nutrition and Diet
Technical Courses for Dental Hygiene (DHY):

DHY 101: Oral Morphology and Histology
DHY 102: Dental Roentgenology
DHY 110: Clinical Dental Hygiene I
DHY 120: Clinical Dental Hygiene II
DHY 201: Dental Materials
DHY 204: Oral Embryology and Oral Pathology
DHY 206: Pharmacology and Anesthesiology
DHY 210: Clinical Dental Hygiene III
DHY 220: Clinical Dental Hygiene IV
DHY 260: Public Health Dental Hygiene

Medical Office Assistant

The graduate of this program should be well versed not only in standard office practices and business principles, but also in medical terminology and basic scientific principles in order to implement a wide range of tasks in assisting the contemporary physician. They must be qualified to perform those duties involved with scheduling and receiving patients; obtaining patient information; maintaining medical records; handling correspondence and telephone calls; and assume responsibility for office care, accounts, fees, and collections. Their medical duties would also include assisting with examinations and treatments; taking medical histories; performing certain diagnostic tests, carrying out laboratory procedures that can be done in a physician's office; and sterilizing instruments and equipment. A sufficiently qualified medical assistant may also be responsible for personnel and/or office management.

Related Courses:

Biology 106: Anatomy and Physiology

Technical Courses for Medical Office Assistant (MOA):

MOA 100: Medical Office and Medical Laboratory I
The two nursing programs are offered in a career ladder format. Each nursing program prepares men and women to function under the supervision of a professional nurse, psychologist, physician, dentist, or Board of Education to provide direct nursing care to patients in schools, hospitals, and other health care agencies. Each program provides classroom instruction in laboratory facilities on campus and clinical experience under the guidance of the nursing faculty in hospitals and other health agencies in the community.

The first-year program is designed to train students as licensed practical nurses. Graduates of the first-year program will be eligible to take the State Board Examination for practical nurses.

Related Courses:

Biology 105: Microbiology
Biology 106: Anatomy and Physiology

Technical Courses for Nursing Students (NRG):

NRG 101: Foundations of Nursing
NRG 102: Obstetrics and Pediatric Nursing
NRG 103: Medical and Surgical Nursing
NRG 104: Pharmacology
NRG 105: Clinical Nursing (LPN students only)

The second year of the nursing program prepares students as registered nurses. Upon completion of the second year of the curriculum the student receives the Associate Degree and is thereby eligible to take the State Board Examination for registered nurses.

Related Courses:

Biology 210: Human Physiology
This program has recently been developed jointly by the college and the two local medical facilities, Borgess Hospital and Bronson Methodist Hospital. All academic training will be made available at the college and all clinical training will be available at one of the above hospital facilities. Completion of the curriculum prepares the student to take the American Medical Association examination to become a Certified Respiratory Therapist Technician, the first level of certification. A second phase of training, leading to registry as an Inhalation Therapist, is not presently offered at Kalamazoo Valley Community College and students must finish this work at Washtenaw Community College.

As this curriculum has just been organized, the related science and technical courses listed below do not have course numbers. The learning objectives and subject matter of each area will determine whether it will be developed as a separate class or whether an existing course will suffice.

**Related Courses:**
- Anatomy and Physiology
- Microbiology
- Pharmacology

**Technical Courses**
- Nursing Arts
- Medical Terminology
- Inhalation Therapy: Respiratory and Pulmonary Function Testing
In order to describe the diversity of scientific and technical knowledge represented within the above curricula, it is appropriate to discuss briefly the content for each of the courses listed. Those related and technical courses outlined for the Respiratory Therapy curriculum will be omitted as the course content has not yet been finally determined.

BIOLOGY 105: Microbiology. An introductory course that includes the morphology, physiology, reproduction and importance of microscopic organisms. Techniques used in identification and control of bacteria and fungi are emphasized in the laboratory.

BIOLOGY 106: Anatomy and Physiology. A detailed study of man from the standpoint of structure and function of body systems. Emphasis is placed on the normal and abnormal conditions of these systems. Laboratory activities include the study of human materials as well as comparative studies of other vertebrate animals.

BIOLOGY 107: Head and Neck Anatomy. A detailed study of the cephalic region of man in terms of structure and function. Laboratory time emphasizes the structural interrelationships found among the major systems of this area.

BIOLOGY 210: Human Physiology. An in-depth presentation of the functions of human systems from the cellular level to the total individual with emphasis on chemical coordination and cybernetic systems.
Laboratory activities deal mainly with techniques used to differentiate between normal and abnormal metabolism.

CHEMISTRY 100: Fundamentals. Basic chemical concepts of inorganic, organic, and biochemistry. Atomic structure, chemical bonding, and molecular structure are emphasized. The laboratory consists of conducting basic experiments while learning a variety of chemical techniques.

FOOD SERVICE 102: Nutrition and Diet. A study of the nutritional needs of man and the foods necessary to supply those needs. The major dietary foods are studied as well as the metabolic requirements for vitamins and trace elements.

DENTAL HYGIENE 101: Oral Morphology and Histology. A study of the anatomy of the oral cavity including the development, function and structure of the teeth. Laboratory includes the identification, sketching, and carving of individual teeth as well as a microscopic study of the development of teeth and surrounding supportive structures. Reproductions of teeth are made by building up the various structural components in wax.

DENTAL HYGIENE 102: Dental Roentgenology. A series of demonstrations and laboratory activities concerning the application of X-rays for dental diagnostic purposes. Content includes the electrophysics of the apparatus, radiation safety, positions of the films, regulation of the machine, and the developing processes.

DENTAL HYGIENE 110: Clinical Dental Hygiene I. Theoretical background is used to support those procedures to be performed during clinical experience. The student is introduced to the use of instruments in providing diagnostic, preventive, and therapeutic health care services.
DENTAL HYGIENE 120: Clinical Dental Hygiene II. A continuation of Clinical Dental Hygiene I with an introduction to additional procedures. The lecture portion of the course concentrates on the study of preventive dentistry techniques and dental health education.

DENTAL HYGIENE 201: Dental Materials. A study of the theory and manipulative skills associated with materials used in dental practice.

DENTAL HYGIENE 204: Oral Embryology and Pathology. A detailed study of the embryologic development of the oral cavity and the classification of abnormal conditions with an emphasis on etiology.

DENTAL HYGIENE 206: Pharmacology and Anesthesiology. Course content includes a study of drugs and anesthetic agents with special emphasis on those used in a dental office. The student learns the origin of drugs and anesthetics, their physical and chemical properties, preparation, methods of administration and effects upon the body systems.

DENTAL HYGIENE 210: Clinical Dental Hygiene III. Lecture-seminar material emphasizes the relationship of the dental hygienist to the public and employer while continuing to learn additional clinical procedures. The clinical portion of this course is a continuation of Dental Hygiene 110 and 120.

DENTAL HYGIENE 220: Clinical Dental Hygiene IV. Lecture-seminar material concentrates on the dental specialties, general practice of dentistry and the care of patients with special conditions. Clinic is an extension of Dental Hygiene 210.

DENTAL HYGIENE 260: Public Health Dental Hygiene. The student applies the clinical skills and knowledge of preventive dentistry in extending dental health care services to the community in hospital and school situations. The student also designs and implements a community-oriented control program.

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MEDICAL OFFICE ASSISTANT 100: Medical Office and Medical Laboratory I. A course that presents the clinical procedures that are commonly performed in the physician's office. Experiences included are the recording of temperature, pulse, respiration, electrocardiogram and X-ray, blood sampling and screening, urine examination, basal metabolism tests, sterilization techniques and the growth and examination of bacterial cultures.

MEDICAL OFFICE ASSISTANT 201: Medical Terminology. A study dealing with the terminology of various health fields with a concentration on word-building, using programmed texts, visual slides and audio tapes to facilitate identification, spelling, pronunciation and definitions.

MEDICAL OFFICE ASSISTANT 204: Medical Ethics and Legal Responsibilities. A study designed to acquaint the student with the legal aspects and ethical responsibilities of a health care career.

MEDICAL OFFICE ASSISTANT 210: Medical Office and Medical Laboratory II. A continuation of Medical Office Assistant 100.

MEDICAL OFFICE ASSISTANT 212: Medical Office Externship. An on-the-job experience under the supervision of a physician's office.

NURSING 101: Foundations of Nursing. A course designed to establish a foundation for future clinical assignments. Emphasis is placed on learning for mastery the techniques and skills required for health care service. Includes selected clinical experiences in an Extended Care Facility.

NURSING 102: Obstetric and Pediatric Nursing. The student is introduced to the concepts of the child-birth cycle, growth and development from birth to school age, anatomy and basic physiology.
related to pregnancy and nursing, and the care of the well mother and child and the mother and/or child who is ill. The clinical portion of this course is in various community facilities.

NURSING 103: Medical and Surgical Nursing. A continuation of Nursing 101 designed to develop an increased mastery of the techniques and skills necessary for the nurse practitioner to provide safe health care services. Instruction will include basic pharmacology, nutrition and diet therapy. Clinical experience is included.

NURSING 104: Pharmacology. Course content gives the student an insight into the actions of drugs, increases the level of understanding the various disease states, and teaches techniques of drug administration.

NURSING 105: Clinical Nursing. Provides additional practice in nursing for those students working to achieve the career of Licensed Practical Nurse.

NURSING 201: Advanced Medical and Surgical Nursing. Emphasis in this course is placed upon mastering advanced technical skills, learning the pathophysiology of disease processes, and acquisition of the ability to assess the medical and/or surgical needs of a patient.

NURSING 202: Team Leadership. A course that introduces the student to the principles of leadership, management, organization, planning and interpersonal relations of the profession.

NURSING 203: Advanced Maternal and Child Health Nursing. An extension of Nursing 102 that includes advanced technical maternal and pediatric skills and pathophysiology.
NURSING 204: Advanced Psychiatric Nursing. The student is acquainted with current therapeutic techniques associated with psychological disorders.

From the above course descriptions, it is apparent that a diversity of scientific knowledge and technical skills does exist between, as well as within, each of the health care curricula. This diversity, however, rests upon fundamental scientific and mathematical concepts that together form a basic core of knowledge. An integrated basic science course, developed to incorporate this necessary foundation, would serve as a prerequisite for each of the health areas. Such a course could serve several functions including the presentation of basic concepts necessary for the more specialized coursework and clinical experiences as well as providing a means of determining student competency upon entering one of the health curricula.
CHAPTER III

AN ANALYSIS OF STUDENT BACKGROUND DIVERSITY AT KALAMAZOO VALLEY COMMUNITY COLLEGE

Introduction

Because of the open admission policy at Kalamazoo Valley Community College, it became apparent that criteria had to be established for the differential treatment of applicants for one of the allied health curricula based on student need. By implementing the above admission policy, the college could no longer use prior educational status and personal interviews, subjective at best, to determine eligibility for a particular health care career.

Before examining in detail the system that was developed for building student competencies (Chapter IV), an analysis of the diversity of student backgrounds that contribute to instructional difficulties in the various curricula seems appropriate. The data for the analysis were collected from those students who indicated their intentions to pursue a health care career during the 1972-73 school year. The information included sex, age, and science and mathematical backgrounds of the enrollees in three sections of an integrated basic science course, and whose names appeared on the final class lists. The total number of students involved was 282 with 129, 87, and 66 in Sections 134, 718, and 826 respectively. Sections 134 and 826 were taught during the day, whereas Section 718 was a community service night class.
Age

Table III (page 21) gives the distribution of ages of the enrollees in each of these three sections. The data in the Table indicate that approximately 43% of those students anticipating enrollment in an allied health curriculum are older than those who typically comprise the college student population. This figure rises to 50% if the non-respondents are eliminated from the computation. The students past the age of 31 comprise 15% (17% if non-respondents are eliminated), and those 42 or older, 5% (6% if non-respondents are eliminated) of the total group. Section 718 has a higher percentage of older students than does Section 134 and 826. This could be expected since it was offered as a night class.

**TABLE III. The Distribution of Age Groups by Class Section for Students Entering Allied Health Curricula During 1972-73.**

<table>
<thead>
<tr>
<th>Section</th>
<th>17-21</th>
<th>22-26</th>
<th>27-31</th>
<th>32-36</th>
<th>37-41</th>
<th>42-46</th>
<th>47+</th>
<th>No Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>65</td>
<td>20</td>
<td>12</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>718</td>
<td>27</td>
<td>21</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>826</td>
<td>30</td>
<td>15</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>122</td>
<td>56</td>
<td>24</td>
<td>17</td>
<td>9</td>
<td>9</td>
<td>6</td>
<td>39</td>
</tr>
</tbody>
</table>

**Educational Background**

All students were asked to indicate their previous science and mathematical backgrounds prior to enrollment in the basic integrated science course. A checklist system was used to elicit information
about the number of high-school classes the students completed in the areas of biology, chemistry, physics, general science and mathematics. A similar system was used to obtain information about a college course the students had elected in either of these fields.

TABLE IV. Numbers of Courses in High-School Science Elected by Students Entering Allied Health Curricula During 1972-73

<table>
<thead>
<tr>
<th>Section</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>No Response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>10</td>
<td>30</td>
<td>37</td>
<td>26</td>
<td>11</td>
<td>15</td>
<td>129</td>
</tr>
<tr>
<td>718</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>87</td>
</tr>
<tr>
<td>826</td>
<td>10</td>
<td>12</td>
<td>22</td>
<td>12</td>
<td>7</td>
<td>3</td>
<td>66</td>
</tr>
<tr>
<td>Totals</td>
<td>37</td>
<td>59</td>
<td>79</td>
<td>69</td>
<td>29</td>
<td>29</td>
<td>282</td>
</tr>
</tbody>
</table>

*Each course is equivalent to one high-school year.

Table IV (page 22) contains data about the science backgrounds of students entering allied health curricula. These data indicate that 13% (15% if non-respondents are eliminated) have never completed a high-school science course, and 21% (23% if non-respondents are eliminated) have completed only one such course, generally a biological or general science requirement for graduation. Only 55% (62% if non-respondents are eliminated) indicated that they had elected two or more high-school science classes.

Mathematical ability is necessary for successful completion of any of the health care programs, not only as a supporting field to science but also as a technical skill relevant to delivering health
services. Table V (page 23) indicates the mathematical backgrounds of the students. The tabulations were made without regard for the mathematical area or content of the course.

The data indicate that 19% (21% if non-respondents are eliminated) of the subjects had not elected any mathematics in high school, 27% (31% if non-respondents are eliminated) had the preparation of one class, 28% (31% if non-respondents are eliminated) two classes, and only 16% (17% if non-respondents are eliminated) had two or more high school courses. Here again, a wide fluctuation of preparedness is demonstrated for those individuals seeking entrance into an allied health care field.

TABLE V. Numbers of Courses in High School Mathematics Elected by Students Entering Allied Health Curricula During 1972-73.

<table>
<thead>
<tr>
<th>Section</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>No Response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>18</td>
<td>28</td>
<td>43</td>
<td>20</td>
<td>5</td>
<td>15</td>
<td>129</td>
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<tr>
<td>718</td>
<td>18</td>
<td>21</td>
<td>24</td>
<td>5</td>
<td>8</td>
<td>11</td>
<td>87</td>
</tr>
<tr>
<td>826</td>
<td>18</td>
<td>27</td>
<td>12</td>
<td>6</td>
<td>-</td>
<td>3</td>
<td>66</td>
</tr>
<tr>
<td>Totals</td>
<td>54</td>
<td>76</td>
<td>79</td>
<td>31</td>
<td>17</td>
<td>29</td>
<td>282</td>
</tr>
</tbody>
</table>

*Each course is equivalent to one high-school year

Table VI (page 24) indicates the numbers of enrollees who had completed college level courses in both the scientific and mathematical areas. Twenty-two percent had already completed one or more college science course and 6% had experience with some college mathematics prior to entering the allied health fields.
TABLE VI. Numbers of College Courses in Science and Mathematics Elected by Students Entering Allied Health Curricula During 1972-73.

<table>
<thead>
<tr>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>-</td>
<td>5</td>
<td>8</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>718</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>826</td>
<td>12</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Totals</td>
<td>30</td>
<td>17</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>13</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Curriculum Designations

The students were also asked to designate which of the four allied health areas they wished to enter. The information is tabulated in Table VII (page 24). The largest number of students, 60%, indicate a nursing career and 11%, the dental hygiene field. Some students indicated more than one area of interest, and these are listed in the "Not Designated" column.

TABLE VII. Numbers of Students Entering in Different Allied Health Curricula During 1972-73.

<table>
<thead>
<tr>
<th>Section</th>
<th>NRG*</th>
<th>DHY</th>
<th>MOA</th>
<th>RT</th>
<th>Not Designated</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>78</td>
<td>15</td>
<td>7</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>718</td>
<td>53</td>
<td>9</td>
<td>-</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>826</td>
<td>39</td>
<td>7</td>
<td>1</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>Totals</td>
<td>170</td>
<td>31</td>
<td>8</td>
<td>2</td>
<td>75</td>
</tr>
</tbody>
</table>

NRG = nursing, DHY = dental hygiene, MOA = medical office assistant, and RT = respiratory therapy.
Implications

The data in Tables I - VI suggest that each allied health curriculum or for that matter any other, must consider the heterogeneity of students in terms of age and background. This does not mean that educational and technical standards should be lowered to accommodate the diversity. Rather a flexible program must be initiated to aid the individual student to reach a level of competency to help assure acceptable performance in a curriculum. Such a program must also have enough flexibility to enable students already possessing one or many competencies to elect advanced courses without penalty.

The integrated basic science course at Kalamazoo Valley Community College was developed to alleviate student background deficiencies demonstrated above, and incorporates a core of basic knowledge required to successfully complete advanced courses. The necessary flexibility for efficient handling of such a wide range of student abilities is now being realized with the development of a modular approach within the integrated basic science course.
CHAPTER IV

DEVELOPMENT OF AN INTEGRATED BASIC SCIENCE COURSE AND A MODULAR APPROACH TO THE CELL BIOLOGY PORTION OF THE COURSE

Introduction

As previously stated, Kalamazoo Valley Community College initiated two allied health care programs, nursing and dental hygiene, in the Fall, 1970. As both were entirely new endeavors, the selection process used for student entrance into either of the two health curricula was based on a traditional approach to expedite the admission procedure. Student scores on the Minnesota Multiphasic Personality Inventory examination, the New Purdue Reading Test, and standard aptitude tests were evaluated in conjunction with academic backgrounds, personal recommendations and personal interviews. The admission policy then was inconsistent with the college's support of open admission. This anomaly was one of the major reasons, coupled with factors mentioned later, that precipitated the development of student selection procedures based mainly on competency levels.

The first year of instructional experience with the health curricula revealed a number of problem areas concerning student readiness to pursue scientific and/or technical training. Apparently, what appears as a satisfactory background on paper is not always consistent with future achievement or technical performance. The frustration on the parts of the instructors was engendered by their having to teach
materials that might reasonably have been expected to be prerequisite information to a course. Frustrated instructors confuse students concerning expectations, particularly if the students believe they are responsible for knowledge that they never had the opportunity to learn. Instructional difficulties with the two health programs offered at that time can be stated simply in terms of accountability, namely, instructors should be aware of what their students know prior to enrollment to allow adequate preparation for the acquisition of new information or skills; and the student should know what is expected of him in terms of prior attainment and continued achievement.

The combination of these factors, the determination to uphold the open admission policy and the discontinuity of the informational flow from course to course, led to a concerted effort by the administration and allied health instructors to examine what was happening and what might be accomplished to resolve the anomalies. Strict adherence to the open admission policy would undoubtedly add to the instructional difficulties already encountered in advance courses unless an internal criterion was formulated and implemented, to offer each student the opportunity to acquire the competencies necessary for future success. However, such a formulation should not lower educational and technical standards. The heterogeneity of student backgrounds (Chapter III) demanded that the internal program that was established would produce students capable of handling further course work, and also provide opportunities to eliminate incompetencies or demonstrate the prior acquisition of such educational skills.
The major educational concern at this point was one of scientific and mathematical preparedness as the scientific and technical skills of later courses are dependent to a great degree on applying this knowledge. The idea of an integrated basic science course evolved as a possible answer to an internal criterion problem and encompassed the concept of preparing all students equally, but flexibly, to undertake a health career curriculum. The basic aim of such a course as a prerequisite for entrance into a health care area would be to: (1) test those students already possessing the competency level necessary to enter directly into a health care program, (2) provide an opportunity to those students that must acquire the necessary knowledge to eliminate incompetencies in one or more science and mathematical disciplines, and (3) establish a competency criterion on which instructors in health curricula can depend.

The Integrated Basic Science Course

Course Content

The course content for the integrated basic science course was developed on the basis of what instructors in health curricula expected students enrolling into their courses to know. A continuity of knowledge was developed between the content of the basic science course and that of advanced courses in order to eliminate any need for redundancy and to minimize any knowledge gaps. In brief, this continuity was expected to foster a pyramidal concept of what students should learn, why they should learn it, and when they should learn it. The base of the pyramid, the integrated basic science course and its development,
was undertaken by this investigator as a team member to formulate the essential biological concepts to be included within the course content.

The course content integrates the principles of mathematics, physics and chemistry for the first half of the semester and the concepts of cell biology the second, with each area presenting only that information deemed to be essential for future student success. Specific learning objectives were developed for each discipline as the framework on which to build the presentation of information that would accomplish each objective.

Course Design

With the groundwork for the course content established during the Spring, 1971, the operational goal was to offer the course the following summer. This would allow those students entering allied health areas in the Fall, 1971, an opportunity to eliminate any deficiencies prior to that time. The acceptance of any individual into a health curriculum from that time was determined by their demonstrating a competency level in the basic integrated science course. Thus, the college returned to a support of the open admission policy by instituting an internal control of admission and the opportunity to meet it.

The basic design and purpose of the total course has not changed since its inception although the instructional methodology for the biology half has evolved from a lecture and textbook format to one of module use. A pretest is administered during the first class session so that both the instructor and the individual student can assess the student's backgrounds and determine on what he must concentrate to
achieve his goals. A posttest, similar to the pretest, is used to measure final competency levels. Each examination is comprehensive covering course content that is based on the learning objectives. Each student must attain a score of seventy percent in each of the disciplines as the minimal level of acceptance for entrance into the desired curriculum. If a student attains this score on the pretest, he is excused from the class and enters directly into a health care program. If a student is unsuccessful in meeting the minimum competency level on the posttest, he receives an incomplete in the course and may repeat a similar examination at a later date.

The instruction is a team effort led by two faculty members, each responsible for half the course, and the support services of student tutors who are available for individual help in problem areas. Supporting audiovisual aids are available for student use in the Learning Resource Center and definite hours are maintained there by the term tutors.

Development of the Cell Biology Modules

The prime objective of this investigator was the actual development of twelve core concepts that would embody the cellular biology learning objectives as modular units for the second half of the integrated basic science course. The final version of these twelve units appears in Appendix B. The titles follow:

Unit 1: Introduction to Living Systems
Unit 2: Major Biological Molecules
Unit 3: Cell Structure
Unit 4: Cellular Environment and Transport Mechanisms
Unit 5: Energy and Enzymes
Unit 6: Bioenergetics
Unit 7: Integrated Metabolism
Unit 8: The Nucleic Acids
Unit 9: Cell Reproduction: Mitosis and Meiosis
Unit 10: Genetics and Inheritance
Unit 11: Development and Differentiation
Unit 12: Cybernetics

The modular design consists of unit objectives, text presentation of the unit information to support those objectives, a glossary, and a programmed self-test. The learning objectives are used by the student as a framework to relate the new information to and the self-test is used to measure individual progress. The units were tested with students during their development over a period of one school year to obtain and make use of student reactions. The design allows flexibility of use as each unit is a self-contained learning package. Although each unit is a discrete presentation of a basic biological concept, there is a continuity among them by reference when appropriate to interrelated supporting concepts.

With the development of the modular approach to instructional strategy there was a corresponding increase in the options available for a student-oriented learning situation. The student no longer was dependent entirely on taking lecture notes and reading textbooks and references for relevant information. Individual students could now select any one method, or combination of methods that best fit the manner in which they learn. Lecture-discussion schedules are distributed to the class at the first meeting, thereby allowing the student to plan the sessions they will attend on the basis of pretest incompetency areas requiring attention. Lecture-discussion sessions can
now be directly concerned with definite problem areas of concept learning without having to reiterate supporting facts contained within the unit.

Many students do attend all class sessions as a means of reviewing or increasing competency in disciplines in which they have already demonstrated their efficiency. Some students prefer to learn the required information on an individual basis. This option is available as attendance at the lecture-discussion sessions is not mandatory, and individual assistance is available through the team tutors.
CHAPTER V

VALIDATIONS, CONCLUSIONS AND RECOMMENDATIONS

Validation of the Biological Concepts

Throughout the period during which the modules were developed and tested, there was a continuous validation of concepts by the instructors in the health curricula. The concepts originally selected have not changed as a result of this effort, although some may have been modified with respect to depth and manner of presentation. The evaluation process will continue since no course is ever finalized. Every course must be reviewed constantly in terms of updated information, student need, and new instructional methodology to prevent educational stagnation.

Since courses are designed for students, it is only appropriate that students have the opportunity to evaluate their effectiveness in accomplishing their objectives. Graduates of the allied health curricula of the class of 1973 were therefore surveyed to determine the effectiveness of the basic integrated science course in preparing them for advanced course work. These students were members of the first integrated basic science course in Summer 1971.

A total of forty-eight students participated in the survey to validate the biological concepts of the integrated basic science course, and therefore the concepts embodied in the modules developed since that time. Seventeen of the total were completing their work in dental hygiene and thirty-one in the two-year nursing program.
There were no graduates from either the medical office assistant or of the respiratory therapy curriculum because of the recent acquisition of these areas by the college. Each of the students was supplied with a set of the completed modules, asked to review the concepts contained therein, and to ascertain their relevance to coursework of their curriculum.

The students used a code to designate which of the modular concepts were directly essential (++), indirectly essential (+), or not required information (-) for each technical course in their curriculum. The science related courses were evaluated by the same coding system, but as these are more directly supported by the integrated basic science course the learning objectives of each module were used in place of the overall concept. The criterion used to tabulate the results of the student responses was: (1) if there was 80% or better agreement in the validation of either an objective or a biological concept, then that designation was used; and (2) if there was not 80% agreement, then the lower designation of emphasis was used.

Instructors were similarly surveyed for comparing their reactions with student evaluations. Often there is a discrepancy between what the instructor believes the student should know and what the students believe is essential. There was little, if any, disagreement between the results of the two surveys.

Table VIII (page 35, 36, 37) contains the data validating the biological concepts that support the two directly related biology courses, microbiology (105) and anatomy and physiology (106). The remainder of the support courses in science, namely human physiology (210) and head and neck anatomy (107), are extensions of anatomy and physiology and are therefore not evaluated separately.
TABLE VIII. Student Evaluation of Biological Concepts by Learning Objectives That Support Biology Courses.

<table>
<thead>
<tr>
<th>Biological Concept</th>
<th>Unit Objective: To Identify by Name or Description</th>
<th>Course Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction to Living Systems</strong></td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>a) the terms biotic and abiotic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) the characteristics of living systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) the proper sequence of complexity levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) the concept of decreasing cellular independence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) the concept of surface to volume relationships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) the concept of cells as the functional unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Major Biological Molecules</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) the major elements involved in biological molecules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) the sub-unit molecules of macromolecules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) the functional groups of molecular sub-units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) the characteristic bond of macromolecules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) the functions of biological molecules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) the type of chemical reactions in synthesis</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cell Structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) the functional unit of living systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) the cellular location of organelles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) the composition of organelles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) the function of organelles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) the function of non-organelle cell components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) the concept of membrane structure and function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g) the differences between prokaryotic and eukaryotic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>h) the media, or ground substance, of cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cellular Environment and Transport Mechanisms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) the components of the extracellular fluids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) the characteristics of water as a media</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) the influencing factors of the extracellular fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) the process of passive transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) the process of active transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) the concept of phagocytosis and pinocytosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological Concept</td>
<td>Unit Objective: To Identify by Name or Description</td>
<td>Course Number</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Energy and Enzymes</td>
<td>a) the concept of homeostasis and entropy</td>
<td>+ ++</td>
</tr>
<tr>
<td></td>
<td>b) the concept of energy of activation and enzyme activity</td>
<td>+ -</td>
</tr>
<tr>
<td></td>
<td>c) the concept of enzyme mechanism</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>d) the concept of enzyme inhibition</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>e) the major classifications of enzymes</td>
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<td>f) the common forms of energy in biological systems</td>
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<td>g) the high energy compounds and their formation</td>
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<td>h) the oxidation-reduction chain reactions</td>
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<td>Bioenergetics</td>
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<td>b) the major substrate, intermediates and products of anaerobic and aerobic respiration</td>
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<td>c) the major co-enzymes of cellular respiration</td>
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<td>d) the concept of phosphorylation</td>
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<td>e) the organelles involved with bioenergetics</td>
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<td>b) the major products of cellular respiration</td>
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<td>c) the major waste products and their elimination</td>
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<td>d) the limiting factors of cellular metabolism</td>
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<td>b) the differences between DNA and RNA</td>
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<td>c) the process of DNA replication</td>
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<td>d) the three forms of RNA in terms of structure and function</td>
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<td>e) the process of protein synthesis</td>
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<td>f) the organelles involved in protein synthesis</td>
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<td>g) the concept of the genetic code</td>
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<td>Biological Concept</td>
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<td><strong>Cell Reproduction</strong></td>
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<td>a) the five phases of mitosis</td>
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<td>b) the process of meiosis</td>
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<td>c) the structure and function of the spindle apparatus</td>
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<td>d) the stages of gametogenesis</td>
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<td>e) the concept of diploid and haploid cells</td>
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<td><strong>Genetics and Inheritance</strong></td>
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<td>a) the genotypic and phenotypic ratios of a monohybrid cross</td>
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<td>b) the phenotypic ratio of a dihybrid cross</td>
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<td>c) the concept of lethal genes</td>
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<td>d) the gene collaboration and complimentation</td>
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<td>e) genotypic and phenotypic of incomplete dominance</td>
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<td>f) law of dominance and recessive</td>
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<td>g) law of independent assortment and segregation</td>
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<td>h) the concept of linked genes</td>
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<td>i) the process of crossing over</td>
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<td>j) the basic gene and chromosome mutations</td>
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<td><strong>Development and Differentiation</strong></td>
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<td>a) the contributions of male and female gametes</td>
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<td>b) the role of yolk in early cell division</td>
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<td>c) the principle stages of development</td>
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<td>d) the function of extra-embryonic membranes</td>
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<td>e) the major systems derived from primary germ layers</td>
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<td>f) the five types of tissue and their functions</td>
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<td>g) the basic organ systems and their function</td>
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<td><strong>Cybernetics</strong></td>
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<td>b) the essential abilities of a control system</td>
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<td>c) the components of a control system</td>
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<td>d) the concept of negative feedback</td>
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<td>e) the concept of positive feedback</td>
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<td>f) the components of a neuro-muscular system</td>
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<td>g) the components of a neuro-endocrine system</td>
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<td>h) the components of a cellular system</td>
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<td>Biological Concept</td>
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<td>Introduction to Living Systems</td>
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<td>Major Biological Molecules</td>
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<td>Cell Structure</td>
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<td>Cellular Environment and Transport Mechanisms</td>
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<td>Energy and Enzymes</td>
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<td>Bioenergetics</td>
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<td>Integrated Metabolism</td>
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<td>Cybernetics</td>
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</table>

*Course titles and descriptions are given in Chapter II. Symbols used are explained in text as ++ = directly essential, + = indirectly essential, and - = not required information.
TABLE X. Student Evaluation of Biological Concepts That Support Nursing Courses.

<table>
<thead>
<tr>
<th>Biological Concept</th>
<th>Course Number*</th>
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<tbody>
<tr>
<td>Introduction to Living Systems</td>
<td>101 102 103 104 105 201 202 203 204</td>
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<tr>
<td>Major Biological Molecules</td>
<td>++ ++ + + + ++ - ++</td>
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<td>Cell Structure</td>
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<td>Cellular Environment and Transport Mechanisms</td>
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<td>Integrated Metabolism</td>
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<td>The Nucleic Acids</td>
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<td>Cybernetics</td>
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</tbody>
</table>

*Course titles and descriptions are given in Chapter II. Symbols used are explained in text as ++ = directly essential; + = indirectly essential; and - = not required information.
Table IX (page 37) contains data validating which biological concepts are directly essential (++), indirectly essential (+), or not required information (-) for the technical courses of the dental hygiene curriculum. Table X (page 38) contains data validating the biological concepts in a similar way for the technical courses of the two-year nursing program.

Conclusions

The investigational objectives of this paper were previously stated (Chapter I) and included several aspects of the total problem of community college involvement in training allied health personnel.

A diversity of student backgrounds in prior science and mathematical coursework, both at the high school and college level, has been demonstrated to exist. This heterogeneity of student preparedness results in part from the community colleges support of open admission.

The degree of sophistication required by specialized allied health curricula (Chapter II) rests on fundamental concepts in the science and mathematical disciplines. Thus, the rationale for developing an integrated basic science course and incorporating it as a prerequisite into each of the health programs has been shown to be necessary to more efficiently handle the wide range of student competencies.

The development of the biological modules for the biology portion of the integrated basic science course will allow for increased flexibility in dealing with individual student needs. The validation of the biological concepts originally chosen and developed into discrete learning packages reinforces the rationale underlying the original intentions of the course.
No instructional program is a complete embodiment of perfection to answer all problems and the development and implementation of any educational program involves a great deal of time and effort. However, a need was recognized by the the administration and the instructors of health career courses at Kalamazoo Valley Community College several years previously and with the formulation of the integrated basic science course as the beginning step for all health areas the need has in part been met. With the development of the biological modules as core concepts pertaining to that course increased flexibility may be now available to answer that need more efficiently. A student-oriented program has been established to allow entrance into a health career by competency and has provided the opportunity to students to achieve this goal.

Recommendations

Future investigations should be carried out to determine if the modular approach to learning is more effective in terms of student achievement than the traditional lecture-discussion and textbook format. This could now be examined in regards to this course as the modules have been completed for the biology portion. The mathematical, physical and chemical concepts are presently being formulated into modules, and when completed, a total course evaluation will be in order.

It is anticipated that the increased flexibility of modular instruction will more efficiently serve the needs of the various health curriculum presently offered at Kalamazoo Valley Community College as well as any new programs that may be added. Each student will then be able to undertake an individualized course of any combination of modules that fits his particular needs in terms of competency and goals.
BIBLIOGRAPHY


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Simonds, Scott K., "President's Committee on Health Education". Hospitals, J.A.H.A., III, (March 1, 1973), 54-59.

APPENDIX A

A brief description of the 14 major Allied Health categories designated by the American Association of Junior Colleges to group numerous job descriptions under similar titles.

ADMINISTRATIVE SERVICES: These are supportive, managerial and administrative services in institutions and facilities where health care is rendered. Two minor categories:

1. Health administrative assistant - representative college program titles are ward clerk, hospital unit manager, health facilities management.
2. Nursing home administrator - representative program titles are long-term care administration, health care management.

BIOMEDICAL ENGINEERING AND INSTRUMENTATION SERVICES: Persons who service, maintain, operate, and/or repair medical equipment and instruments that are designed to supplement or support body functions, and which are used in diagnostic and/or therapeutic procedures, are prepared in programs of this group. Three minor categories:

1. Biomedical engineering technician - a representative program title is electro-medical technology.
2. Electro-encephalography technician.

DENTAL SERVICES: Occupations in these services prepare persons to assist dentists in varieties of dental practice activities and/or to fabricate dental prosthetic and orthotic devices. Four minor categories:

1. Dental assistant
2. Dental equipment repair technician
3. Dental hygienist
4. Dental laboratory technician

EMERGENCY SERVICES: Programs in this group prepare students to administer medical emergency care, transport the sick and injured, and
and assist professionals in emergency and intensive care units of hospitals. Two minor categories:

1. Medical emergency aide - representative program titles are emergency vehicle attendant, ambulance attendant.
2. Medical emergency technician.

ENVIRONMENTAL CONTROL SERVICES: Occupational tasks in these services range from pollution control and surveillance of food, water, and air resources to monitoring environments and activities where ionizing radiation is in use. Three minor categories are:

1. Environmental science aide - representative program titles are solid waste management, environmental health assistant.
2. Environmental science technician - representative program titles are pollution abatement technology, air and water control technology, environment health engineer.
3. Radiological health technician - a representative program title is radiation safety.

LABORATORY SERVICES: Career programs in this group include a variety of specialties and sub-specialties which require knowledge and skill in clinical laboratory procedures. Five minor categories are:

1. Cytotechnologist
2. Histology/cytology technician
3. Medical laboratory assistant - a representative program title is certified laboratory assistant
4. Medical laboratory technician
5. Medical technologist

MEDICAL CARE ASSISTANTS: Under this category are programs which prepare personnel to provide assistance to clinical specialists (orthopedists, pediatricians, surgeons). Eight minor categories are:

1. Cardiovascular technician
2. Dialysis technician - a representative program title is nephrology technician
3. Inhalation therapist - representative program titles are respiratory therapy, inhalation therapy technology
4. Intravenous technician
5. Orthopedic assistant
6. Physician's assistant
7. Podiatric assistant
MEDICAL RECORDS AND OFFICE SERVICES: Programs in this group train health workers to prepare or maintain health records and to provide clerical support. The group includes secretarial assistants who work under the direct jurisdiction of physicians and dentists (in their offices) as well as technicians who analyze, code, file and/or transcribe medical records in health institutions. Three minor categories are:

1. Medical office assistant - representative program titles are administrative and/or clinical medical assisting, medical assisting, office services, medical and dental.
2. Medical records technician
3. Medical secretary

MENTAL HEALTH AND PSYCHIATRIC SERVICES: Programs in this group prepare practitioners to assist professional personnel in the care of patients with mental or psychiatric disorders in agencies rendering out- or in-patient care. Three minor categories are:

1. Mental health assistant
2. Mental retardation specialist
3. Psychiatric aide

MISCELLANEOUS SERVICES: In this category are programs that prepare personnel to function as assistants in a variety of supportive services such as dietary, institutional pharmacy, geriatric, biomedical photography, and veterinary services. Five minor categories are:

1. Dietary technician
2. Geriatric assistant
3. Medical photographer
4. Pharmacy technician
5. Veterinary technician

NURSING SERVICES: These are professional nursing and supportive services. Five minor categories are:

1. Home health aide
2. Licensed practical nurse
3. Nursing aide
4. Registered nurse
5. Surgical technician

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OPTICAL AND VISUAL CARE SERVICES: Under this group are programs for personnel who assist ophthalmologists and/or optometrists with specialized procedures. In addition to these are careers for personnel who assist with corrective eye exercises, who fill prescriptions for corrective lenses or corrective contact lenses. Two minor categories are:

1. Optician - representative program titles are ophthalmic dispensing, ophthalmic optics, opticianry
2. Vision care technician - representative program titles are orthoptists, ophthalmological assistant, optometric technician

RADIOLOGICAL SERVICES: These occupations and careers prepare personnel who expose, develop, and critique diagnostic X-ray films, and who assist in therapeutic procedures requiring radio-isotopes or radiation. Three minor categories are:

1. Nuclear medicine technician
2. Radiation therapy technician
3. Radiologic technician - a representative program title is X-ray technician

REHABILITATION SERVICES: These are careers in which personnel assist professionals in the administration of therapeutic and rehabilitative procedures designed to restore patients to optimum activity levels. Six minor categories are:

1. Occupational therapy assistant
2. Physical/occupational therapy assistant
3. Physical therapy assistant
4. Prosthetic/orthotic technician
5. Recreational therapy technician
6. Speech and hearing technician

The primary source authority in determining whether a reported program was indeed an allied health program was the Division of Allied Health Manpower and consultant groups from the Environmental Protection Agency, Division of Nursing, Division of Dental Health, and the National Institute of Mental Health. For instance, the NIMH distinguishes
the psychiatric aide as one which is trained specifically to work in
an institutional setting where psychiatric care is rendered in contrast
to the mental health worker who works with psychiatrists and psycho-
logists in clinics or offices.

Many programs reported to be allied health programs were not
included in the Directory because no specific health training was
indicated in the program descriptions. Samples of these are child
care training, funeral directing, community work, housekeeping, social
services, and food service management which did not specify dietetic
emphasis or content.
Appendix B

In order to maintain the integrity of each of the twelve biological modular units, they will be page numbered according to individual learning packages.
INTRODUCTION

Unit 1

OBJECTIVES

To identify by name or description from a list:

a) the terms biotic and abiotic
b) the characteristics of living systems
c) the proper sequence of complexity levels
d) the concept of decreasing cellular independence
e) the concept of surface to volume relationships
f) the concept of cells as the functional structural unit of all living systems
INTRODUCTION

Both the living (biotic) and nonliving (abiotic) substances that compose our physical world represent matter and energy in some sort of relationship. You are, of course, familiar with many examples from both the living and nonliving worlds which surround and make up your own existence. You, as an example of the living world, are different from the car you drive or the chair you sit in, which are examples of the nonliving world. Can you define the differences between the biotic and abiotic system? Can you state what "life" is? Both substances are composed of matter and energy, so what makes them differ?

The study of life is called biology. Biology deals with many diverse forms of life, from a unicellular algae to complex multicellular systems such as man. The term "life" or "living" is basically undefinable and it is necessary to describe a living system on the basis of characteristics. Even though life occurs in a multitude of forms and complex arrangements, there are certain underlying concepts which unite all systems into approximately six unifying principles. The following six characteristics of living systems, or life, define the basic principles which unite all of the diverse living systems into an integrated relationship.

ORGANIZATION: Any single entity of a life system is called an organism, a term which indicates that this entity is composed of an organized system. Organization implies a systematic arrangement of parts which contribute to the function of the whole, and indeed, all living systems are composed of functional units called cells. Cells
maintain a specific chemical organization which enables them to main-
tain life sustaining activities.

The cell theory, first put forth in the late eighteen hundreds and since elaborated on, states that:

a) the cell is the functional unit of all living systems; and
b) that all cells arise from pre-existing cells.

METABOLISM: The sum total of all chemical reactions within a living system is termed metabolism. The ability to accomplish complex metabolic chemical reactions is a characteristic of all living systems, and vital for the maintenance of the system through the utilization of energy.

IRRITABILITY: All organisms, or living systems, have the ability to respond to their environment. This characteristic of living systems is known as irritability. Biotic systems must be able to interact within an abiotic environment, and therefore, are dependent upon the ability to respond to any change within their surroundings. Irrit-
ability includes all responses that involve immediate, but usually temporary, reactions to environmental stimuli.

ADAPTABILITY: The change within an organism, or species, due to environmental changes is called adaptation. This type of reaction allows the development of new species in time that show differences from the original population. Adaptation ensures the perpetuation of a type of organism as it responds to environmental changes and is the basic mechanism of the process of natural selection during evolution.

GROWTH: All organisms have the capacity to grow. Growth is defined as an increase in the size and/or number of cells. This characteristic may be expanded to include the concept of development.
You, as a member of the human species, resulted from the growth of one cell to a complex unit composed of billions of cells. This is an example of not only growth, but development as well. Development includes the concept of differentiation, or the fact that cells become specialized as a multicellular organism grows.

REPRODUCTION: The ability to reproduce a like image is essential in all living organisms and allows for the perpetuation of a species in time. Not only must organisms possess this ability, but also the individual cells of a multicellular organism. Reproduction by cells will result in replacing injured and dead cells in a multicellular organism as well as contributing to growth of the total individual.

COMPLEXITY LEVELS

The above six characteristics are encompassed in all living organisms whether they are unicellular or multicellular. Thus, life may be defined by characteristics and not by definition. Knowing the characteristics of living systems does not, however, give us any guide line for creating any sort of order out of the diversity which exists. Knowing that a single cell of algae functions to satisfy our six principles, as well as an elephant, does not explain the complexity of living species that abound in our physical world. A more inclusive framework of creating order out of diversity lies in the concept of complexity levels.

The first level of complexity, or organization, and the simplest in terms of matter is that of the atom. The atom is the smallest particle which retains a unique characteristic of its own. The second level of organization involves the formation of molecules by atoms joined
together by chemical bonds. Smaller molecules form the third level of complexity by joining together in large complexes, or macromolecules. Macromolecules form larger aggregates known as organelles, or cell parts, which unite to form a viable cell. Cells that function together for a common purpose are called tissues, and tissues that function together for a common purpose form organs. Organ systems are the result of organs functioning together for a common purpose and work together for the purpose of maintaining an organism. Each level of complexity encompasses all lower levels into an organized total, in which the whole is more than the sum of all the parts. In viewing biological organization in this manner, death can be considered to be the decomposition of one level into the next lower level, than the next, etc.

The term organism indicates any individual entity capable of independent existence regardless of what level of complexity it encompasses. Amoeba are unicellular organisms which encompass the cell
level of complexity and sponges are organisms which include the development of tissues. Man, as the most complex living organisms, includes all levels of complexity in an organized unit.

To describe any entity as being alive, it must be able to carry out all the functions which characterize life. The first level of complexity which can accomplish all six previously mentioned characteristics is the level of cellular organization. Lower levels, therefore, are considered to be nonliving, which is why a virus is not classified as a living entity. A virus is not capable of maintaining itself without another living cell to sustain it.

A single cell, or unicellular organism, must accomplish all functions of living or perish. Cells that are a part of a multicellular organism become specialized to handle one or more of the necessary functions, but lose the ability to handle the remainder. Specialization, therefore, is a division of labor in which efficiency of operation is increased, but independence of a single cell is reduced. A muscle cell, as an example, is extremely efficient in accomplishing contraction - or the life characteristic of irritability - but has lost the ability to reproduce.

Thus, if the cell is the lowest level of complexity that is considered to be living, and cells compose all higher levels of complexity as the basic unit of life, it is not surprising that all living systems are basically a result of cellular structure and function. Indeed, you are a complex entity of cells working together on the highest level of organization, and therefore, you are a result of cellular actions. How cells accomplish living processes is basic to an understanding of
life, and at the cellular level, function and structure are inter-
dependent and inseparable. It will, therefore, be necessary to under-
stand those lower levels of complexity that lead to cellular existence
before one can understand how cellular existence leads to levels of
higher complexity. Life is a process, and ultimately a cellular one,
and not a static entity that merely exists.

Each level of complexity does not exist in a vacuum, but has an
environment to respond to and interact with, just as you have an external
environment to which you respond and interact with. Cells are funct-

ional units which must receive chemical substances from its environmen
to carry out metabolic reactions and must return the waste substances
of these metabolic reactions to the environment in order to survive.
Cells, therefore, must be able to interact within its environment in
an efficient manner. One important concept regarding this interaction
deals with cell size, and/or cell shape. As any sphere increases in
size, its surface area increases as the square of the radius, and its
volume increases as the cube of the radius. Or in other words, as a
cell becomes larger there is less surface area through which all sub-
stances must pass in proportion to the volume contained within the cell.

The above concept of surface to volume (s/v) relationships will
be a determining factor of cell size, and often cell shape. More
active cells retain a smaller size due to the more favorable surface
to volume relationship. As a cell grows, it will compensate for this
relationship by either dividing into two smaller cells or by reducing
its rate of metabolic activity.
Each cell of a multicellular organism has in reality two areas of responsibility. First, it must maintain itself as a viable functioning unit, or die; and second, it must participate in maintaining the total existence of the organism of which it is a part, for if enough cells fail to function, the organism may die.

GLOSSARY

Abiotic Characterized by the absence of life.
Adaptation The process of organisms adjusting to environmental changes over periods of time.
Atom The smallest whole unit of an element; the smallest substance which retains its own unique characteristics.
Biology The science dealing with the study of living systems.
Biotic Characterized by the presence of life.
Cell The functional and structural unit of living systems.
Development Formation of a multicellular organism from a single cell.
Differentiation Developmental process which permanently modifies cells for specialized functions.
Growth The increase in size and/or number of cells.
Irritability The ability to respond to a stimulus.
Macromolecule A very large molecule composed of hundreds of thousands of atoms.
Metabolism The sum total of all chemical reactions within a cell or organism.
Molecule The smallest unit of elements consisting of more than one atom joined in a chemical relationship.
Multicellular Organisms composed of more than one cell.
Organ A group of tissues that perform one or more particular functions.
Organ system A group of organs that perform one or more particular functions.
<table>
<thead>
<tr>
<th>Organelle</th>
<th>A recognizable cell part specialized for particular functions.</th>
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<tbody>
<tr>
<td>Organism</td>
<td>Any individual capable of independent existence.</td>
</tr>
<tr>
<td>Tissue</td>
<td>A group of cells that perform one or more particular functions.</td>
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<tr>
<td>Unicellular</td>
<td>An organism composed of one cell.</td>
</tr>
</tbody>
</table>

**PROGRAMMED SELF TEST - UNIT 1**

The term biotic refers to those substances which are
- living

The study of living organisms, or living systems is
- biology

Life is defined in terms of its
- characteristics

The basic functional unit of living systems is the
- cell

Cells maintain a specific chemical
- organization

The sum total of all chemical reactions within a living system is called
- metabolism

The ability to respond to environmental stimulus is
- irritability

The change within an organism over a period of time due to environmental stimuli is called
- adaptation

An increase in the size and/or number of cells is called
- growth
The continuation of a species results from the ability to reproduce. The smallest particle which retains a unique characteristic is the atom. Atoms join together to form molecules. A recognizable cell structure, or part, is called an organelle. Organelles are composed of complexes of macromolecules. Tissues that work together for a common purpose are organs. Cell size is going to be limited by the concept of s/v. The substances necessary for cellular existence must pass through the surface area. As a cell grows, the surface area is increased in proportion to cell volume. As cells specialize within a multicellular organism, they lose their independence. Differentiation of cells implies that they become specialized. A multicellular organism is composed of many cells, each accomplishing a limited number of type of functions.
MAJOR BIOLOGICAL MOLECULES

UNIT 2

LEARNING OBJECTIVES

To be able to identify from a list or diagram by name or description

a) the major elements involved in biological molecules
b) the sub-unit, or building block, molecules of macromolecules
c) the functional groups of macromolecular sub-units
d) the characteristic bond of macromolecules
e) the functions of biological molecules
f) the type of chemical reactions involved in synthesis reactions
MAJOR BIOLOGICAL MOLECULES

This unit will be concerned with four fundamental classes of organic compounds found in all living systems. Carbohydrates, lipids, proteins and nucleic acids are macromolecules that function in a variety of ways that are chemically and biologically significant. The structural backbone for these various substances is carbon, to which may be found attached hydrogens and several functional groups. Functional groups are groups of atoms which are usually more chemically reactive than their carbon backbones to which they are attached. Or, in other words, they characterize certain groups of chemical substances and are a determining factor on how a substance will react. The more important functional groups include:

- Methyl group (-CH₃)
- Hydroxyl group (-OH)
- Phosphate group (-H₂PO₄)
- Carbonyl group (-CO)
- Carboxyl group (-COOH)
- Amino group (-NH₂)

The larger macromolecules are composed of relatively smaller substances known as the sub-unit component. These sub-units are 'building block' molecules which have two common aspects: (1) a structural backbone of carbon, and (2) two reactive functional groups that enable it to become linked into a chain of sub-units to form a macromolecule. As
you investigate the properties of the four groups of major molecules, note their differences (functional groups) and their similarities.

CARBOHYDRATES

The class of molecules known as carbohydrates are the most abundant organic substances in living systems. They are composed of carbon, hydrogen and oxygen in the ratio of \((\text{CH}_2\text{O})_n\) where \(n\) is any number. In common terminology they are divided into the starches, large macromolecules, and sugars, smaller molecules which taste sweet. Scientifically, they are classified as monosaccharides (simple sugars), disaccharides (double sugars), and polysaccharides (many sugars).

MONOSACCHARIDES: The sub-unit component, or building block molecules, of carbohydrates are the simple sugars known as monosaccharides and contain an \(n\) number of carbons from three to seven. Monosaccharides are classified according to the number of carbons in the following way:

- **Triose** or 3 carbon monosaccharides = \(\text{C}_3\text{H}_6\text{O}_3\)
- **Tetrose** or 4 carbon monosaccharides = \(\text{C}_4\text{H}_8\text{O}_4\)
- **Pentose** or 5 carbon monosaccharides = \(\text{C}_5\text{H}_{10}\text{O}_5\)
- **Hexose** or 6 carbon monosaccharides = \(\text{C}_6\text{H}_{12}\text{O}_6\)
- **Heptose** or 7 carbon monosaccharides = \(\text{C}_7\text{H}_{14}\text{O}_7\)

The most common monosaccharides utilized in living systems are the trioses as intermediates in metabolism, the pentoses as components of nucleotides, and the hexoses as chemical fuels and building blocks of polysaccharides.

**TRIOSES:** The smallest simple sugars are the trioses, or 3 carbon sugars, which are important intermediates of metabolism. Consideration of the structural arrangement of this class of sugars will point out four characteristics common to all monosaccharides.
(1.) The carbon skeleton is usually unbranched, or in other words, is a straight chain of carbon atoms bonded co-valently to each other:

\[ \text{C}_3 \quad \text{or} \quad \text{C} - \text{C} - \text{C} \]

(2.) Each carbon atom except one is bonded to a hydroxyl functional group (OH⁻):

\[ \text{C} - \text{OH} \quad \text{or} \quad \text{C} - \text{OH} \]

(3.) The carbon atom which does not contain a hydroxyl group contains a carbonyl oxygen (C=O) functional group:

\[ \text{C} = \text{O} \quad \text{or} \quad \text{C} = \text{O} \]

(4.) If the carbonyl oxygen is located on the end carbon the sugar is known as an aldehyde, and if it is located on a carbon other than the end carbon (usually the second carbon) it is known as a ketone. The remainder of the bonding sites available on each carbon atom are filled with hydrogens. Thus, the only two forms which a triose sugar may take are structurally shown as:

\[ \text{CH}_2 = \text{O} \quad \text{CH}_2 = \text{O} \]

\[ \text{aldehyde} \quad \text{ketone} \]

All of the common monosaccharides and disaccharides are named in terms ending in -ose except for the two trioses pictured above. The triose aldehyde is known as glyceraldehyde and the ketone is known as dihydroxyacetone. Both have the same empirical formula of C₃H₆O₃, but each is different due to the arrangement of the atoms in a spatial relationship, and therefore differ in chemical and physical properties, and are isomers (iso = same; meros = parts).
PENTOSES: The two most important pentose sugars in living systems are ribose and deoxyribose, both of which are involved as components of the group of molecules known as nucleic acids. Their structural straight chains are pictured below:

\[
\begin{align*}
\text{ribose} & : \quad \text{HC}=\text{O} \quad \text{CHOH} \quad \text{CHOH} \quad \text{CHOH} \quad \text{CH}_2\text{OH} \\
\text{deoxyribose} & : \quad \text{HC}=\text{O} \quad \text{CHOH} \quad \text{CHOH} \quad \text{CHOH} \quad \text{CH}_2\text{OH} \quad \text{CH}_2\text{OH}
\end{align*}
\]

The two pentoses, ribose and deoxyribose, are not isomers of each other as their empirical formulas are not identical. Deoxyribose is identical to ribose with the exception of an oxygen atom missing on the second carbon.

The pentoses are structurally arranged in two forms. The straight chain as pictured above and the ring structure pictured below. The ring is always formed between the carbonyl oxygen functional group and the next to last hydroxyl functional group, located on carbon number four in this case.

\[
\begin{align*}
\text{(a)} & : \quad \text{HC}=\text{O} \quad \text{CHOH} \quad \text{HCHOH} \quad \text{HCHOH} \quad \text{CH}_2\text{OH} \\
\text{(b)} & : \quad \text{HC}=\text{O} \quad \text{CHOH} \quad \text{HCHOH} \quad \text{HCHOH} \quad \text{CH}_2\text{OH} \\
\text{(c)} & : \quad \text{HOH}_2\text{C} \quad \text{H} \quad \text{OH} \quad \text{OH} \quad \text{OH}
\end{align*}
\]

The structure portrayed in (c) above is usually shortened to the following figure in which each corner of the ring contains a carbon, and each carbon contains a hydrogen and hydroxyl indicated by the lines.
drawn upright:

Carbon number five and the atoms associated with it are included in the shortened version of the ring structure as it is located outside of the actual ring formation.

**HEXOSES:** The empirical formula for a hexose is $C_6H_{12}O_6$. Glucose, fructose, galactose and mannose are all six carbon sugars with an identical empirical formula (isomers) which are arranged differently in space. The hexoses, particularly glucose, are the basic sub-units or building block molecules of the disaccharides and polysaccharides. Hexoses occur in both a straight chain formation and a ring structure. The two hexoses to be considered here are glucose, an aldehyde, and fructose, a ketone.

![Glucose and Fructose Diagram](attachment:image.png)

Notice that the two hexoses, glucose and fructose, form different ring structures due to the fact that the ring is always formed between the carbonyl oxygen (C=O) and the next to the last hydroxyl (OH). Glucose has only one carbon outside of the ring ($^6$) and fructose has two carbons outside of the ring ($^6$ and $^6$).

**DISACCHARIDES:** A disaccharide (double sugar) is formed when two monosaccharides are joined together in a chemical bond characteristic of carbohydrates known as a *glycosidic* bond. The process is known as
a condensation chemical reaction as a molecule of water is eliminated as the glycosidic bond is formed. For example, the disaccharide known as maltose is synthesized from two glucose molecules:

\[
\text{glucose} + \text{glucose} \rightarrow \text{Maltose} + \text{water}
\]

Other than maltose there are two additional disaccharides of biological importance. Sucrose, or table sugar, is a disaccharide composed of a glucose molecule linked by a glycosidic bond to a fructose molecule. Lactose, or milk sugar, is formed by the union of glucose and galactose.

**POLYSACCHARIDES:** There are three polysaccharides which will be considered in this discussion of carbohydrate macromolecules. Glycogen, starch, and cellulose are large molecules composed of repeating glucose sub-units linked together by glycosidic bonds. The polysaccharide starch is the storage form of carbohydrates in plants and may be made up of glucose units numbering in the thousands. Starch macromolecules are often branched chains of glucose units held by glycosidic bonds.

Glycogen is the storage form of carbohydrates found in animals. This polysaccharide is also composed of repeating glucose units, usually about three hundred in number, and is often more highly branched than starch.

Cellulose, a structural component of plant cell walls, is also a
polysaccharide composed of repeating glucose units. Cellulose differs, however, from both starch and glycogen in the type of glycosidic bond formed during the condensation reactions involved in synthesizing this macromolecule. This difference in bond formation involves the position of the hydrogen and hydroxyl groups on carbon \( \alpha \) of the glucose molecule. An example of both types of glycosidic bonds is demonstrated below:

\[ \text{starch or glycogen} \]
\[ \text{cellulose} \]

Many animals, including man, are not capable of digesting cellulose as a source of glucose due to the difference in spatial arrangement of the glycosidic bond.

Carbohydrates function in living systems as an energy source in both plants and animals and as a structural component in plants. The hexose, glucose, is one of the most important monosaccharides as it is utilized as fuel for cellular respiration and any excess is quickly stored for future use as starch by plants and glycogen by animals.

LIPIDS

The basic elements of lipids are carbon, hydrogen and oxygen. In contrast to carbohydrates, however, the ratio of oxygen to carbon and hydrogen is lower and will thereby result in these molecules serving as a more concentrated energy source. Lipids also function as insulating and padding materials for protective purposes. There is no general empirical formula for this class of biological molecules.

One of the major groups of molecules classified as lipids are those
known as fatty acids, and which consist of long hydro-carbon chains containing an acid, or carboxyl, functional group. Fatty acids are generally even-numbered in terms of the carbon atoms, the more frequent fatty acids consisting of fourteen to eighteen carbons. To demonstrate the structure of all fatty acids, let us look at butyric acid which is four carbons in length.

\[
\begin{aligned}
\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} & \quad \text{or} \quad \text{CH}_3\text{-CH}_2\text{-CH}_2\text{COOH} \\
\end{aligned}
\]

These types of molecules are known as 'acids' as the carboxyl group (COOH) dissociates in water to form hydrogen ions (H\(^+\)):

\[
\begin{aligned}
\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} & \quad \rightarrow \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^- \quad + \quad \text{H}^+ \\
\end{aligned}
\]

Saturated fatty acids are those which are filled with hydrogen bonds. Unsaturated fatty acids are those which contain double bonds, and therefore, could be saturated with additional hydrogen atoms. Oleic acid (18 carbons) is a common unsaturated fatty acid:

\[
\begin{aligned}
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}=\text{CH}\text{-CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH} \\
\end{aligned}
\]

Generally, animal fatty acids are saturated, and plant fatty acids are unsaturated, many of them containing more than one double bond which is known as polyunsaturated. Unsaturated fatty acids are generally liquid at room temperature and saturated fatty acids are solids at room temperature.

TRIGLYCERIDES: The most common form of lipids in living tissue is found in the class of molecules known as triglycerides, or neutral fats.
These fat molecules are composed of both an alcohol molecule, usually a 3-carbon alcohol known as glycerol, in conjunction with a number of fatty acids. The molecular structure of glycerol (3-carbon alcohol) is shown as:

```
   H
   H-C-OH (1)
   H-C-OH (2)
   H-C-OH (3)
```

A fatty acid can be joined by an ester linkage at carbon #1 above to form a monoglyceride in the following manner:

```
   H
   H-C-O-HHO-C-CH(CH2)n-CH3
 (1)   H-C-OH
   H-C-OH
 (2)   H-C-OH
   H
```

```
(1) H-C-O-C-CH(CH2)n-CH3 + H2O
(2) H-C-OH
(3) H-C-OH

Another fatty acid can be joined at the second (2) carbon to form a diglyceride, and a third at carbon three (3) to form a triglyceride. A triglyceride is therefore formed from one molecule of glycerol and three fatty acids bonded by ester linkages. They are known as neutral fats because the carboxyl groups of each fatty acid are now tied up in chemical bonds and are no longer capable of dissociation as acids. The chemical reaction involved is known as a condensation reaction as a molecule of water is eliminated during the process. An important derivative of triglycerides in active cell membranes are the class of compounds designated as phospholipids. These compounds are diglycerides which

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contain a phosphate group on the third carbon:

\[
\begin{array}{c}
\text{CH}_2\text{-O-C-R} \\
\text{CH-O-C-R} \\
\text{CH}_2\text{-O-P-OH} \\
\end{array}
\]

(R=remainder of molecule)

STEROIDS: Steroids and sterols are complex lipids based on the four carbon ring structure shown below. The most abundant representative molecule of this group in animal tissue is cholesterol. Other derivatives of this structure include animal secondary sex hormones, cholic acid and vitamin D.

![Steroid structure](image)

PROTEINS

Proteins are nitrogenous organic substances which hold a central position in the architecture and functions of living systems. Proteins are intimately connected with all phases of chemical and physical activity that constitutes the life of any cell. Whereas carbohydrates and lipids are universal in nature, proteins are unique for each species of organisms (species specific) as well as unique for each individual within the species.

Proteins are basically composed of the elements carbon, hydrogen, oxygen and nitrogen. They function as structural components in most an-
imal cells and as metabolic regulators in the form of enzymes, hormones, antibodies, and oxygen carriers. The building block molecules of the protein macromolecules are **amino acids**.

**AMINO ACIDS**: Approximately twenty to twenty-two amino acids are commonly found in all proteins. All amino acids have two functional groups in common and differ from each other only in the side chain, or **R** group. A structural formula of a generalized amino acid is shown as:

![A structural formula of a generalized amino acid](image)

The **amino** group (NH$_2$) is a basic functional group and the **carboxyl** (COOH) is an acidic group. Amino acids are therefore referred to as ampholytes as they may behave as both acids and bases depending on the pH of the medium. The R side chain of each amino acid contributes to this property as they are acidic, basic and neutral in chemical properties. It is due to this type of chemical diversity that amino acids and the barred proteins which they constitute are valuable as buffers against any radical shift in pH.

Amino acids are linked together by a condensation reaction which forms a **peptide** bond between the amino group of one amino acid and the carboxyl group of another.

![A peptide bond](image)

The addition of another amino acid in the same manner will result in a **tripeptide**, and so on until many amino acids are held together by...
Figure 1. R group variations of twenty common amino acids.
peptide bonds to create a polypeptide. A polypeptide is generally not regarded as a protein until it has reached a length of fifty or more amino acids. The sequence of amino acids linked by peptide bonds is known as the primary (1°) structure and each protein has its own unique series of amino acids much as each word in the dictionary has its own unique series of letters in the alphabet. The primary structure of a protein will cause the chain to assume a particular secondary (2°) level of organization in space due to the presence of the varied R side groups. This secondary structure is generally a helical (coiling) formation held by numerous hydrogen bonds. A third level of structure known as tertiary (3°) results when the helical shape folds and bends to form a globular configuration, a spatial arrangement often stabilized by disulfide (-S-S-) bridges between those few amino acids which contain sulfur as an elemental constituent. Hydrophobic and hydrophilic tendencies among the various side chains contribute to the spatial stability of the protein in addition to the hydrogen and disulfide bonds.

Some proteins, but not all, have a fourth level of structure which is referred to as quaternary (4°) organization and is the result of several individual polypeptide chains becoming associated together as a functional macro-molecule.

The four levels of organization listed above allow proteins to assume an endless variety of shapes and sizes, each of which may be vital to a specific chemical function. If the spatial configuration (shape) is altered, then the particular chemical function will cease to occur. Denaturation (destruction of the spatial arrangement) of proteins can be caused by pressure, a change in pH, high temperature, ultra-violet radiation and high concentration of salts.
NUCLEIC ACIDS

A fourth major group of macromolecules are the nucleic acids which are composed of repeating sub-units known as nucleotides. Nucleotides contain the elements of carbon, hydrogen, oxygen, nitrogen, and phosphorus and form the basis of three important cellular systems:

1. the genetic system as nucleic acids (Unit 8),
2. co-enzyme system as di-nucleotides (Unit 6), and
3. energy carriers as tri-phosphated nucleotides (Unit 5).

A nucleotide is composed of three sub-components; a pentose, a phosphate group, and a nitrogenous base. The phosphate group is identical in all nucleotides, whereas the pentose may be either ribose or deoxyribose. The nitrogenous base may be either one of two purines, or one of three pyrimidines.

The two common purines found in nucleotide structure are adenine and guanine. They are both based on the purine ring structure and vary only slightly from each other in the position of different functional groups. The three common pyrimidines found in nucleotides are uracil, thymine, and cytosine. These three are based on a single pyrimidine ring and also vary only in the position of functional groups.

![Basic Purine Structure](image1)

![Basic Pyrimidine Structure](image2)

In order to explain the structural basis of all nucleotides let us look at adenosine monophosphate, a nucleotide composed of a phosphate, ribose and adenine.

14
Adenine and ribose are termed adenosine when they are joined as a chemical unit known as a nucleoside (a nucleotide without the phosphate), and is termed adenosine monophosphate (AMP) upon the addition of a phosphate group to form a nucleotide. The remaining four bases are also capable of forming nucleotides in the same manner and are known as cytosine monophosphate (CMP), cytidine monophosphate (CMP), thymidine monophosphate (TMP), and uridine monophosphate (UMP). The pentose contained within these nucleotides is ribose. Nucleotides formed with deoxyribose are designated as deoxyadenosine monophosphate, etc.

CONJUGATED MOLECULES

Many biological molecules are a result of the combination of two or more of the major types of chemical substances. Egg yolk is an example of a lipoprotein (lipid and protein), viruses are nucleoproteins (nucleic acids and proteins), and mucin is a glycoprotein (carbohydrates and protein). Monosaccharides can be substituted with a carboxyl group to give a sugar acid, or an amino group to form an amino sugar. Phospholipids are lipids combined with a phosphate group, whereas phosphoproteins are composed of proteins plus phosphate groups.
### GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine</td>
<td>A purine nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Aldehyde</td>
<td>A monosaccharide containing the carbonyl functional group on the end carbon.</td>
</tr>
<tr>
<td>Amino Acid</td>
<td>Sub-unit of proteins containing an amino and a carboxyl functional group.</td>
</tr>
<tr>
<td>Ampholyte</td>
<td>A substance capable of ionizing into both anions and cations.</td>
</tr>
<tr>
<td>Buffer</td>
<td>A substance capable of neutralizing both acids and bases without appreciably changing the original pH of a solution.</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>Organic compounds containing C, H, and O that function as supporting plant tissues and as energy sources in all cells.</td>
</tr>
<tr>
<td>Cellulose</td>
<td>A polysaccharide composed of glucose units that functions as supporting material in plant cell walls.</td>
</tr>
<tr>
<td>Condensation</td>
<td>A chemical reaction between two or more molecules leading to the formation of a larger molecule by the elimination of a molecule of water.</td>
</tr>
<tr>
<td>Cytosine</td>
<td>A pyrimidine nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Denaturation</td>
<td>A chemical or physical alteration of protein structure resulting in a loss of biological activity.</td>
</tr>
<tr>
<td>Deoxyribose</td>
<td>A pentose that occurs in the nucleotides of DNA.</td>
</tr>
<tr>
<td>Dihydroxyacetone</td>
<td>A ketone triose.</td>
</tr>
<tr>
<td>Disaccharides</td>
<td>Organic molecules composed of two monosaccharides.</td>
</tr>
<tr>
<td>Ester</td>
<td>A chemical bond found in triglycerides.</td>
</tr>
<tr>
<td>Fatty Acids</td>
<td>Hydrocarbon chains which contain a carboxyl group.</td>
</tr>
<tr>
<td>Fructose</td>
<td>A hexose commonly known as fruit sugar; a ketone.</td>
</tr>
<tr>
<td>Functional groups</td>
<td>A group of atoms that causes characteristic behavior of the molecules in which it occurs.</td>
</tr>
<tr>
<td>Galactose</td>
<td>A hexose.</td>
</tr>
<tr>
<td>Glucose</td>
<td>A hexose commonly known as blood sugar; an aldehyde.</td>
</tr>
<tr>
<td>Glyceraldehyde</td>
<td>An aldehyde triose.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycogen</td>
<td>Storage form of carbohydrates in animals composed of repeating glucose molecules.</td>
</tr>
<tr>
<td>Glycosidic</td>
<td>Characteristic chemical bond of carbohydrates.</td>
</tr>
<tr>
<td>Guanine</td>
<td>A purine nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Heptose</td>
<td>A seven carbon monosaccharide; not common in biological systems.</td>
</tr>
<tr>
<td>Hexose</td>
<td>A six carbon monosaccharide.</td>
</tr>
<tr>
<td>Isomers</td>
<td>Molecules which contain the same type and number of atoms but are arranged differently in space.</td>
</tr>
<tr>
<td>Ketone</td>
<td>A monosaccharide containing the carbonyl group on the second carbon.</td>
</tr>
<tr>
<td>Lactose</td>
<td>A disaccharide composed of glucose and galactose.</td>
</tr>
<tr>
<td>Lipid</td>
<td>A major class of biological molecules that are not soluble in polar solvents; contain C, H, and O.</td>
</tr>
<tr>
<td>Maltose</td>
<td>A disaccharide composed of two glucose units.</td>
</tr>
<tr>
<td>Mannose</td>
<td>A hexose.</td>
</tr>
<tr>
<td>Monosaccharide</td>
<td>Simple carbohydrate sugars containing three to seven carbons.</td>
</tr>
<tr>
<td>Nucleic Acids</td>
<td>Macromolecules composed of nucleotides that function as the basis for the genetic system.</td>
</tr>
<tr>
<td>Nucleoside</td>
<td>A pentose and a nitrogenous base.</td>
</tr>
<tr>
<td>Nucleotide</td>
<td>A pentose, phosphate, and a nitrogenous base.</td>
</tr>
<tr>
<td>Polysaccharide</td>
<td>A macromolecule of carbohydrates composed of many monosaccharides or simple sugars.</td>
</tr>
<tr>
<td>Pentose</td>
<td>A five carbon monosaccharide.</td>
</tr>
<tr>
<td>Peptide</td>
<td>Characteristic bond of proteins.</td>
</tr>
<tr>
<td>Polypeptide</td>
<td>Many amino acid sub-units linked together by peptide bonds.</td>
</tr>
<tr>
<td>Primary structure</td>
<td>The sequence of amino acids linked together.</td>
</tr>
<tr>
<td>Purine</td>
<td>Nitrogenous bases based on a double ring structure.</td>
</tr>
<tr>
<td>Pyrimidine</td>
<td>Nitrogenous bases based on a single ring structure.</td>
</tr>
<tr>
<td>Quaternary Structure</td>
<td>Fourth level of protein organization found in some proteins in which separate polypeptide chains unite into a functional protein.</td>
</tr>
<tr>
<td>Ribose</td>
<td>A pentose found in the nucleotides of RNA.</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>Secondary</td>
<td>Second level of protein organization; a helical coil held together by hydrogen bonds.</td>
</tr>
<tr>
<td>Structure</td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>Storage form of carbohydrates in plants composed of repeating glucose molecules.</td>
</tr>
<tr>
<td>Steroids</td>
<td>Lipid molecules based on four ring structures.</td>
</tr>
<tr>
<td>Sterols</td>
<td>See steroids. Cholesterol is an example of sterols.</td>
</tr>
<tr>
<td>Sucrose</td>
<td>A disaccharide composed of glucose and fructose.</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Third level of organization in proteins that forms a globular structure held together by sulfide bonds.</td>
</tr>
<tr>
<td>structure</td>
<td></td>
</tr>
<tr>
<td>Tetrose</td>
<td>A four carbon monosaccharide; not common in biological systems.</td>
</tr>
<tr>
<td>Thymine</td>
<td>A pyrimidine nitrogenous base of nucleotides.</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>Neutral lipids composed of glycerol and three fatty acids.</td>
</tr>
<tr>
<td>Triose</td>
<td>A three carbon monosaccharide.</td>
</tr>
<tr>
<td>Uracil</td>
<td>A pyrimidine nitrogenous base found in nucleotides.</td>
</tr>
</tbody>
</table>

**PROGRAMMED SELF TEST - UNIT 2**

The element that makes up the structural backbone of major biological molecules is carbon.

Molecules react differently chemically due to the presence of functional groups.

Macromolecules are composed of smaller molecules known as sub-units, or building block molecules.

Carbohydrates are composed of the elements carbon, hydrogen and oxygen.

The sub-unit of carbohydrates is the monosaccharide.
A three carbon monosaccharide is known as a triose.

A five carbon monosaccharide is known as a pentose.

A six carbon monosaccharide is known as a hexose.

The functional groups of monosaccharides are carbonyl oxygen (C=O), hydroxyls (OH).

A monosaccharide which contains the C=O on the end carbon is an aldehyde.

Glyceraldehyde and dihydroxyacetone are monosaccharides called trioses.

Glyceraldehyde and dihydroxyacetone contain the same number and types of atoms and therefore are called isomers.

The two most important pentoses are ribose, deoxyribose.

Glucose and fructose are examples of monosaccharides known as hexoses.

Are glucose and fructose isomers? Yes.

Pentoses and hexoses are able to exist in two structural forms, one is a straight chain and the other is ring form.

A disaccharide is composed of two monosaccharides.

The bond formed between monosaccharides is glycosidic.
Three common disaccharides are maltose, sucrose, lactose.

A polysaccharide is a macromolecule composed of many monosaccharides.

Starch and glycogen are both composed of the monosaccharide glucose.

Cellulose is composed of glucose units and functions as a structural unit of plants.

Hexoses function as structural components and as the source of energy as fuel for respiration.

The elements found in the biological molecules known as lipids are carbon, hydrogen, oxygen.

Lipids contain less oxygen than carbohydrates and are thus more concentrated forms of energy.

Neutral fats are mainly the group of molecules known as triglycerides.

Fatty acids are hydrocarbon chains containing a functional group known as a carboxyl group.

Triglycerides are composed of glycerol and three fatty acids.

The most abundant sterol in animal tissue is cholesterol.

Phospholipids are composed of two classes of molecules which are phosphates, lipids.

Proteins contain the elements of carbon, hydrogen, oxygen, nitrogen.
The sub-unit of proteins is the group known as **amino acids**.

The functional groups of amino acids are **amino** (NH₂) and **carboxyl** (COOH).

The bond found in proteins is the **peptide** bond.

The sequence of amino acids determines which structure is primary.

Hydrogen bonds hold which level of protein organization together as secondary.

The globular formation of proteins is due to sulfur bonds at what level of organization is tertiary.

If a protein macromolecular spatial organization is destroyed it is called **denatured**.

Enzymes, hormones, oxygen carriers and buffers are functions of the major molecules known as **proteins**.

The sub-unit of nucleic acids are **nucleotides**.

Nucleotides are composed of the three molecules, or components as pentose, phosphate, and nitrogenous base.

The two purine nitrogenous bases are **adenine**, **guanine**.

The three pyrimidine nitrogenous bases are **thymine**, **cytosine**, **uracil**.

Nucleotides are important for what three systems are **genetic**, **co-enzymes**, **high energy**.
CELL STRUCTURE

Unit 3

OBJECTIVES

To identify from a list or diagram by name or description:

a) the functional unit of living systems
b) the cellular location of organelles
c) the composition of organelles
d) the function of organelles
e) the function of non-organelle cell components
f) the concept of membrane structure and function
g) the differences between prokaryotic and eukaryotic cells
h) the media, or ground substance, of cells
THE STRUCTURAL UNIT OF LIVING SYSTEMS

Plant and animal life occurs in such diverse forms in both unicellular and multicellular organisms that it appears on the surface to be an impossible task to discover any similarities between them in structure or function. However, all of the chemical substances from atoms to macro-molecules of which any organism is composed are organized into specific units of structure and function designated as cells. Cells are highly organized chemical systems which encompass all lower levels of complexity into an ordered state that demonstrates the basic characteristics of life, and is therefore the first level of complexity at which life exists. The cell is the unit which unifies living systems, and even though cells themselves occur in many diverse forms and sizes, they do demonstrate basic similarities of structure in terms of function.

All of the processes of living organisms are based on these processes which occur at the cellular level. All of the processes that occur within the cell are involved with energy transformations, many of which take place in definite cell parts known as organelles. Cellular activity cannot be neatly divided into structure versus function, as function is changing structure at this molecular level of organization and existence.

The development of the electron microscope has revealed the organization of cells to be far more complex than the earlier descriptions of "bags of protoplasm bounded by membranes and containing nuclei".

1

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The term protoplasm for years indicated the media of cells as a homogeneous mixture of chemical substances which showed no variance in consistency or composition. The term is not often used today to indicate the ground substance of which cells are composed as modern research has shown that this fluid, or media, of life varies from cell to cell as well as varies within a cell during its existence. In other words, it is not homogeneous but heterogeneous in nature. One of the most striking discoveries revealed by electron micrographs, the picture or image produced by electron microscopes, is that cells are composed to a great extent of membranes and membrane systems. Before delving into cellular structure at this point, let us take a closer look at membrane structure in general in order to point out their functions as boundaries to organelles as well as to the cell itself.

There are presently several speculations, or hypotheses, as to the molecular organization of membranes. All agree that the sub-units of membrane composition are complexes of phospholipids and proteins arranged in a definite manner. The lamellar model of membrane structure is diagrammatically shown in Figure 1, and portrays the "sandwich" theory of the arrangement of lipids and proteins due to polar and non-polar regions of the molecules involved. This membrane model has been shown to be correct for those membrane structures which are involved with little or no enzymatic activity as part of their function. The thickness of this membrane for most types of cells is approximately 75 \( \text{A} \), and has been designated in scientific terms as the "unit membrane".
Figure 1. Schematic arrangement of molecules in lamellar membrane model (A). Electron micrograph (B) of rat liver showing nucleus (N), nuclear pore (NP), mitochondrion (M), endoplasmic reticulum (ER), lysosome (L), glycogen granules (G) and plasma membrane (PM). 19,000x. (Courtesy of Upjohn Company.)
A second hypothesis pertaining to membrane structure is the particulate theory. This model is basically an extension of the lamellar model to include particulate protein integration into the interior lipid layers and involves those membranes which are more active in terms of enzymatic processes, such as those involved with chloroplasts and mitochondria organization.

Membranes function as protective barriers between that which they are surrounding and the immediate environment. In this manner, they play a vital role in controlling the rate, as well as types, of chemical substances that move into and out of the structure involved. This function of selectivity, allowing some substances to pass through while preventing others, imparts the term "semi-permeable" to living membranes. Most of the cell organelles, as well as the cell itself, are incorporating by unit membranes, and in general seem to function in two ways. First, they establish the compartments within a cell, and second, they provide the surface area necessary for organized spatial arrangements or enzymes and other organic molecules necessary for particular chemical pathways.

CYTOPLASMIC ORGANELLES

Let us now look at the definite structure and function of those organelles involved with the cytoplasmic organization of cellular existence. Figures 2 and 3 portray diagrams of typical animal and plant cells as viewed as a composite of many diverse forms. The "typical" cell does not exist as such, but is well worth investigating as a means of demonstrating the presence of recognizable cell structures,
Figure 2. Ultrastructure schematically shown of an animal cell.

Label the organelles for future reference.
Figure 3. Ultrastructure schematically shown of a plant cell.

Label the organelles for future reference.
or organelles. Label these diagrams for future reference once you understand their structure and function in terms of cellular metabolism.

THE CELL MEMBRANE: Living cells are enclosed by a semi-permeable plasma membrane which functions to keep the remainder of the cell and its structures in close contact and to maintain cellular shape. The chemical composition of substances within a cell are much different than those found in the cellular environment. The cell membrane can be viewed as an important living barrier in controlling the integrity of cell content by regulating the rate and types of chemicals that move into and out of the cell. The thickness of the cell membrane varies with cell specialization in many cases, but generally appears to agree with the unit membrane previously mentioned. This membrane is not always a smooth envelope surrounding a cell, but is often a wrinkled and folded surface depending on specific cellular function. It can be folded into microvilli, or finger-like evaginations, or vesicles, invaginations, which increase the amount of surface area available for the transport of molecules between the cell and its surroundings.

The cell membrane not only maintains a chemical difference, or gradient, between itself and the environment, but also maintains an electrical gradient. Generally, the interior of the cell in multi-cellular organisms is negative to the extra-cellular fluid which bathes it. This occurs as a result of the difference in atomic size and therefore, the difference in diffusion rates among the ions commonly associated with living systems. The three major ions involved in membrane electro-chemical gradients are sodium ($\text{Na}^+$), potassium ($\text{K}^+$), and chloride ($\text{Cl}^-$).
EXTRANEOUS CELL COATS: Cells often possess a more rigid, non-living, porous covering which has been secreted by the cellular cytoplasm. Plant cell walls are composed mainly of cellulose, a polysaccharide, for increased strength and support. Unicellular organisms often are encased in pellicles for protective functions, insect cells secrete chitin as a substance utilized in exoskeletons, and many multicellular organisms form shells. Animal cells in multicellular organization are held together internally by forms of protein and polysaccharide molecules of "glue". The rigidity of this substance is dependent on the function of the cells responsible for its production.

MITOCHONDRIUM: Mitochondria are rounded or elongated spherical organelles found dispersed within the cytoplasm. Their basic structure has been determined by electron micrographs and can be diagramatically represented as shown in Figure 4. Mitochondria are composed of a double unit membrane, the outer one providing a smooth boundary to the cytoplasmic environment, whereas the inner membrane is folded into numerous projections, or shelves, that extend into the interior or the lumen, of the organelle. These shelves are termed cristae and contain the necessary enzymes for the oxidation of nutrients. The mitochondrion is a vital organelle in which the aerobic respiratory pathways occur; pathways in which the potential chemical energy of foodstuffs are converted into usable energy in the form of ATP (adenosine-tri-phosphate), and carbon dioxide and water. Due to this function the mitochondrion is often nicknamed the "power house" of the cell.
Figure 4. Schematic interpretations of the two energy conversion organelles. Upper drawing is the chloroplast and lower drawings is the mitochondrion. Both are membraned organelles of eukaryotic plant and animal cells.
LYSOSOMES: Lysosomes are cellular organelles similar to the size of mitochondrion (see Figure 5) and are also surrounded by a unit membrane. They contain numerous degradative enzymes that are able to catalyze the breakdown of carbohydrates, proteins and nucleic acids. The cell is protected from self-destruction by maintaining these enzymes in the lysosome sac. Lysosomes function in the process of intra-cellular digestion involving vacuole formation by phagocytosis and pinocytosis, a mechanism of moving materials into the cell discussed in the unit concerned with transport. These organelles also play a vital role in the digestion of debris resulting from cell injury or cell death.

PLASTIDS: Plastids are organelles found in plant cells which vary considerably in number, form and size dependent on plant structure and function. Leucoplasts are colorless plastids which function as storage sites for polysaccharides, lipids, or proteins. The chromoplasts contain pigments of various colors which are the basis for the different hues of flowers and fruits. The most important of these are the chloroplasts which contain the green pigment chlorophyll and are the sites of photosynthesis.

Chloroplasts may vary in size and shape but generally have an elipsoid conformation as shown in Figure 4. These organelles are bounded by a double membrane which surrounds a homogeneous ground substance known as stroma. Within the stroma a system of internal membranes, lamella, hold disc-shaped layers of lipoproteins to which the chlorophyll molecules are anchored. These discs, or grana, are the actual sites utilized in the conversion of radiant energy into the usable chemical energy of organic compounds upon which living systems are dependent.
Figure 5. Electron micrograph of rat liver (22,000×) showing the nucleus (N), nuclear membrane (NM), nuclear pore (NP), mitochondrion (M), lysosome (L), golgi apparatus (G), nucleolus (NE), and the endoplasmic reticulum (ER). (Courtesy of the Upjohn Co.)
MICROTUBULES: Microtubules are long rod-shaped contractile protein filaments scattered throughout the cytoplasm. Due to the fact that they are stiff molecules, they afford the cell with a degree of rigidity, and because they are contractile in nature, they allow a mechanism for internal mixing of the cytoplasm. This phenomenon is especially significant in the formation of pseudopodia, or false feet, involved in amoeboid type of movement.

CENTRIOLES: Centrioles, organelles found in animal cells and those of lower plants, occur in pairs and are found near the nucleus. Centrioles are closely related to microtubules in structure as each centriole is composed of nine microtubules arranged in a cylindrical manner. Centrioles function during the process of cellular division and the movement of chromosomes.

CILIÆ AND FLAGELLA: Many cells have hair-like extensions which allow for either cellular propulsion or for the movement of materials past the cell. Cilia, shorter extensions, and flagella, longer whip-like extensions, develop from basal bodies which are formed from centrioles and are identical with their microtubule structure.

ENDOPLASMIC RETICULUM: The endoplasmic reticulum is the intracellular membrane system revealed by the electron microscope and includes all of the internal membranes not directly involved in the formation of other organelles. These membranes have the same basic structure as the plasma membrane and are organized in pairs which are parallel to each other. This system extends generally from the nucleus to the cell membrane and may be continuous with either, or both. The
endoplasmic reticulum thus contributes an increased surface area for chemical reactions to occur as well as forms a communication and transport vehicle for the movement of substances. (See Figure 5)

**RIBOSOMES:** Ribosomes are ultra-microscopic spherical particles, among the smallest organelles in the cytoplasm. They are composed of protein and RNA (ribo-nucleic acid) and function as the site of the synthesis of proteins. Proteins which are synthesized for intracellular use are produced by the ribosomes found dispersed within the cytoplasm itself, whereas the protein synthesis of products to be secreted or exported are created by ribosomes attached to the endoplasmic reticulum. That portion of the endoplasmic reticulum which has ribosomes associated with it is known as rough endoplasmic reticulum, as opposed to smooth endoplasmic reticulum which is lacking in ribosomal attachment.

**GOLGI APPARATUS:** The Golgi apparatus, or complex, is a neat, compressed stack of internal membranes which resemble those of the endoplasmic reticulum. The function of these organelles is still questionable, but due to their high incidence in animal secretory cells, it is believed that they serve as a storage and assembly site for products of a secretory nature, generally those belonging to the classes of glyco-proteins and lipoproteins. Figure 5 clearly shows the Golgi complex as compressed membranes forming minute vesicles.

**CYTOPLASM:** Cytoplasm is the term used to describe the ground substance, or media, which is found within the plasma membrane but outside of the nucleus. As previously mentioned, it is not a homogeneous substance and the composition will vary from cell type to cell type in addition to varying within the cell during its existence.
Cytoplasm is basically an aqueous fluid containing approximately 70 to 90% water, a factor important in accounting for many of the unique characteristics which this substance possesses. Water plays a dynamic role in living systems as it participates in numerous chemical reactions and functions as a solvent in which other particles are dissolved, such as solids, liquids and gases. Cytoplasm is a dispersion system which combines a true solution and true colloid into a basic living media. A true solution is a system in which the particles, or molecules, concerned are small enough to remain evenly dispersed within water for an indefinite amount of time. Ions and molecular subunits such as amino acids, monosaccharides and nucleotides fall into this category. A colloid, however, contains particles larger than those dissolved in a solution, such as protein macromolecules and lipid complexes, which can maintain their own identity but remain suspended or dispersed throughout the solvent. The third form of a dispersion system is found as a suspension, in which the particles are large enough to settle out, or precipitate over a period of time. Cytoplasm is not a suspension.

A colloidal system has the ability to exist in either a liquid, or sol, state as well as a semi-liquid, or gel, state. This capacity of converting from one state to another is essentially based on the interaction of the particles as well as on the amount of water present. Cytoplasm forms the media in which the cellular organelles discussed above are dispersed.
NUCLEUS: The nucleus is usually a spherical organelle which can easily be located within the magnification power of a light microscope if the specimen is properly stained. The nucleus is surrounded by a thin, double unit, membrane, often referred to as the nuclear envelope. This membrane, however, is not a continuous covering as electron micrographs demonstrate the presence of pores which allow for the passage of materials between the nucleus and the cytoplasmic areas of the cell. The nucleus, in conjunction with the organelles found within it, functions as a control center for cellular activities. (See Figure 5)

NUCLEOPLASM: The nucleoplasm is the colloidal fluid of the nucleus and is often referred to as the nuclear sap. This media is very similar to the cytoplasmic fluid, both in consistency and in characteristics, but does contain a higher amount of granular substances rich in proteins and salts.

NUCLEOLUS: The nucleolus, or nucleoli if there is more than one present, is a more or less spherical body containing large quantities of protein and RNA (ribonucleic acid) which is not separated from the nucleoplasm by a membrane system. The function of nucleoli has been indirectly shown by modern research to be the site of the synthesis and assembly of the cytoplasmic organelles known as ribosomes. A nucleus may contain more than one nucleolus within its boundaries.

CHROMATIN: The chromatin material appears within a non-dividing cell as a granulate substance or mesh of fine threads. Chromatin is composed of nucleic acids, mainly in the form of DNA (deoxyribonucleic acid), and proteins. This network constitutes the working, or active, form of chromosomes. When a cell begins to undergo cellular division,
the chromatin material shortens and thickens due to water loss and becomes recognizable as the rod-shaped organelles known as chromosomes. Chromosomes serve the cell functionally as the carriers of genetic information, and thus are involved as the ultimate agents of cellular metabolism and heredity.

INCLUSIONS: In addition to the cytoplasmic and nuclear organelles described previously, a cell often contains such inclusions as vacuoles, droplets, granules and crystals within the cytoplasm. These types of substances are not considered to be organelles due to their impermanent nature, even though they serve useful purposes in cellular existence. Vacuoles can be ultra-microscopic in size or, in the case of many plant cells, almost as large as the cell itself. The fluid contained within most vacuoles is essentially water and possibly salts and they generally function as a means of water control. Some vacuoles are involved as the product of phagocytosis and pinocytosis in cell engulfment of external particles. Droplets, granules and crystals function as storage sites for products of cellular metabolism.

Not all cells contain the same number and type of organelles described, but each cell contains those which are vital and necessary for the specialized functions of its existence. Cells which are extremely active, for example, and require large amounts of energy in the form of ATP will contain many more mitochondria than a cell which functions at a less demanding energy rate. Cells which function for the purpose of secreting hormones will be differentiated from other cells by containing a greater amount of rough endoplasmic reticulum and Golgi complexes. Here again, there is a definite relationship between
structure and function, and the reason cells differ as they specialize can be summed up in the following three points:

1. The nature of the chemical substances present, which will determine,
2. The types of reactions possible, which will determine,
3. The rates of the reactions that occur.

The cells of plants and animals which have been described as being "typical" are known as **Eukaryotic** cells. The term "karyo" refers to nuclear organization and indicates that this type of cell contains an internal membrane system. Cells which do not contain an internal membrane system, and therefore none of the organelles which are bounded by membranes, are known as **Prokaryotic** cells. Prokaryotic cells are examples of a more primitive type of cellular organization and includes the bacteria and blue-green algae as examples.

**GLOSSARY**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATP</td>
<td>Adenosine-tri-phosphate; high energy compound.</td>
</tr>
<tr>
<td>Cristae</td>
<td>Infoldings of inner membrane of mitochondria.</td>
</tr>
<tr>
<td>Degradation</td>
<td>The breakdown of a chemical compound.</td>
</tr>
<tr>
<td>Enzyme</td>
<td>Biological catalysts composed of proteins.</td>
</tr>
<tr>
<td>Glycoprotein</td>
<td>Macromolecules composed of carbohydrates and proteins.</td>
</tr>
<tr>
<td>Heterogeneous</td>
<td>Composed of different substances.</td>
</tr>
<tr>
<td>Homogeneous</td>
<td>Composed of the same substance.</td>
</tr>
<tr>
<td>Hormones</td>
<td>Chemical messenger molecules secreted by endocrine glands.</td>
</tr>
<tr>
<td>Intracellular</td>
<td>Within the cell.</td>
</tr>
<tr>
<td>Lamellar</td>
<td>Refering to a membrane or layered like arrangement.</td>
</tr>
<tr>
<td>Lipoprotein</td>
<td>Macromolecule composed of lipids and proteins.</td>
</tr>
</tbody>
</table>
Multicellular: An organism composed of more than one cell.
Particulate: Composed of distinct particles.
Organelle: A recognizable cell structure.
Semi-permeable: Permeable to certain substances only.
Ultrastructure: Submicroscopic, elemental structure of the cell.
Unicellular: Organism that is composed of a single cell.

PROGRAMMED SELF TEST - UNIT 3

The level of complexity at which life exists is the __cell__

Recognizable cell parts or structures are called __organelles__

Protoplasm is not homogeneous, but is a mixture or __heterogeneous__

A membrane is composed of the two substances known as __phospholipids, proteins__

Membranes allow certain substances to pass or are __semipermeable__

The differences within a cell from its environment is both __chemical, electrical__

Animal cells may possess a covering but never possess a __cell wall__

The organelle responsible for aerobic respiration is the __mitochondrion__

The inner membrane shelves of the mitochondria are called __cristae__
Membrane bound bags of enzymes are called lysosomes page 6.

Lysosomes play a part in the process of engulfment called phagocytosis, or pinocytosis page 6.

The important plant plastid used in photosynthesis is the chloroplast page 6.

Single contractile protein filaments are called microtubules page 10.

Microtubules are associated with internal movement page 10.

Organelles involved with animal cell division are called centrioles page 10.

Centrioles are composed of microtubules page 10.

Microtubules also form the basal bodies of cilia, and flagella page 10.

The intracellular membrane system is called the endoplasmic reticulum page 10.

Small spherical organelles that might be attached to the endoplasmic reticulum are ribosomes page 10.

Ribosomes function as the site of protein synthesis page 10.

Ribosomes are composed of protein, ribonucleic acid page 10.
The organelle which apparently functions as a secretory unit is the **golgi complex**.

The ground substance, or media, within the cell but outside of the nucleus is called **cytoplasm**.

Cytoplasm is what type of dispersion system? **True solution, colloid**.

The control center of the cell is the **nucleus**.

Chromatin material is composed of proteins and **deoxyribonucleic acids**.

When chromatin becomes visible as rod-like organelles, it is called a **chromosome**.

Cells vary according to function, and will therefore vary in the type and number of organelles.

Bacteria and blue-green algae are cells known as **prokaryotic**.
OBJECTIVES

To identify by name or description from a list or diagram
a) the components of the extracellular fluids
b) the characteristics of water as a media
c) the influencing factors of the extracellular fluid
d) the process of passive transportation of substances
e) the process of active transportation of substances
f) the concept of phagocytosis and pinocytosis

To be able to work out problems associated with osmotic systems
THE CELL AND ITS ENVIRONMENT

Living cells do not exist in a vacuum but rather within a micro-environment from which they must secure matter and energy and to which they must eliminate waste products in order to survive. All living cells, whether they are unicellular organisms or components of complex multicellular organisms, are bathed by external fluids. The living cells of man are bathed by lymph and blood plasma which together constitute the "extracellular fluid" of the internal cellular environment. This internal environment remains relatively stable and unchanging (homeostasis) in terms of its composition and temperature consistency regardless of wide fluctuations in the external environment of the individual. This unit of study will examine the composition of the extracellular fluid and the basic mechanisms involved in the exchange of materials between it and the cell.

THE EXTRACELLULAR FLUID

WATER: The basic component of all living systems is the inorganic compound of water (approximately 70%). This substance has a variety of unique characteristics that enable it to serve as the "common denominator of all life". Water is the only inorganic substance found in nature that occurs in great quantities. It is also the only inorganic substance which occurs in three physical states (gas, liquid, solid) within the temperature range found on earth and generally is in the liquid state within the biokinetic range of living organisms.
Water has additional unique chemical characteristics including its high specific heat and high heat of vaporization. This means that water can absorb a great amount of heat without changing its own temperature and can release a great amount of heat during vaporization with a minimum amount of water. These two characteristics, coupled with the fact that water is a good heat conductor, are of utmost importance in stabilizing internal body temperatures against any rapid change.

Water is a universal polar solvent as it dissolves more substances than any other solvent, and as a liquid it is an excellent medium for the transport of materials between and into cells. Water also serves as the medium within which most chemical reactions of living systems occurs and participates in many of these reactions as a reactant or product.

The maximum density of water is at 4°C and therefore is heaviest just before it freezes. This allows aquatic organisms to remain protected in fluid surroundings as ponds and fresh water lakes will freeze from the top down.

The importance of water to a living system can readily be seen in the fact that organisms will suffer disastrous effects from a lack of it long before they suffer any effect from a lack of food.

GASES: The extracellular fluid contains gases which are soluble in water. The most important of these are oxygen and carbon dioxide both of which are directly involved with cellular metabolism.

IONS: A variety of dissolved minerals, or salts, in the form of ions are found within the extracellular fluid. Some ions, such as Na⁺,
$K^+$, $Ca^{++}$, $Mg^{++}$, $Cl^-$, $PO_4^{2-}$, and $HCO_3^-$, are present in relatively large quantities, whereas other ions, such as $Fe^{++}$, $Cu^{++}$, $Mn^{++}$ and $Zn^{++}$, are present in trace amounts. Relative concentrations of the various ions must often be held within certain limits to insure optimal conditions for cellular metabolism.

VITAMINS: Non-ionic trace elements, or substances, which are necessary for normal cell functioning are classified as vitamins. These organic compounds usually are essential as components of co-enzymes.

NUTRIENTS: Organic compounds which serve as food for cellular metabolism are also contained within the extracellular fluid. These substances supply the cell with an energy source as well as material for growth and repair. The building block sub-units of lipids, proteins and carbohydrates (Unit 2) are therefore an essential component of the internal cellular environment.

HORMONES: In higher animals, such as man, the extracellular fluid contains chemical substances which are released by specialized cells and affect the metabolism of other cells. Hormones are chemical messengers involved with chemical communication between cells and aid in correlating multicellular activities.

WASTE PRODUCTS: The waste products of cellular metabolism also compose a portion of the extracellular fluid. Important waste products of animal metabolism are nitrogenous excretions resulting from protein and nucleoprotein degradation that can become toxic if their concentration is allowed to exceed particular limits. Soluble carbon dioxide, a waste product of cellular respiration, must also be maintained within certain limits of concentration.
ADDITIONAL FACTORS: Two additional factors, pH and temperature, must be maintained within limits as cells are extremely sensitive to any alteration away from optimal conditions. The proteins contained within the extracellular fluid act as buffers against serious pH changes and warmblooded animals (homeotherms) maintain a consistent temperature to ensure efficient metabolism. A change of ten degrees in temperature will alter metabolic chemical reactions by a rate of two to three times. A high temperature will also interfere with protein structure (denaturation) which is essential for biological activity.

TRANSPORT MECHANISMS

Substances contained within the extracellular fluid must enter and leave the cell by passing through the plasma membrane. Two basic means of transporting materials through this membrane are recognized on the basis of energy requirements and concentration gradients.

Passive transport requires no outside energy to accomplish the movement of matter as the movement is down a concentration gradient. Active transport, however, does require an outside energy source to accomplish a movement of matter against a concentration gradient.

PASSIVE TRANSPORT: Atoms, and therefore molecules, contain kinetic energy due to the fact that they are composed of sub-atomic particles in motion. This random movement of atoms, or molecules, will disperse them from areas of higher concentration to areas of lower concentration, or down a concentration gradient.

If a bottle of ammonia is opened in a closed room, the odor will eventually become apparent in any part of the room due to the process.
of diffusion. The molecules of ammonia will move away from an area of high concentration (bottle = 100% ammonia) to an area of low concentration (room = 0%) until the molecules are evenly distributed throughout. The ammonia molecules have moved away from each other due to random collisions caused by their inherent kinetic energy. The process of diffusion ceases once the molecules reach a state of equilibrium, even though they are still randomly moving, as there will be no net change in concentration in any given area of the room. The direction of movement and the rate will be dependent on the concentration gradient (original differences between the two concentrations) and on additional factors such as temperature and pressure. Temperature increases the kinetic energy of molecules and therefore will increase the rate of diffusion. Pressure also accelerates the movement of molecules. The force resulting from the combination of these variable factors is called diffusion pressure.

Osmosis is a special case of diffusion which involves the movement of water molecules from an area of high concentration to an area of low concentration while passing through a semi-permeable membrane. If water diffuses into a cell by osmosis an internal force, turgor pressure, will increase. Turgor pressure within plant cells will not reach a breaking point due to the rigid cell wall which encloses it, but in animal cells this pressure may result in rupturing the cell membrane. Plasmophtysis is the result when a cell bursts due to an excess of water by osmotic movement. Plasmolysis is the reverse of plasmophtysis and results from a water loss due to osmotic movement of water into the environment and leads to cell shrinkage.
Three terms are used to describe relationships of osmotic systems which are separated by semi-permeable membranes. Hypertonic, hypotonic, and isotonic are relative terms used to designate the concentration of solutes within an osmotic system. If a cell is placed in a hypotonic solution (indicating a lower solute concentration outside of the cell) it will gain water by osmosis as the concentration of water is greater outside than inside. If a cell is placed in a hypertonic solution (indicating a higher concentration of solutes outside of the cell) it will lose water to its environment as the water concentration is greater inside. Isotonic refer to a situation of solutions containing equal solutes, and therefore equal concentrations of water which will result in no net movement. Figure 1 demonstrates the three osmotic relationships.

Diffusion and osmosis are strictly physical processes over which the cell has no control. No cellular energy is expended to accomplish this form of molecular movement and is therefore referred to as passive transport. Whether these molecular movements will benefit or destroy a cell depends upon the cellular environment in terms of concentration gradients and the direction of movement. REMEMBER: the terms of hypertonic, hypotonic, and isotonic refer to solute concentration only, and that the movement of molecules is in terms of water concentrations.

ACTIVE TRANSPORT: When a cell uses energy to move molecules or ions against a concentration gradient (from low to high) it is called active transport. Energy is required to offset the physical processes of diffusion and osmosis and reverses the flow of chemical substances.
A. A cell placed in a hypotonic solution. Water will enter the cell by osmosis.

B. A cell placed in a hypertonic solution. Water will leave the cell by osmosis.

C. A cell placed in an isotonic solution. Water remains in equilibrium and there is no net change by osmosis.

Figure 1: Examples of osmotic systems that vary due to the concentration of solutes. The terms of hypotonic, hypertonic and isotonic refer to the relative concentrations of solute and not of water. Water is the substance moving from an area of high water concentration to an area of low water concentration by osmosis.

The terms of hypotonic, hypertonic, and isotonic are always used as an expression of solute relationships between two solutions that are separated by semipermeable membranes. In other words, one solution (or cell) is hypotonic, hypertonic, or isotonic to another solution (the environment). You cannot state that a solution is hypertonic by itself, but only in relation to another solution.
Small molecules and ions move through the cell membrane by way of pores during both active and passive transport. Larger molecules also enter and leave cells by means of engulfment.

PHAGOCYTOSIS: Certain cells take in solid particles by engulfment, or phagocytosis, to form food vacuoles, or phagosomes. The large particles engulfed are broken down by lysosomal enzymes once the food vacuole and lysosome fuse to form a digestive vacuole. The usable products diffuse into the cytoplasm whereas the waste products are ejected into the environment by reverse phagocytosis.

PINOCYTOSIS: Pinocytosis is a process similar to phagocytosis in which the engulfed material is in liquid form. Both processes require an energy expenditure on the part of the cell and are therefore special cases of active transport.

GLOSSARY

Active transport Movement of molecules against a concentration gradient and requiring the use of energy.

Biokinetic range Temperature range in which all life exists.

Conductor A substance that readily conducts heat, electricity, etc., through it.

Density Mass per unit volume.

Diffusion The movement of molecules from an area of high concentration to an area of low concentration.

Extracellular fluid The fluids outside of cells yet internal within the organism.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat of vaporization</td>
<td>Heat absorbed or radiated during a change of phase, such as a liquid becoming a gas.</td>
</tr>
<tr>
<td>Homeostasis</td>
<td>The tendency of a system to maintain stability; a dynamic equilibrium.</td>
</tr>
<tr>
<td>Hormones</td>
<td>Chemical substances secreted by the endocrine system that alter the metabolism of target cells.</td>
</tr>
<tr>
<td>Ion</td>
<td>An electrically charged atom or group of atoms formed by the gain or loss of electrons.</td>
</tr>
<tr>
<td>Kinetic</td>
<td>Energy of motion.</td>
</tr>
<tr>
<td>Osmosis</td>
<td>The movement of water molecules from an area of high concentration to an area of low concentration and passing through a semipermeable membrane.</td>
</tr>
<tr>
<td>Passive transport</td>
<td>The movement of molecules without the use of energy from an outside source but based on inherent kinetic energy; diffusion and osmosis.</td>
</tr>
<tr>
<td>Phagocytosis</td>
<td>The engulfment of particulate matter by cells.</td>
</tr>
<tr>
<td>Phagosomes</td>
<td>Vacuole formed by the process of phagocytosis.</td>
</tr>
<tr>
<td>Pinocytosis</td>
<td>The engulfment of liquid molecules by cells.</td>
</tr>
<tr>
<td>Plasmolysis</td>
<td>Cell shrinkage due to osmotic water loss.</td>
</tr>
<tr>
<td>Plasmoptysis</td>
<td>Cell bursting due to osmotic water increase.</td>
</tr>
</tbody>
</table>

**PROGRAMMED SELF TEST - UNIT 4**

Two factors that will affect the extracellular fluid are

- temperature, pH

Passive transport of molecules in living systems includes

- diffusion, osmosis

Passive transport requires no expenditure of

- energy

Movement of molecules from an area of high concentration to low concentration is

- diffusion
The movement of water through a semipermeable membrane from an area of high concentration to low concentration is

osmosis page 4

A movement of molecules against a concentration gradient is

active transport page 3

Active transport requires the cell to expend

energy page 3

The internal pressure resulting from osmotic increase of water

turgor pressure page 4

If a cell shrinks due to water loss it is undergoing

plasmolysis page 4

If a cell bursts due to water gain it is undergoing

plasmophtysis page 4

The term hypertonic indicates a solution with a solute concentration that is

higher page 4

The term hypotonic indicates a solution with a solute concentration that is

lower page 4

Engulfment of solid matter by a cell involves the process

phagocytosis page 6

Phagocytosis and pinocytosis are special cases of

active transport page 6

The stability maintained by a living system, or the dynamic equilibrium of the extracellular fluid is termed

homeostasis page 1

A red blood cell is placed in distilled water, or a hypotonic solution. It will (lose, gain) water.

gain page 4

10
A cell is placed in a hypertonic solution. It will (gain, lose) water.

lose  page 4

Cells placed in an isotonic solution will (gain, lose) water.

neither  page 4

A cell takes up ions against a concentration gradient. This is an example of

active transport  page 6

Energy is required to move molecules (against, with) a concentration gradient in active transport

against  page 3

If molecules are moving with a concentration gradient there is no need for the cell to expend

energy  page 3
ENERGY AND ENZYMES

UNIT 5

OBJECTIVES

To identify from a list by name or description

a) the concept of homeostasis and entropy in terms of energy
b) the concept of energy of activation and enzyme activity
c) the concept of enzyme mechanism
d) the concept of how enzymes are inhibited
e) the major classifications of enzymes
f) the common forms of energy in biological systems
g) the concepts of high energy compounds and their formation
h) the concept of oxidation-reduction chain reactions
ENERGY AND ENZYMES

All ordered systems have a natural tendency to run down or become less ordered and therefore more random. As order decreases, entropy (measurement of randomness) increases. A living cell is a highly ordered system and it also has a natural tendency to become disorganized.

To demonstrate the concepts of entropy, energy and homeostasis let us use the bedroom of a typical teenager. It is improbable that this room will be in a highly ordered, or organized, state and more probable that it will be disorganized with items randomly placed. To return the room to an organized condition requires work (the movement of matter) and energy (the ability to do work). To maintain the room in an ordered state one would have to continuously supply energy to offset the natural tendency toward disorganization. Because energy cannot be created or destroyed, the energy used to organize the room has been transformed into the ordered state and will be released as entropy increases. To sum up these concepts, let us put this in diagramatic form:

- Order State
  - Improbable
  - Less Stable
  - More Energy
- Unordered State
  - More Probable
  - More Stable
  - Less Energy

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As stated above, a viable cell is a highly ordered state and therefore requires a continuous source of usable energy to maintain itself against the natural tendency to become disorganized or more random. The dynamic steady state thus maintained is termed homeostasis and if the supply of available energy ceases, the cell will no longer be able to maintain a homeostatic condition and will die during an increase of entropy.

Chemical energy is the energy that a molecule possesses due to the kinds of atoms it contains and the manner in which they are bonded together. Cells are composed of chemical substances which contain differing amounts of energy. These substances enter into many chemical reactions and in doing so their energy content is altered. The sum total of all chemical reactions within the cell is termed metabolism. Those reactions which release energy as molecules are rearranged are known as exergonic reactions, whereas those reactions which require additional energy to be accomplished are known as endergonic reactions. The chemical processes involving the breaking down of complex substances into simpler substances, usually exergonic reactions, are known as catabolic reactions. Anabolic processes are those reactions which involve a synthesis of more complex molecules or chemical substances from simpler substances, and are usually endergonic. Metabolism, therefore, is the total of both catabolism and anabolism, as chemical substances exchange energy as reactions occur.

The amount of energy necessary to break existing chemical bonds so that others may be formed is known as activation energy. Heat will increase molecular movement, thereby increasing the amount of energy
in a system, and supply the necessary activation energy for a reaction to occur. The degree of heat necessary for biochemical reactions can be fatal to the organism however, and another means of overcoming the necessary activation energy will be vital to cellular existence.

Enzymes are organic catalysts which reduce the energy of activation for biochemical reactions, or in other words, allow the reactions to occur at lower temperatures. Enzymes are not altered during the reaction, and can be utilized over and over again. Enzymes will not cause any reaction to occur that would not normally take place in time, but does speed up the reaction rate. Diagramatically this can be shown as:

\[ \text{Energy level} \]

1. Energy Activation Without Enzyme
2. Energy Activation with Enzyme
3. Energy Change of Reaction

A chemical reaction occurs only if the reactant molecules are close enough to each other for bonds to be broken and/or formed. Molecules will react upon collision with each other, which of course, is why an increase in temperature, or the addition of heat, increases reaction rates. Heat causes an increase in kinetic energy of molecules, which cause increased collisions, and therefore cause more reactions. The contact necessary for a reaction can also be brought about by the
introduction of a substance (catalyst) that will effect the reaction without being altered by it. Enzymes are organic catalysts which allow reactions to occur at lower temperatures and faster rates by bringing reactant molecules close together.

Enzymes are proteins which have specific spatial arrangements dependent upon their primary sequence of amino acids (Unit 2). The reactants upon which they work are called substrates. The enzyme and the substrate recognize each other by having a complementary spatial arrangement of atoms. The areas of recognition of the enzyme molecule are known as active sites, and are those sites in which the substrate molecules fit much as a key fits into a particular lock. Once the substrate has been fitted into the active site, there is enough pressure upon substrate bonds to force the splitting of a molecule in the case of decomposition reactions. In synthesis reactions, two reactants are brought together in such close contact that a new bond may be formed between them. The direction of the reaction will be determined by concentrations of reactants and products and energy requirements. In diagramatic form, the reaction is viewed as:

\[
\text{Glucose (G) + Glucose (G) \rightarrow Maltose (M)}
\]

In the above diagram, it can be seen that the reactants, or substrates, form a complex with the enzyme during the reaction. This complex then will separate into the products and return the enzyme
unaltered to repeat another reaction. This is often demonstrated in the following way:

\[ S + E \rightarrow ES \rightarrow E + P \]

Enzymes are large molecules in comparison to their substrates. Sucrose, a disaccharide, contains 45 atoms whereas sucrase, the enzyme which acts upon sucrose, is over a thousand atoms. Enzymes are highly specific and usually will catalyse only one reaction involving one substrate. A different enzyme is therefore necessary to catalyze each of the many chemical reactions occurring within the cell. Enzymes which are utilized outside of cellular reactions are known as extracellular enzymes and are involved with digestion processes.

Enzyme specificity is due to the configuration of the active site and the substrate which fits into it. If a similar substrate partially fits by spatial arrangement into the active site, the enzyme catalyzed reaction may be inhibited, as the normal substrate will be prevented from forming an enzyme-substrate complex. This mode of preventing an enzyme from functioning is known as competitive inhibition. This can be viewed as:

Normal Enzyme Action

\[ \text{\includegraphics[width=0.5\textwidth]{normal_enzyme.png}} \]

Competitive Inhibition:

\[ \text{\includegraphics[width=0.5\textwidth]{competitive_inhibition.png}} \]

Some enzymes need non-protein components to be able to function. The protein portion of these enzymes are then called apoenzymes and the non-protein component a co-factor, which may or may not be directly attached to the protein portion. Together they are functional, or show activity, and are known as a holoenzyme. These enzymes may be
Sulfanilamide

Para-aminobenzoic Acid

Normal enzyme reaction: Enzyme + PABA $\rightarrow$ Enzyme + Folic Acid

Inhibited reaction: Enzyme + Sulfanilamide $\rightarrow$ No reaction

Figure 1. An example of how enzyme inhibition has become a useful mechanism to man in fighting disease. Pathogenic bacteria require the production of folic acid from the substance of para-aminobenzoic acid (PABA) to incorporate it into a vitamin B complex. By using the drug sulfanilamide, a substrate analog, the enzyme which catalyzes this reaction can be inhibited. The enzyme will combine with the drug and not its natural substrate and the active site becomes tied up. This is a case of competitive inhibition and the amount of inhibition will depend upon the amount of the drug taken.

If the bacteria is unable to produce the required product to sustain its metabolism it will not be able to maintain itself or undergo growth. In this way the pathogenic bacteria are kept under control and eventually eliminated as a disease causing agent in multicellular organisms.

The entire inhibition mechanism is possible because of the close similarity or spatial configuration of the substrate with the analog.
inhibited by removing the co-factor from the apoenzyme to destroy its catalytic activity. This form of inhibition is known as non-competitive inhibition as there is no competition for the active site itself.

Some reactions of metabolism require not only the specific enzyme but also a co-enzyme (Unit 2) which is necessary to remove atoms or molecules released during the reaction. The reaction will be blocked if the co-enzyme is not available as an acceptor molecule. This blockage is another form of non-competitive inhibition of enzyme action.

It is customary to classify enzymes on the basis of their action and to indicate the fact that they are enzymes by adding the suffix of "ase". Certain enzymes which have been known about for many years, such as trypsin and pepsin, have not been converted to the newer classification system. On the basis of function, enzymes have been grouped into six categories as follows:

1. Oxidoreductases: those enzymes which catalyse oxidation-reduction reactions. More specific examples would include:
   a) oxidases
   b) dehydrogenases

2. Transferases: enzymes which catalyse the transfer of a chemical group from one molecule to another. Examples would be:
   a) transaminases
   b) kinases

3. Hydrolases: enzymes which catalyse the hydrolysis of substrates:
   a) proteases
   b) lipases
   c) amylases

4. Lyases: enzymes which catalyse the removal of a group of atoms:
   a) decarboxylases
   b) deaminases
5. Isomerases: enzymes which rearrange isomers. Examples would be:
   a) epimerases
   b) mutases

6. Ligases: enzymes which function to link two molecules together.
   a) DNA ligase
   b) polymerases

The naming of enzymes may also indicate what substrate is acted upon as well as the type of action which is completed. It is important to remember to break down the scientific nomenclature in order to read the name of an enzyme. For example:

Sucrase: enzyme which hydrolyses sucrose.

Esterase: enzyme which acts upon ester bonds.

Hexokinase: enzyme which phosphorylates a hexose.

Ethyl-amino-methyl-transferase: enzyme which transfer a methyl group from an amino acid containing an ethyl group.

Lactic dehydrogenase: removes hydrogens from lactic acid.

Most cellular metabolic pathways are in a series of steps and involve multienzyme systems. Chemical changes are made in small steps in order to more efficiently transform energy released into a usable form, allowing as little loss as possible in the formation of heat. Combustion reactions outside of biological systems can be viewed as in the example of burning a fuel:

heat

\[ \text{wood (fuel)} + \text{match (activation energy)} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Ash (products)} \]

The energy released from the fuel in the example above is in the form of heat, or chaotic energy. The cell cannot tolerate such a release of fuel energy (glucose) in one large reaction as much of
the energy would be in the form of unusable heat. The cell, therefore, releases energy in many small steps in order to efficiently transform as much of the energy as possible into a usable form with a minimum amount of heat loss. A multienzyme system is one involved with a series of small steps in a chemical pathway that alters the energy content of chemical substances from a beginning substrate to an end-product.

\[
A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow P
\]

Each of the above steps of a metabolic pathway involves the catalytic reaction of a specific enzyme. By accomplishing a series of chemical changes in small steps cells are able to manage the energy released, or required, in a more efficient manner. Heat energy is not a usable form of energy for cellular metabolism as it escapes into the environment, as in combustion, and would also prove detrimental to enzyme, or protein, structure. By transforming energy content in small steps, the cell is able to capture, or utilize, it with as little heat loss as possible.

All environmental factors that alter proteins (Unit 2) will affect any enzyme of a multienzyme system. Any increase in temperature is going to increase reaction rates between chemical substances. Any change in concentration of initial substrate (A in the above example) or end-product (P in the above example) will also influence the rate of reaction as well as the direction of the reaction. If any single enzyme of a pathway is inhibited or not present, then a buildup of any of the intermediates (B through E of the above reaction) can be a serious result of metabolic failure.
BIOLOGICAL ENERGY

Energy is associated with all chemical bonds found within a living system, but usable biological energy is usually associated with either electrons, often carried in association with a proton (H\(^+\)), and with phosphate groups involved in high energy compounds.

The nucleotide structure is the basis for high energy compounds (Unit 2). Adenosine-monophosphate is a nucleotide which is composed of adenine as a nitrogenous base, ribose as a pentose sugar, and a single phosphate group. A second phosphate group can be added to the first to form adenosine-diphosphate. This second phosphate bond requires more energy to form and therefore will release more energy when it is broken. A third phosphate group can be added to the second to form adenosine-triphosphate, or ATP, and is also a high energy chemical bond. All of the five nitrogenous bases found in nucleotides are capable of this same formation to create high energy compounds. ATP, however, is the common form of usable potential energy in cellular metabolism.

![Nucleotide Structure Diagram]

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The formation of ATP is known as phosphorylation. Three processes of phosphorylation are recognized as photophosphorylation, substrate phosphorylation and oxidative phosphorylation (Unit 6) and differ only in the energy source utilized to add a phosphate group to ADP. The high energy compound formed is thus able to be broken when energy requiring reactions occur in what are known as coupled reactions. As an exergonic reaction releases energy, an endergonic reaction utilizes it:

\[
\begin{align*}
A + B & \rightarrow \text{ATP} \\
\text{C} & \rightarrow \text{ADP} + \text{P}
\end{align*}
\]

Oxidation-reduction reactions: The passage of electrons between molecules are involved in oxidation-reduction reactions. Oxidation is the loss of electrons, and reduction is the gain of electrons. The passing of an electron from one acceptor to another constitutes a chain of reactions, each of which is catalyzed by enzymes. As an electron passes through a chain or acceptor molecules, it gradually loses its energy in small steps. These small amounts of energy are utilized to synthesize ATP, and are one of the chief means of releasing energy. An example of an electron transport chain would be: \((a,b,c,\text{ etc.} = \text{acceptor molecules})\)

![Electron transport chain diagram]

Electrons are therefore examples of kinetic energy changes, going from high energy levels to low, which release energy in small steps in
order that living systems can transform that energy into a potential energy source, or ATP. To repeat, all chemical molecules contain energy in their chemical bonds, but the usable forms of chemical energy are associated with the movement of electrons and the transformation of this energy into potential energy sources such as ATP. ATP functions as the energy source of cells to maintain homeostasis and overcome the natural tendencies of all organized states to become random, more stable, and less energetic. Without a continuous supply of usable energy the cell will not be able to maintain itself and will therefore decompose into lower levels of complexity which will result in the death of the organized unit known as the cell.

GLOSSARY

Activation energy The amount of energy necessary to initiate a reaction.
Active site The area on a molecule which is involved in chemical reactions.
Anabolism Chemical reactions involving the synthesis of more complex molecules from simpler ones.
Apoenzyme The protein portion of an enzyme which requires a co-factor for activity.
ATP Adenosine-tri-phosphate; the most common high energy compound found in living systems.
Catabolism Chemical reactions involving the degradation of complex molecules into simpler ones.
Catalyst A substance that causes a chemical reaction to occur at lower temperatures and at a faster rate.
Co-enzyme An organic molecule required by certain enzymes to catalyse a particular chemical reaction by accepting atoms or groups of atoms.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-factor</td>
<td>Any of several inorganic substances, or ions, necessary for enzyme activity.</td>
</tr>
<tr>
<td>Competitive inhibition</td>
<td>The process of stopping or decreasing the rate of enzyme activity by tying up the active site.</td>
</tr>
<tr>
<td>Endergonic</td>
<td>A chemical reaction that absorbs energy, usually an anabolic reaction.</td>
</tr>
<tr>
<td>Energy</td>
<td>The ability to do work, or move matter.</td>
</tr>
<tr>
<td>Entropy</td>
<td>A measurement of disorganization or randomness.</td>
</tr>
<tr>
<td>Enzyme</td>
<td>Biological catalysts; mainly proteins.</td>
</tr>
<tr>
<td>Exergonic</td>
<td>A chemical reaction that releases energy, usually a catabolic reaction.</td>
</tr>
<tr>
<td>Extracellular</td>
<td>Occurring outside of a cellular structure.</td>
</tr>
<tr>
<td>Holoenzyme</td>
<td>A functional enzyme with a necessary co-factor.</td>
</tr>
<tr>
<td>Homeostasis</td>
<td>A dynamic steady state or equilibrium of living systems maintained by a constant flow of energy.</td>
</tr>
<tr>
<td>Intermediate</td>
<td>A derivative of a substrate formed before the end product in a series of chemical reactions.</td>
</tr>
<tr>
<td>Kinetic energy</td>
<td>Energy of motion.</td>
</tr>
<tr>
<td>Metabolism</td>
<td>The sum total of all chemical reactions within a living system.</td>
</tr>
<tr>
<td>Multienzyme system</td>
<td>A metabolic pathway involving numerous small steps, each of which is catalyzed by a different enzyme.</td>
</tr>
<tr>
<td>Non-competitive inhibition</td>
<td>The process of stopping or decreasing the rate of enzyme activity by any means other than tying up the active site.</td>
</tr>
<tr>
<td>Oxidation</td>
<td>The loss of electrons.</td>
</tr>
<tr>
<td>Pathogenic</td>
<td>Disease producing.</td>
</tr>
<tr>
<td>Phosphorylation</td>
<td>The process of adding a phosphate group.</td>
</tr>
<tr>
<td>Photophosphorylation</td>
<td>The process of adding a phosphate group to ADP in photosynthesis using light energy.</td>
</tr>
<tr>
<td>Potential energy</td>
<td>Energy of position or energy available for future work.</td>
</tr>
</tbody>
</table>
Reduction  Gain of electrons.
Substrate  The initial substance acted upon in a metabolic pathway of chemical reactions.
Work      The movement of matter.

PROGRAMMED SELF TEST - UNIT 5

All ordered systems have a natural tendency to become random, or less ordered
The measurement of randomness, or disorder is entropy
In regards to energy, an ordered system contains more
As an ordered state becomes more disorganized there is a release of energy
The dynamic steady state maintained by a living system against the natural forces leading to disorganization is termed homeostasis
The sum total of all chemical reactions within a living system metabolism
Those metabolic reactions which release energy are exergonic
Most exergonic reactions involve the metabolic reactions of catabolism
Those metabolic reactions which absorb or use energy are endergonic
Most endergonic reactions involve the metabolic reactions of anabolism
Catabolic and anabolic reactions together are termed metabolism.
The amount of energy necessary to start a chemical reaction is activation energy.
Organic catalysts are known as enzymes.
Enzymes are mainly composed of the macromolecules proteins.
Enzymes operate by reducing the energy of activation.
The area on an enzyme which recognizes the substrate is active site.
Enzymes that function outside of a cellular unit are extracellular enzymes.
The type of enzyme inhibition resulting from an abnormal substrate tying up the active site is competitive.
An apoenzyme requires what substance to be active co-factor.
If a co-factor or co-enzyme is tied up the inhibition is non-competitive.
An apoenzyme plus its cofactor shows activity and is called a holoenzyme.
A transferase would be involved in doing what function transferring an atom or group of atoms.
An enzyme that catalyses the rearrangement of molecules is isomerase.
A chemical pathway involving small steps would involve a multienzyme system.

In the pathway of $A \rightarrow B \rightarrow C \rightarrow D \rightarrow P$, B would be an intermediate.

The common form of potential usable energy is ATP.

The loss of electrons is oxidation.

The gain of electrons is reduction.

Biological energy is usually associated with electrons and phosphates.

Electron transport chains transform the energy of electrons to potential energy in the form of ATP.
OBJECTIVES

To identify from a list or diagram by name or description:

a) the concept of energy conversion in photosynthesis

b) the major substrate, intermediates and products of anaerobic and aerobic cellular respiration

c) the major co-enzymes involved with cellular respiration

d) the concept of phosphorylation

e) the organelles involved with bioenergetics
BIOENERGETICS

Life is a unique interaction of matter and energy. The element of matter cycle within our biosphere whereas energy flows through it. Elements remain constant in quantity as long as they are retained on our planet whereas energy enters our system as radiant energy transformed into usable chemical energy and is ultimately dissipated as heat, or chaotic energy, as it passes through.

The ultimate source of energy for sustaining living systems is the sun which emits light energy in the form of photons, or wavelengths. Radiant energy is of little value unless it can be transformed into usable chemical forms such as ATP, or organic molecules such as monosaccharides. The process which converts the energy of light into organic compounds is the process of photosynthesis, the major anabolic pathway found in green plants. The chloroplasts, plant organelles containing chlorophyll, are energy conversion systems within which radiant energy is transformed into chemical energy and are basically the only means of providing a constant flow of energy into the living world. The topic of photosynthesis will therefore be considered in this unit to aid in the understanding of cellular respiration, a process which utilizes the energy of organic molecules produced by photosynthesis.

The necessary reactants for photosynthesis are water and atmospheric carbon dioxide. The overall reaction can be written as:

$$6\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$

The overall reaction does not indicate exactly the process which
occurs as the combination of carbon dioxide and water leads to the formation of carbonic acid and not sugar. As one might guess, the process of photosynthesis is much more complicated than the formula suggests. Before looking into the phases of photosynthesis one important concept must first be understood, that of photoexcitation.

PHOTOEXCITATION: Photoexcitation is the process of raising an electron from a lower energy level to a higher energy level. This is an endergonic reaction with the energy supplied by a photon or energy unit of light. The electron spinning in its normal orbit is at ground state, whereas it is in an excited state when pushed into a higher energy level. The absorption of energy by the electron means that the radiant energy has been converted, or transformed, into the energy of the electron. The excited electron is less stable due to the excess energy it contains and it has a natural tendency to return to a more stable state, or to return to its original orbit. The energy it had absorbed would then be released, or transformed, as heat or light. The following diagram illustrates the photoexcitation of an electron contained within a chlorophyll molecule:

![Diagram of photoexcitation](image)

PHOTOSYNTHEIS

The entire process of photosynthesis is divided into two basic reactions called the light and dark reactions based on whether they are directly dependent upon sunlight to occur. The two light reactions occur

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on the grana of the chloroplast to which the chlorophyll molecules are attached. The dark reaction is dependent upon the products produced in the light reaction to fix carbon dioxide into organic molecules and occurs in the stroma of the chloroplast.

**CYCLIC LIGHT REACTION:** The cyclic light reaction involves the process of forming ATP by photophosphorylation. Photoexcitation of an electron raises the electron to an excited state which is picked up before it returns to ground state by an iron containing compound called ferredoxin. Ferredoxin hands the excited electron to a cytochrome system, or a chain of molecules which undergo oxidation-reduction reactions, to slowly lower the electron in small steps of energy release. In this manner the energy which would have been released as heat or light may be utilized to add a phosphate group to ADP to create ATP. Thus, the energy wavelength of sunlight, or photon, has been transformed first into the energy of the electron and now into the energy of a chemical bond as ATP. ATP is a usable potential energy source for cellular metabolism. Diagramatically this process of cyclic light reactions can be shown as:

![Cyclic Light Reaction Diagram]

**NONCYCLIC LIGHT REACTION:** The above reaction is called cyclic because the electron is returned to the chlorophyll molecule to be re-excited and repeat the process. The noncyclic light reaction is somewhat more complicated as the electron will not be returned to the

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phyll molecule.

Photoexcitation again raises electrons to an excited state which are again captured by ferredoxin. In this case, however, ferredoxin hands the excited electrons to a co-enzyme capable of accepting them, or NADP. NADP has the ability to handle excited electrons but accepts them only in conjunction with protons to produce NADP\textsubscript{H}\textsubscript{2}, or the reduced form of NADP.

\[
\text{NADP} + 2e^- + 2H^+ \rightarrow \text{NADP}\textsubscript{H}\textsubscript{2}
\]

NADP\textsubscript{H}\textsubscript{2} is the main product of the noncyclic light reaction and the electrons can not be returned to the chlorophyll pigment, which is now short of electrons for photoexcitation. Chlorophyll must be supplied with a source of electrons to continue any further reactions. The source of replacement will ultimately result from the ionization of water:

\[
2H_2O \rightarrow 2H^+ + 2OH^-; \text{ or } 2H^+ + 2OH^- + 2e^- 
\]

The above reaction will provide the source of protons (H\textsuperscript{+}) for NADP and an electron source for the chlorophyll pigment. The remaining OH molecules will recombine to form water and oxygen, a by-product that is released into the atmosphere by diffusion. The diagram following this discussion will aid in following the processes of noncyclic light reactions of photosynthesis. The entire chemical pathway has been simplified to emphasis particular relationships and is of course much more involved than this explanation indicates.
Two products, NADPH₂ and ATP, are thus formed by the two light reactions and the radiant energy from sunlight is now captured in the form of a phosphate bond (ATP) and electron energy levels of NADP⁺H₂. These two products will be used in the dark reaction to incorporate atmospheric carbon dioxide into organic compounds. Oxygen is released into the atmosphere as a by-product of the ionization of water and is not directly involved with the carbon dioxide cycle.

DARK REACTION: The fixation of carbon into organic molecules involves a metabolic cycle which generates both a sugar product and regenerates the beginning molecule of the reaction sequence.

RDP (ribulose diphosphate) is a five carbon sugar capable of combining with carbon dioxide to form a six carbon compound. This six carbon compound is extremely unstable and splits immediately into two three carbon organic acids known as PGA or phosphoglyceric acid. Energy is necessary for the conversion of PGA into PGAL, or Phosphoglyceraldehyde, which is a triose phosphate. The energy required is in the form of ATP and excited electrons carried by NADP⁺H₂, or the products of the light reaction, which are used to accomplish the conversion of an acid into a sugar.
Two triose products can be combined to form fructose, or plant sugar, which can be rearranged to form glucose. Excess glucose can then be linked into storage chains or starch. Two of the important intermediates within the dark reaction cycle are PGA and PGAL. PGA will give rise to amino acids by the addition of amino groups, to fatty acids as components of triglycerides and to organic carboxylic acids. PGAL not only gives rise to carbohydrates but also to glycerol for the formation of triglycerides as well as recombining through various steps to regenerate the RDP molecule. The diagram that follows shows the above steps.

[Diagram]

---

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CELLULAR RESPIRATION

Cellular respiration involves a series of exergonic chemical reactions which enable cells to release the energy stored in the chemical bonds of organic molecules, particularly carbohydrates. Glucose is the major fuel of cellular respiration and results from the degradation, or hydrolysis, of the macromolecules of starch and glycogen which are storage forms. In order to put this concept into a framework, let us state that the above plant undergoing photosynthesis was a potato plant. The excess amounts of PGAL produced were converted into glucose and stored in the tuber as starch granules until utilized. The potato is eaten by man and extra-cellular digestion begins to hydrolyse the starch polysaccharide into disaccharides (maltose) within the mouth by the enzyme amylase. This process is halted in the stomach due to the acidic pH, but is continued in the small intestine by pancreatic amylase and maltase. The end product of extra-cellular digestion is glucose which is absorbed into the blood stream and circulated to the cells as the beginning substrate for cellular respiration.

The respiratory chain of reactions involving the oxidation of glucose is divided into three phases. The first phase is termed glycolysis and occurs in the cytoplasm of the cell. It is termed anaerobic respiration as it does not require the presence of molecular oxygen. Each of the small chemical steps involved in the sequence of reactions is catalyzed by a specific enzyme.

GLYCOLYSIS: The first step in the oxidation of glucose is the activation of the hexose by the addition of a phosphate group from ATP:
The glucose-6-phosphate molecule is then rearranged by an isomerase to form fructose-6-phosphate. Fructose-6-phosphate accepts a second phosphate group from another ATP to form fructose-1,6-diphosphate, or fructose-diphosphate. The numbers in the above terms are there to indicate on which carbon the phosphate group can be found.

Fructose diphosphate splits into two triose phosphates. One half of the fructose molecule forms phosphoglyceraldehyde (PGAL) and the other half forms dihydroxyacetone-phosphate. These triose sugars are isomers and all dihydroxyacetone-phosphate molecules are converted into the PGAL form to continue down the oxidative pathway.
FGAL is converted to PGA (phosphoglyceric acid) in a series of small steps, all of which are not shown in the reaction below. This sequence of reactions are reverse to those found in the dark reaction of photosynthesis. ATP and NADPH$_2$ were necessary for the formation of PGAL in that case, and will now be released in the respiration sequence as PGA is formed.

\[
\text{glyceraldehyde-3-phosphate} \rightarrow 3\text{-phosphoglyceric acid}
\]

PGA is converted into pyruvic acid by way of another series of small steps. Pyruvic acid is the end product of the glycolytic pathway as the phosphate groups are removed from PGA and added to ADP to form ATP.

\[
\text{3-phosphoglyceric acid} \rightarrow \text{Phosphoenolpyruvic acid} \rightarrow \text{pyruvic acid}
\]

The over-all reaction of glycolysis results in the production of two pyruvic molecules, the formation of 2 NADH, and the creation of 4 ATP molecules from an initial substrate of one glucose molecule:

- Two pyruvic \text{ step 5}
- Two NADH \text{ step 4 (one for each half of glucose) }
- Four ATP \text{ step 4 and 5 (one at each step for each half of the glucose molecule)
Two ATP's were used in the initial reactions (step 1 and 2) and so the net synthesis of ATP, or net gain, is two ATPs for each glucose molecule.

The fate of pyruvic acid will depend on a number of factors. If the cell in question does not possess the organelle known as the mitochondrion it is not capable of aerobic respiration. In this case the NADH must deposit the hydrogens on some acceptor molecule in order to free NAD to return as a co-enzyme to step 4. The conversion of PGAL to PGA will not occur if this necessary co-enzyme is not free of hydrogen atoms. Pyruvic in this case will be converted into ethyl alcohol and carbon dioxide by accepting the hydrogens from NADH.

\[
\begin{align*}
\text{COOH} & \quad \text{NADH} & \quad \text{NAD} & \quad \text{H}_2\text{COH} \\
\text{C} = \text{O} & \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \text{CH}_3 + \text{CO}_2
\end{align*}
\] (5a)

ethyl alcohol

If the cell does possess a mitochondrion capable of aerobic respiration but there is no oxygen available then pyruvic acid will be converted to lactic acid by accepting the hydrogens from NADH.

\[
\begin{align*}
\text{COOH} & \quad \text{NADH} & \quad \text{NAD} & \quad \text{COOH} \\
\text{C} = \text{O} & \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \text{CH} & \quad \text{CH}_2
\end{align*}
\] (5b)
lactic acid

Both steps, 5a and 5b, above are continuations of anaerobic respiration and occur within the cytoplasm. The term fermentation implies this form of glucose oxidation. A molecule still exists as the end product and this process is therefore considered to be an incomplete form of oxidation.
KREBS CYCLE: Pyruvic can continue to be oxidized if there is a supply of oxygen and the mitochondrion is present to receive it. A molecule of CO₂ will be released and hydrogens given to NAD as a co-enzyme (co-enzyme A or CoA) picks up the two carbon fragment remaining and carries it into the mitochondrion. The two carbon fragment and the co-enzyme A together are called Acetyl CoA.

\[
\begin{align*}
\text{COOH} & \quad + \quad \text{NAD} \quad \text{NADH} \\
\text{CH₃} & \quad \rightarrow \quad \text{Co-A} \\
\text{O=C} & \quad \text{O=C} \quad \text{CoA} + \quad \text{CO₂}
\end{align*}
\]

Pyruvic  co-enzyme A  acetyl CoA

Acetyl CoA feeds the two carbon fragment into a complex metabolic cycle known as the Krebs cycle, or citric acid cycle. The two carbon fragment is handed to oxaloacetic acid or OAA which is a four carbon organic acid to form citric acid, a six carbon organic acid. CoA, once it has fed the two carbon fragment into this second major phase of cellular respiration (Krebs cycle), it is free to return for additional two carbon fragments to reform acetyl-CoA.

The six carbon citric acid molecule is rearranged through a series of steps involving the gain and loss of water molecules before it releases a molecule of carbon dioxide (CO₂) and two hydrogens (H₂) to form a five carbon organic acid called α-ketoglutaric acid. The hydrogens are picked up by NAD to form NADH₂ and the carbon dioxide is eliminated as a waste product. α-ketoglutaric undergoes rearrangement, the loss of hydrogens to NAD to form NADH₂, and the loss of carbon dioxide (CO₂) to form a four carbon organic acid called succinic acid. This chemical reaction involves enough of an energy drop to create one molecule of ATP from ADP and a free phosphate group.
Succinic is rearranged to eventually form fumaric acid, also a four carbon organic compound, with the release of hydrogens to the co-enzyme FAD to form FAD$^\cdot$H$_2$. Fumaric is converted into OAA, our starting organic acid, by the additional loss of hydrogens to NAD to form NAD$^\cdot$H$_2$. The entire sequence of reactions is shown schematically in Figure 1.

ELECTRON TRANSPORT CHAIN: The third and final phase of cellular respiration involves a series of oxidation-reduction reactions. The original two carbon fragment that entered the citric acid cycle has now been degraded completely to carbon dioxide and hydrogens, or electrons in association with protons, in the form of NAD$^\cdot$H$_2$, and FAD$^\cdot$H$_2$. These carrier molecules now enter a respiratory electron transport chain which consists of cytochrome molecules capable of lowering the energy level of electrons slowly, and in small enough steps, to transform the energy into the chemical bonds of ATP by adding a phosphate group to ADP. This form of phosphorylation is oxidative as molecular oxygen is required as the final electron acceptor. Oxygen plus the lowered electrons and protons form the end product of metabolic water Three ATP molecules are formed for each NAD$^\cdot$H$_2$ co-enzyme that enters the pathway, whereas only two are formed for each FAD$^\cdot$H$_2$ co-enzyme.

Aerobic cellular respiration involves all three phases, and is a complete oxidation of the glucose molecule as it has been completely eliminated as carbon dioxide and water. The overall chemical equation would appear as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 12H_2O \text{ energy}$$
Figure 1. Diagram demonstrating the Krebs cycle (A) and its major intermediates, coenzyme action and elimination of carbon dioxide. The electron transport chain (B) is where oxidative phosphorylation occurs.
Aerobic cellular respiration is much more efficient in the transformation of energy from glucose into the potential energy of ATP, the energy source of the cell. Anaerobic respiration resulted in the net production of only 2 ATP molecules, whereas aerobic respiration produces a total of 38 ATP molecules from each glucose molecule oxidized. These 38 ATP molecules are derived in the following way:

### Glycolysis:

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<th>ATP</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>$1 \times 2$</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>$1 \times 2$</td>
</tr>
<tr>
<td>1 &amp; 2</td>
<td>-2</td>
<td>$1 \times 2$</td>
</tr>
</tbody>
</table>

**Net Total**

<table>
<thead>
<tr>
<th>ATP</th>
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</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

### Krebs Cycle:

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<td>2</td>
</tr>
</tbody>
</table>

### Electron Transport Chain:

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<th>Calculation</th>
</tr>
</thead>
<tbody>
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<td>24</td>
<td>$(2 \times 4 \times 3)$</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>$(1 \times 2 \times 2)$</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>$(1 \times 2 \times 3)$</td>
</tr>
</tbody>
</table>

**Total**

<table>
<thead>
<tr>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
</tr>
</tbody>
</table>

### Glossary

- **Acetyl-CoA**: An intermediate of cellular respiration composed of a two-carbon fragment attached to the coenzyme A.
- **ADP**: Adenosine-di-phosphate.
- **Aerobic**: Respiration that uses molecular oxygen.
- **α-ketoglutaric**: A five-carbon organic acid occurring in the Kreb cycle.
- **Anabolic**: A constructive, or building, reaction of metabolism.
- **Anaerobic**: Respiration that does not require molecular oxygen.
ATP
Adenosine-tri-phosphate; high energy compound.

Endergonic
A biochemical reaction that requires energy to occur.

Ethyl alcohol
The end product of fermentation in anaerobes.

Exergonic
A biochemical reaction that releases energy.

Catabolic
A degradative chemical reaction of metabolism.

Chloroplast
Plant organelle in which photosynthesis occurs.

Chlorophyll
Pigment that is capable of participating in the light reactions of photosynthesis.

Citric
A six carbon organic molecule in the Krebs cycle.

Cytochrome
A molecule involved in oxidation-reduction reactions.

Fermentation
Anaerobic respiratory process; produces ethyl alcohol and carbon dioxide.

Ferredoxin
Plant molecule capable of accepting excited electrons.

Fructose
A hexose or six carbon sugar; a ketone.

Fumaric
A four carbon organic acid in the Krebs cycle.

Glucose
A hexose or six carbon sugar; an aldehyde.

Glycerol
A three carbon alcohol; composes triglycerides.

Glycolysis
The first phase of cellular respiration; anaerobic.

Krebs cycle
A metabolic cycle found in the mitochondrion which oxidizes the remainder of pyruvic to CO₂ + hydrogens.

Lactic acid
End product of anaerobic respiration in muscle cells.

Mitochondrion
The organelle involved with aerobic respiration.

NAD
Nicotinamide adenine dinucleotide; a co-enzyme.

NADP
Nicotinamide adenine dinucleotide phosphate; a co-enzyme.

Oxaloacetic acid
OAA: a four carbon acid of the Krebs cycle.

PGA
Phosphoglyceric acid; a phosphate 3 carbon acid

PGAL
Phosphoglyceraldehyde; a phosphated triose.

Phosphorylation
The formation of ATP from ADP + P.

Photoexcitation
The process of raising an electron from a lower energy orbital level to a higher level by radiant energy.
Photon  A unit of light energy.
Photosynthesis  A major anabolic pathway found in green plants; involves the building of organic molecules from CO₂ and H₂O.
Radiant  A form of energy: sunlight.
Respiration  A major catabolic pathway in which organic molecules are oxidized to CO₂ and H₂O with release of energy.
Succinic  A four carbon acid of the Krebs cycle.
Triglycerides  Common form of lipids composed of glycerol and three fatty acids.
Triose  A three carbon sugar.

PROGRAMMED SELF TEST - UNIT 6

The transformation of radiant energy into the energy of an excited electron is a process known as

photoexcitation  page 1

The two light reactions of photosynthesis produce

ATP, and NADP⁺H₂  page 2, 3

The energy products of the light reaction are incorporated into what triose during the dark reaction of photosynthesis

PGAL, or phosphoglyceraldehyde  page 4

All matter cycles, but energy flows through the biosphere from the

sun  page 1

Atmospheric, or molecular oxygen arises in photosynthesis from the ionization of

water  page 4

Carbon dioxide is fixed into an organic compound as an

acid, COOH  page 4

ATP and NADP⁺H₂ are utilized in changing an acid, PGA, into

PGAL  page 4

Excess products of photosynthesis are stored as

starch  page 4
The process of photosynthesis occurs in the plant organelle

chloroplast

The oxidation of glucose within a cell is known as

cellular respiration

The beginning substrate for cellular respiration is

glucose

The first phase of cellular respiration is called

glycolysis

Glycolysis occurs in the

cytoplasm

Cellular respiration without oxygen is called

anaerobic

The form of phosphorylation in glycolysis is called

substrate

The end product of glycolysis is

pyruvic acid

The net synthesis of ATP during glycolysis is

2

If there is no mitochondrion or oxygen then pyruvic becomes

ethyl alcohol & CO₂

If there is a mitochondrion but no oxygen present then pyruvic is turned into

lactic acid

What co-enzyme picks up a two carbon fragment from pyruvic
if there is a mitochondrion and oxygen present

CoA

The two carbon fragment plus CoA that enters the mitochondrion is called

acetyl-CoA
What happened to the other carbon from pyruvic when CoA accepted two of the three carbons

\[ \text{carbon dioxide, } \text{CO}_2 \]

The acceptor molecule of the Krebs cycle is

\[ \text{Oxaloacetic acid or OAA} \]

The six carbon organic molecule formed by OAA and the two carbon fragment is

\[ \text{citric} \]

The major five carbon organic acid of the Krebs cycle

\[ \text{keto glutaric} \]

The co-enzyme which accepts hydrogens in glycolysis

\[ \text{NAD} \]

The two co-enzymes that accept hydrogens in the Krebs cycle

\[ \text{NAD, FAD} \]

The carbon dioxide released during respiration arises from

\[ \text{the organic molecule} \]

The hydrogens are transported by NAD and FAD to the

\[ \text{electron transport chain} \]

The electron transport chain involves the chemical reactions

\[ \text{oxidation and reduction} \]

The final electron acceptor of the electron transport chain

\[ \text{oxygen} \]

The fate of molecular oxygen is

\[ \text{water} \]

How many ATP's are produced in aerobic respiration per glucose

38

Aerobic respiration occurs in the organelle

\[ \text{mitochondrion} \]

How many ATP molecules are produced by NADH in the electron transport chain

3
INTEGRATED METABOLISM

UNIT 7

OBJECTIVES

To identify from a list or diagram by name or description

a) the major intermediates for the oxidation of proteins and lipids

b) the major products of cellular respiration

c) the major waste products and their elimination routes

d) the limiting factors of cellular metabolism
INTEGRATED METABOLISM

The discussion of cellular respiration (Unit 6) centered around glucose as a starting fuel and, indeed, glucose is a focal point as the beginning substrate for the respiratory sequence. Other molecules also participate in cellular respiration, however, and their relationship to the main line of oxidation-reduction reactions must be considered to obtain an overall view of cellular metabolism. As a brief review of glucose catabolism the following chart sums up the sequence of reactions discussed previously in detail (Unit 6):

Glycolysis
(Anaerobic respiration occurring in the cytoplasm.)

Citric Acid Cycle
(Aerobic respiration occurring in the mitochondrion.)

Electron Transport Chain
(Aerobic respiration occurring on cristae of mitochondrion.)

Glucose

\[ \text{Glucose} \rightarrow \text{Triose} \rightarrow \text{Pyruvic acid} \rightarrow \text{Acetyl CoA} \rightarrow \text{CO}_2 \]

2-Carbon fragment

Oxaloacetic acid $C_4$

\[ \text{Oxaloacetic acid } C_4 \rightarrow \text{Citric acid } C_6 \rightarrow \text{CO}_2 \]

\[ \text{Malic acid } C_4 \rightarrow \text{a-Ketoglutaric acid } C_5 \]

\[ \text{Fumaric acid } C_4 \rightarrow \text{Succinic acid } C_6 \rightarrow \text{CO}_2 \]

\[ \text{ADP} + P \rightarrow \text{ATP} \]
Any intermediate of the entire glycolytic-citric acid cycle may enter the main line of respiration even though it was produced by some other series of reactions. The following discussions of lipid and protein degradation will emphasize the fact that like molecules from several different reaction series will contribute intermediates to the main line of carbohydrate oxidation and ATP formation.

**LIPID OXIDATION:** The majority of lipids in the diet are in the form of neutral fats or triglycerides. Extracellular digestion of lipids begins in the small intestine with the aid of cholic acid salts as an emulsifying agent and lipase which is water soluble. The products of fat digestion are glycerol and free fatty acids which are absorbed mainly into the lymphatic circulatory system.

Cellular respiration of lipids deals with the oxidation of fatty acids and the conversion of glycerol to a glycolytic intermediate. The following reaction of glycerol into dihydroxyacetone will shuttle this component of triglycerides directly into the respiratory sequence as dihydroxyacetone can be rearranged into glyceraldehyde, the three carbon triose which continues down the pathway to pyruvic:

\[
\begin{align*}
\text{glycerol} & \quad \text{glycerophosphate} & \quad \text{dihydroxyacetone phosphate} \\
\text{CH}_2\text{-OH} & \quad \text{CH}_2\text{-O-P} & \quad \text{CH}_2\text{-O-P} \\
\text{CH} \quad \text{-OH} & \quad \text{CH} \quad \text{-OH} & \quad \text{CH} \quad \text{-OH} \\
\text{CH}_2\text{-OH} & \quad \text{CH}_2\text{-O-P} & \quad \text{CH}_2\text{-O-P} \\
\end{align*}
\]

The fatty acids remaining from the triglyceride molecule are oxidized two carbons at a time, which is the reason that common fatty acids are even numbered carbon chains. The following reaction will
be repeated until the entire fatty acid is completely eliminated:

$$(\text{CoA} = \text{CoA-S-H})$$

$$\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-C-OH} + \text{H-S-CoA} \rightarrow \text{CH}_3\text{-C}^\text{O} \text{S-CoA} + 4 \text{ C acid}$$

six carbon fatty acid + CoA $\rightarrow$ Acetyl CoA + fragment

Acetyl CoA can now enter the respiratory sequence of carbohydrate metabolism and enter the mitochondrion to undergo aerobic oxidation. In this manner the triglyceride has been completely oxidized by entering the main line of cellular respiration in the form of intermediates of glucose catabolism.

PROTEIN OXIDATION: The extracellular digestion of proteins begins in the stomach. The acidic pH plus gastric enzymes begin to hydrolyze the complex protein structures into peptide chains. Intestinal digestion includes the protease enzymes which continue the hydrolyzes of peptides into the end product of digestion or amino acids. Amino acids are absorbed into the blood circulatory system and reach the cell as free amino acids.

Before the carbon skeleton of amino acids can be shuttled into the respiratory chain the amino group must be removed by a deamination reaction. Three carbon amino acids can be thus converted into the respiratory product of pyruvic acid:

$$\text{COOH}$$

$\text{CH}_3\text{-NH}_2 \rightarrow \text{COOH} + \text{NH}_3$

alanine pyruvic ammonia

Four carbon amino acids are converted by deamination reactions into one of several four carbon organic acids involved in the citric acid cycle, such as the following example:
Five carbon amino acids are likewise converted into the intermediate a-ketoglutaric acid of the citric acid cycle:

\[
\text{COOH} \quad \text{CH}_2 \quad \text{NH}_2 - \text{CH} - \text{COOH} \quad \text{O=C} - \text{COOH} \\
\text{aspartic} \quad \text{oxaloacetic (OAA)}
\]

Amino acids which contain more than five carbon skeletons are degraded to 3, 4, or 5 carbon skeletons through a series of reactions to be shuttled into cellular respiration in the same manner. Deamination reactions always involve the waste product of ammonia as a result of the removal of amino groups from the amino acids.

Thus it can be seen that the fuel for cellular respiration can be prepared by a large number of reactions involving the transformation of a large number of food molecules into relatively few intermediates of the respiratory sequence of reactions. The mitochondrion serves the cell as an energy conversion organelle which converts various intermediates into potential usable energy in the form of ATP.

PRODUCTS OF RESPIRATION: The main product of cellular respiration is the potential energy usable to the cell in the form of ATP. The uses of this energy-rich compound in cellular work include the following:

- Glycolysis
- Krebs Cycle
- Oxidative Phosphorylation
- Bioluminescence
- Electrical Discharge
- Protein Synthesis
- Polysaccharide Synthesis
- Lipid Synthesis
- Nucleic Acid Synthesis
- Cell Division
- Active Transport
- Muscular Contraction
- Nervous Transmission

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Cellular respiration is also important as the supplier of basic intermediates for biosynthesis of macromolecules as all of the reactions discussed above are reversible. The cell may need to synthesize triacylglycerides and will do so by pulling out a triose-phosphate from the main line of respiration and convert it to glycerol. Fatty acids may be formed by the reverse sequence of fatty acid oxidation and attached to the glycerol molecule to form the triglycerides needed. In the same manner, or reversal of respiratory sequences, amino acids may be synthesized by the removal of carbon skeletons and an amino group added, usually by a chemical reaction known as transamination, or the addition of an amino group transferred from another amino acid. The following equation is an example of a transamination reaction:

\[
\begin{align*}
\text{Amino Acid} & \quad \text{Organic Acid} \\
\text{COOH} & \quad \text{COOH} \\
\text{H-C-NH}_2 & \quad \text{C=O} \\
\text{R}^1 & \quad \text{R}^2 \\
\rightarrow & \\
\text{Organic Acid} & \quad \text{Organic Acid} \\
\text{COOH} & \quad \text{COOH} \\
\text{C=O} & \quad \text{H-C-NH}_2 \\
\text{R}^1 & \quad \text{R}^2 \\
\end{align*}
\]

WASTE PRODUCTS: Two major waste products result from intermediate cellular respiration in the form of CO\(_2\) and NH\(_3\). These waste products must be eliminated from the cell and its environment to ensure the efficient continuation of metabolic processes.

Carbon dioxide is soluble in water and forms carbonic acid:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3
\]

Carbon dioxide diffuses from the cell into the extracellular fluid and then into the plasma of the circulatory system. At the pH of blood, most of the H\(_2\)CO\(_3\) is present as the bicarbonate ion HCO\(_3^-\), which is an important blood buffer against radical changes in pH. The
soluble carbon dioxide is eliminated by diffusion in the lungs as the
blood passes through the air sacs where gas exchange occurs between
the circulatory system and the external environment.

Nitrogenous wastes from the degradation of proteins and nucleo-
proteins are in the form of ammonia, which can be toxic if allowed to
accumulate in any concentration. Ammonia is converted into urea mainly
in the liver and results in a product less toxic to living cells:

\[
\begin{align*}
\text{NH}_3 + \text{NH}_3 & \rightarrow \text{NH}_2 \\
\text{excess ammonia} & \rightarrow \text{urea}
\end{align*}
\]

The urea thus produced in the liver is carried via the circulatory
system to the kidney where it is filtered out as a constituent of urine.

LIMITING FACTORS: A multitude of factors are going to affect
metabolism in a variety of ways. The supply of nutrients necessary
for respiration, or concentration of substrates, will affect the
respiratory reactions due to the laws of mass action. The supply of
oxygen for aerobic respiration will be vital as oxygen is necessary
as the final electron acceptor in the electron transport chain and if
absent the mitochondrial sequence will be eliminated and pyruvic forced
to go to lactic acid as an alternate pathway.

The inhibition of any enzyme, or co-enzyme, will result in an
intermediate build up of the chemical substance which is the substrate
for the particular reaction in question. If there is no alternative
pathway, the inhibition of that enzyme can be fatal, as the subsequent
reactions of oxidation will not be completed.

Temperature increases will increase the reaction rate of respiration
and metabolism until a critical limit is reached. A ten degree change in
temperature results in an increased metabolic rate of two to three times. An extremely high temperature will result in the denaturation of the proteins involved (enzymes) and will cause a cessation of reactions. A slight change in pH will also affect the metabolism of glucose as an acidic shift increases the oxidation of glucose, whereas a basic shift increases the storage of glucose as glycogen. A drastic shift in pH will affect the functional activity of enzymes through the process of denaturation.

The elimination of waste products must be accomplished, as the build up of these products can become toxic to cellular metabolism. In multicellular organisms (man) the chemical reactions of hormones on cellular metabolism will also play a vital role in maintaining optimal conditions.

A summary of intermediate metabolism is shown in Figure 1. This interreaction of the sub-units of macromolecules has often been designated as the metabolic mill in which many nutrients are degraded into few respiratory intermediates for the process of cellular respiration and the formation of ATP as a usable potential energy source for the cell to utilize in the process of biological work.

Figure 2 represents an overall view of photosynthesis and cellular respiration in relationship to cellular metabolism in terms of anabolic and catabolic pathways. Heat is released during metabolism as each reaction is not completely efficient in transforming the energy of chemical reactions into usable forms, such as ATP.
Figure 1: The interrelationship of macromolecular sub-units in cellular respiration. Note the entrance of lipid and protein components into the main line of carbohydrate oxidation.
Figure 2: The relationship of energy flow to metabolic processes in living cells. Radiant energy is necessary for organic synthesis and released during catabolism for biological work. The energy not transformed into useful biological energy is dissipated as heat.
GLOSSARY

Acetyl-CoA  A two carbon fragment \((\text{CH}_3\text{CO}^-)\) plus the co-enzyme A.
Aerobic  Requiring the presence of free molecular oxygen.
Alanine  A three carbon amino acid.
Amino acid  The sub-unit of proteins.
Amino group  The functional group of amino acids \((\text{NH}_2)\).
Ammonia  A pungent colorless gaseous substance highly soluble in water \((\text{NH}_3)\).
Anabolic  Chemical reactions involving synthesis of larger molecules from smaller molecules; usually endogenic.
Anaerobic  Not requiring the presence of free molecular oxygen.
Aspartic  A four carbon amino acid.
Bicarbonate ion  \(\text{HCO}_3^-\); resulting from the dissociation of carbonic acid.
Bioluminescence  The production of light by living organisms.
Carbon dioxide  \(\text{CO}_2\); a waste product of cellular respiration.
Carbonic acid  The product of \(\text{CO}_2\) and \(\text{H}_2\text{O};\ \text{H}_2\text{CO}_3\).
Catabolism  Chemical reactions involving the degradation of larger molecules into smaller molecules; usually exergonic.
Cholic acid  An organic acid based on the general sterol structure.
Citric acid  A six carbon organic acid that serves as an intermediate of the citric acid cycle.
Cristae  Inner shelves formed within the mitochondrion by the infolding of the inner membrane.
Deamination  A chemical reaction involving the removal of an amino group \((\text{NH}_2)\) from an amino acid to form ammonia \((\text{NH}_3)\).
Dihydroxyacetone  A ketone triose.
Denaturation  Destruction of protein structure.
Emulsify  To form a colloidal suspension of one substance into another.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty acid</td>
<td>Hydrocarbon chains containing a carboxyl functional group.</td>
</tr>
<tr>
<td>Glutamic</td>
<td>A five carbon amino acid.</td>
</tr>
<tr>
<td>Glyceraldehyde</td>
<td>An aldehyde triose.</td>
</tr>
<tr>
<td>Glycerol</td>
<td>A three carbon alcohol.</td>
</tr>
<tr>
<td>Glycogen</td>
<td>Storage form of glucose units in animal cells.</td>
</tr>
<tr>
<td>Lipase</td>
<td>An enzyme that hydrolyses lipids.</td>
</tr>
<tr>
<td>Metabolism</td>
<td>Sum total of all chemical reactions within a living system.</td>
</tr>
<tr>
<td>Mitochondrion</td>
<td>The organelle in which aerobic respiration occurs.</td>
</tr>
<tr>
<td>Oxaloacetic acid</td>
<td>OAA, An organic acid involved as an intermediate of the citric acid cycle.</td>
</tr>
<tr>
<td>Protease</td>
<td>Enzymes capable of breaking down proteins.</td>
</tr>
<tr>
<td>Radiant energy</td>
<td>Energy of light.</td>
</tr>
<tr>
<td>Transamination</td>
<td>A chemical reaction involving the transfer of an amino group from one molecule to another.</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>Neutral fats; composed of three fatty acids and a molecule of glycerol.</td>
</tr>
<tr>
<td>Urea</td>
<td>A less toxic form of ammonia; a waste product of protein and nucleoprotein degradation.</td>
</tr>
<tr>
<td>Urine</td>
<td>Excretory product of the kidney in man.</td>
</tr>
</tbody>
</table>

**PROGRAMMED SELF TEST - UNIT 7**

All living cell utilize what carbohydrate as the major fuel for cellular respiration.

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>glucose</td>
<td>1</td>
</tr>
</tbody>
</table>

Most diet lipids are in the form of

<table>
<thead>
<tr>
<th>Lipid Type</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>triglycerides</td>
<td>2</td>
</tr>
</tbody>
</table>

Triglycerides are composed of

<table>
<thead>
<tr>
<th>Component</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>glycerol, three fatty acids</td>
<td>2</td>
</tr>
</tbody>
</table>
Glycerol is a three carbon alcohol.

Glycerol enters the glycolytic pathway by being transformed into dihydroxyacetone-phosphate.

Dihydroxyacetone-phosphate can be rearranged into its isomer phosphoglyceraldehyde (PGAL).

Fatty acids are oxidized by forming two carbon fragments as acetyl-CoA.

Acetyl-CoA is the molecule that enters the organelle known as mitochondrion.

Extracellular digestion of proteins results in producing the sub-units known as amino acids.

Amino acids contain a carboxyl group and an amino group.

Amino groups are removed by a chemical reaction known as deamination.

A three carbon amino acid skeleton will enter the respiratory chain after deamination as pyruvic acid.

A four carbon amino acid skeleton can enter at one of three different areas of the respiratory chain: oxaloacetic, fumaric, and succinic acid.

A five carbon amino acid skeleton can enter at a-ketoglutaric acid.

The main product of cellular respiration is ATP.
<table>
<thead>
<tr>
<th><strong>Intermediates of metabolism may be utilized in anabolic biosynthesis of macromolecules</strong></th>
<th>page 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transamination reactions involve the transfer of an amino group</strong></td>
<td>page 5</td>
</tr>
<tr>
<td>An increase in temperature will (increase, decrease) the rate of metabolism</td>
<td>increase</td>
</tr>
<tr>
<td>Oxygen is necessary in aerobic respiration as the final electron acceptor</td>
<td>page 6</td>
</tr>
<tr>
<td>A lack of oxygen will force pyruvic acid to go to lactic acid</td>
<td>page 6</td>
</tr>
<tr>
<td>What component, or intermediate, of the main line of oxidation will build fatty acids</td>
<td>acetyl-CoA</td>
</tr>
<tr>
<td>Deamination reactions remove the functional group amino group ((\text{NH}_2))</td>
<td>page 3</td>
</tr>
<tr>
<td>Deamination reactions result in the waste product ammonia</td>
<td>page 5</td>
</tr>
<tr>
<td>Ammonia is converted by the liver into the waste product urea</td>
<td>page 5</td>
</tr>
<tr>
<td>Urea is eliminated by the kidney in man as a component of urine</td>
<td>page 5</td>
</tr>
<tr>
<td>The main line of cellular respiration produces the waste product of carbon dioxide</td>
<td>page 5</td>
</tr>
<tr>
<td>Carbon dioxide in water forms the chemical substance carbonic acid</td>
<td>page 5</td>
</tr>
<tr>
<td>Each chemical reaction of metabolism is catalyzed by an enzyme</td>
<td>page 6</td>
</tr>
</tbody>
</table>
THE NUCLEIC ACIDS

UNIT 8

OBJECTIVES

To identify by name or description from a list or diagram

a) the structure of nucleic acids

b) the structural differences between DNA and RNA

c) the process of DNA replication

d) the three forms of RNA in terms of structure and function

e) the process of protein synthesis

f) the organelles involved in replication and protein synthesis

g) the concept of the genetic code
THE NUCLEIC ACIDS

The macromolecules which function as the basis of genetic systems and serve to control cellular activity are the nucleic acids. The sub-unit molecules of nucleic acids are nucleotides (Unit 2) attached to form chains in the following manner:

There are two classes of nucleic acids, DNA (deoxyribonucleic acids) and RNA (ribonucleic acids), each of which functions in a specific way to control the inheritance of the genetic code and its interpretation into gene coded proteins. This unit of study will investigate the differences between the two nucleic acids as well as the mechanisms of DNA replication and DNA-RNA controlled protein synthesis.

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DEOXYRIBONUCLEIC ACIDS

Four major nucleotides containing deoxyribose as the pentose sugar are found in DNA macromolecules. Two of these contain the purine nitrogenous bases of adenine and guanine, and two contain the pyrimidines of cytosine and thymine. The Watson-Crick model of the DNA structure is shown in Figure 1, and consists of two chains of nucleotides wound around each other to form a double helix held together by hydrogen bonds between the bases. Note that each strand contains a backbone of alternating sugars and phosphate groups and that the nitrogenous bases are paired in a definite relationship of purines to pyrimidines. The purine of adenine (A) always bonds to the pyrimidine of thymine (T), and the purine of guanine (G) always pairs with the pyrimidine of cytosine (C).

The molecule responsible for the passage of genetic information from one cell to another must possess the ability to duplicate itself. The DNA macromolecule is unique in this regard and does possess the capability of creating an exact duplicate of itself through a process of replication. A nuclease enzyme (DNase) unwinds the DNA molecule by breaking the hydrogen bonds between the bases. Each exposed DNA chain is now able to build a complimentary strand according to the sequence of bonding adenine to thymine and cytosine to guanine. The source of energy and nucleotide building block molecules are provided by free triphosphated nucleosides in the form of ATP, GTP, TTP, and CTP. DNA-polymerase utilizes the energy released as two high energy phosphate bonds are cleaved to incorporate the remaining nucleotides into new DNA strands. Figure 2:A schematically portrays the process of DNA replication which allows for genetic continuity from one generation of
Figure 1: A schematic portrayal of the DNA molecule structure.

Part A demonstrates the relationship between the nucleotides of the double strand; part B shows the helical formation.
cells to another. The replication of DNA always proceeds the reproduction of cells (Unit 9) and thus ensures that the new controlling DNA molecules are identical. The sequence of bases provides the chemical genetic code for determining the structure and function of cellular existence through the process of protein synthesis which involves the second class of nucleic acids, RNA.

RIBONUCLEIC ACIDS

The ribonucleic acids are single strands of nucleotides and contain the pentose sugar of ribose. The nitrogenous bases found in RNA include cytosine, guanine, adenine and uracel in place of thymine. Three forms of RNA exist and are named as to their function in the process of protein synthesis.

rRNA: The ribonucleic acid found as a component of the organelles known as ribosomes is designated as ribosomal RNA, or rRNA. This form of RNA is mor stable than the other forms due to the fact that it forms a complex with proteins as structural components of these organelles.

tRNA: The ribonucleic acids which are involved with the transportation of amino acids to the site of protein synthesis are known as transfer RNA, or tRNA. These transport molecules are specific as to which amino acid they will transport and therefore each amino acid has its own transfer RNA molecule. tRNA molecules assume a partial helical shape as the single strand of nucleotides folds back upon itself. This formation ensures a more stable molecule and the exposure of three nucleotides at one end which constitute an area known as the anticodon.
Figure 2: The duplication of DNA is shown in A as complimentary strands are built according to the base sequence of the original DNA strands. Part B shows the synthesis of mRNA on the basis of complimentary base pairing. Note that uracil replaces the base of thymine in RNA synthesis.
mRNA: The ribonucleic acid responsible for carrying a message from the DNA is known as messenger RNA, or mRNA. This single strand of nucleotides does not fold as tRNA into a partial helix and is not a component of an organelle as rRNA and is therefore extremely unstable. Its primary function in the process of protein synthesis is to carry a genetic message in terms of a chemical code, and to aid in the translation of that message into amino acid language, or the building of a functional protein.

PROTEIN SYNTHESIS

All three forms of RNA are produced by DNA in a similar process to DNA replication. The DNA macromolecule again unwinds to produce RNA as a compliment to one side of the DNA molecule. DNase is again necessary to break the hydrogen bonds holding the DNA helix together, but instead of unwinding the entire DNA chain as in replication, only a segment of the DNA is unwound to produce RNA. RNA-polymerase builds
a chain of ribo-nucleic acids from available triphosphated nucleotides (ATP, CTP, GTP, and UTP) as shown in Figure 2:B. The sequence of bases in DNA has now been given to RNA in a process known as transcription of the genetic code.

The process of transcription will produce a chain of nucleotides which constitutes a molecule of mRNA. the mRNA will leave the nucleus and find a ribosome to which it attaches. The genetic code will now be translated from nucleic acid language, an alphabet of four letters, to amino acid language, an alphabet of over twenty letters, through the process of protein synthesis. The genetic code for amino acids is stated in terms of RNA language and a series of three nucleotides, or bases, are necessary to code for one amino acid. This series of three bases is known as a codon, and each codon specifies an amino acid according to the following triplet sequences.

<table>
<thead>
<tr>
<th>AMINO ACID</th>
<th>TRIPLET CODE ON mRNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine (Ala)</td>
<td>GCU GCC GCA GCG</td>
</tr>
<tr>
<td>Arginine (Arg)</td>
<td>AGA AGG</td>
</tr>
<tr>
<td>Asparagin (AspN)</td>
<td>AAU AAC</td>
</tr>
<tr>
<td>Aspartic acid (Asp)</td>
<td>GAU GAC</td>
</tr>
<tr>
<td>Cysteine (Cys)</td>
<td>UGU UGC</td>
</tr>
<tr>
<td>Glutamic acid (Glu)</td>
<td>GAA GAC</td>
</tr>
<tr>
<td>Glutamine (GluN)</td>
<td>CAA CAG</td>
</tr>
<tr>
<td>Glycine (Gly)</td>
<td>GGU CCC GCA GGG</td>
</tr>
<tr>
<td>Histidine (His)</td>
<td>CAU CAC</td>
</tr>
<tr>
<td>Isoleucine (Ileu)</td>
<td>AUU AUA</td>
</tr>
<tr>
<td>Leucine (Leu)</td>
<td>CUU CUC CUA CUG</td>
</tr>
<tr>
<td>Lysine (Lys)</td>
<td>AAA AAG</td>
</tr>
<tr>
<td>Methionine (Met)</td>
<td>AUG</td>
</tr>
<tr>
<td>Phenylalanine (Phe)</td>
<td>UUU UUC</td>
</tr>
<tr>
<td>Proline (Pro)</td>
<td>CUC CCC CCA CCC</td>
</tr>
<tr>
<td>Serine (Ser)</td>
<td>AGU AGC</td>
</tr>
<tr>
<td>Threonine (Thr)</td>
<td>ACU ACC ACA ACG</td>
</tr>
<tr>
<td>Tryptophan (Tryp)</td>
<td>UGG</td>
</tr>
<tr>
<td>Tyrosine (Tyr)</td>
<td>UAU UAC</td>
</tr>
<tr>
<td>Valine (Val)</td>
<td>GUA GUU GUC GUG</td>
</tr>
</tbody>
</table>
The fact that amino acids have more than one codon is implied when it is stated that the genetic code is *degenerate*, or in other words, an amino acid may be coded by more than one series of three bases, but a series of three bases may only code for one amino acid.

In order to explain the process of protein synthesis, let us assume that a molecule of mRNA has been produced by a segment of DNA and that a portion of this mRNA contains the sequence of bases in the order of GCU-AGU-CCU. The chain of mRNA will leave the nucleus and attach itself to a ribosome for translation of this genetic code into a protein product. As the mRNA passes through the ribosome, it will be "read" and thus translated into a protein with the help of tRNA which will plug in the proper amino acid according to the triplet codon presented by the mRNA.

In the above example of protein synthesis, the codon of CCU codes for the amino acid of proline. The *anti-codon* site of the tRNA for proline is complimentary to the *codon* of CCU by complimentary bonding, or contains the sequence of GGA, which recognizes the triplet presented by mRNA. This transfer RNA temporarily bonds to the triplet series of bases and allows the amino acid of proline to be placed in the proper position of the growing polypeptide chain to form a peptide bond.
Once this peptide bond has been formed, the tRNA molecule will be released to find another proline amino acid. The amino acid serine will be placed in the growing polypeptide chain in the same manner, as will all other amino acids according to the series of nucleotides in the mRNA chain.

The primary sequence of proteins, or the actual series of which amino acid follows which amino acid, is thus determined by the sequence of codons, or the sequence of which base follows which base, in the DNA molecule. The primary sequence of amino acids determines how the protein molecule produced is going to fold and coil, which determines whether or not the protein produced will be biologically active as to the formation of active sites for biochemical activity.

Proteins are the macromolecules which differentiate the species, as well as differentiating between individual members of the species. Protein structure is controlled by the sequence of nucleotides in the DNA molecule through the process of protein synthesis. The chemical code utilized by DNA is universal in nature, as each codon codes for the same amino acid in all organisms, and the differences between individuals lie in the exact sequence of codons. The primary structure of proteins, or the exact sequence of amino acids, determines the secondary and tertiary folding of the amino acid chain into a functional structural protein or a metabolic regulator.

DNA thus provides a continuity from cell to cell through the process of replication, and also provides the controlling influence of cellular metabolism by providing the genetic code necessary for the production of structural and metabolic proteins through the process of
protein synthesis. The genetic code is thus a **degenerate, triplet,** and **universal** code which is **inherited** from one generation of cells to another to ensure a continuity between those cells produced from those which exist.

**GLOSSARY**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine</td>
<td>A purine nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Anticodon</td>
<td>A series of three exposed bases in tRNA that correspond to the codon of mRNA by complimentary bonding.</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine-tri-phosphate, a tri-phosphated nucleoside.</td>
</tr>
<tr>
<td>Codon</td>
<td>A series of three nucleotides in mRNA that code for one amino acid.</td>
</tr>
<tr>
<td>Complimentary</td>
<td>A term referring to the spatial recognition of one nitrogenous base for another.</td>
</tr>
<tr>
<td>CTP</td>
<td>A tri-phosphated nucleoside containing cytosine as the nitrogenous base.</td>
</tr>
<tr>
<td>Cytosine</td>
<td>A pyrimidine nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Deoxyribose</td>
<td>A pentose sugar found in the nucleotides of DNA.</td>
</tr>
<tr>
<td>DNA</td>
<td>Deoxyribonucleic acids, the macromolecules that serve as the basis of the genetic system.</td>
</tr>
<tr>
<td>DNAsase</td>
<td>An enzyme that breaks the hydrogen bonds between complimentary bases holding the double strands of DNA.</td>
</tr>
<tr>
<td>DNA polymerase</td>
<td>An enzyme which catalyzes the building of a DNA molecule.</td>
</tr>
<tr>
<td>GTP</td>
<td>A tri-phosphated nucleoside containing guanine as the nitrogenous base.</td>
</tr>
<tr>
<td>Guanine</td>
<td>A nitrogenous base found in nucleotides.</td>
</tr>
<tr>
<td>Helix</td>
<td>A spiral, or coiled, configuration of a molecule.</td>
</tr>
<tr>
<td>Nucleoside</td>
<td>A pentose and a nitrogenous base.</td>
</tr>
<tr>
<td>Nucleotide</td>
<td>A pentose, nitrogenous base and a phosphate group.</td>
</tr>
<tr>
<td>Ribose</td>
<td>A pentose found in the nucleotides of RNA.</td>
</tr>
<tr>
<td><strong>RNA</strong></td>
<td>Ribonucleic acids, molecules that serve to translate the genetic code into proteins.</td>
</tr>
<tr>
<td><strong>mRNA</strong></td>
<td>Messenger RNA, the RNA which carries the genetic code to be translated into a protein.</td>
</tr>
<tr>
<td><strong>rRNA</strong></td>
<td>Ribosomal RNA, the RNA which functions as a component of the organelle of protein synthesis, or ribosome.</td>
</tr>
<tr>
<td><strong>tRNA</strong></td>
<td>Transfer RNA, the molecule which transfers amino acids to the ribosome for incorporation into a protein.</td>
</tr>
<tr>
<td><strong>RNA polymerase</strong></td>
<td>An enzyme that catalyzes the building of a RNA molecule.</td>
</tr>
<tr>
<td><strong>Thymine</strong></td>
<td>Nitrogenous base found only in DNA nucleotides.</td>
</tr>
<tr>
<td><strong>Transcription</strong></td>
<td>The passage of the genetic code from DNA to RNA during RNA synthesis.</td>
</tr>
<tr>
<td><strong>Translation</strong></td>
<td>The process of protein synthesis, or the translation of the genetic nucleic acid code into the language of proteins.</td>
</tr>
<tr>
<td><strong>Triplet</strong></td>
<td>Used in reference to the genetic code in the fact that it requires three nucleotides to code for one amino acid.</td>
</tr>
<tr>
<td><strong>Universal</strong></td>
<td>Characteristic of all living systems.</td>
</tr>
<tr>
<td><strong>Uracil</strong></td>
<td>Nitrogenous base found only in RNA nucleotides.</td>
</tr>
<tr>
<td><strong>UTP</strong></td>
<td>A tri-phosphated nucleoside containing uracil as the nitrogenous base.</td>
</tr>
</tbody>
</table>

**PROGRAMMED SELF TEST - UNIT 8**

The nucleic acids function as the basis of what system

| genetic | page 1 |

The sub-unit of nucleic acids are

| nucleotides | page 1 |

The two forms of nucleic acids are known as

| DNA, RNA | page 1 |
A nucleotide is composed of what three components

pentose, phosphate, base

Deoxyribonucleic acids (DNA) contain the pentose

deoxyribose

The purine nitrogenous bases of DNA are

adenine, guanine

The DNA molecule is a double stranded structure folded into

a helix

Within the double helix, adenine always bonds to

thymine

Cytosine always bonds to

guanine

The two pyrimidines found in DNA are

thymine, cytosine

The enzyme capable of splitting the DNA molecule is

DNAse

The enzyme which catalyzes the building of DNA is

DNA polymerase

Ribonucleic acids contain the pentose

ribose

Ribonucleic acids differ from DNA in that the number of strands are

single

The nitrogenous base not found in RNA

thymine

rRNA is found as a structural component of the organelle

ribosomes
tRNA is the molecule that functions to transfer amino acids.

The site on the tRNA molecule which recognizes the codon is anti-codon.

The RNA molecule that carries the message to be translated is mRNA.

The triplet of UGG would be an example of a codon.

The sequence of DNA nucleotides will determine the sequence of what in a protein is amino acids.

The genetic chemical code is the same in all living systems, or it is called universal.

The genetic code is passed from one generation to another, or is inherited.

Protein synthesis occurs on the organelle ribosome.

Transcription of the genetic code is RNA synthesis.

Translation of the genetic code is protein synthesis.
CELL REPRODUCTION: MITOSIS AND MEIOSIS

Unit 9

OBJECTIVES

To identify by name or description from a list:

a) the five phases of mitosis
b) the process of meiosis
c) the structure and the function of the spindle apparatus
d) the stages of gametogenesis
e) the concept of diploid and haploid cells
CELLULAR REPRODUCTION

One of the six characteristics of life (Unit 1) is the ability to reproduce, a characteristic essential for multicellular organisms as well as for individual cells. All living things die and the perpetuation of living systems depends on their capacity to reproduce like images of themselves, thus insuring a continuity from generation to generation. All multicellular organisms begin life as a single cell, and all cells arise from pre-existing cells by means of self-reproduction, or cell division.

The fundamental process of cell division in eukaryotic cells is called mitosis and involves a parent cell dividing into two daughter cells, each of which contains an exact copy of the original genetic material. Mitosis in unicellular organisms will result in the asexual reproduction of the next generation, whereas mitotic division within multicellular organisms will result in an increased number of cells, or growth.

The mitotic process has been divided by biologists into five successive stages, each of which is characterized by specific events occurring within the cell. The first four stages specifically involve the division of the nuclear material (karyokinesis), whereas the actual division of the cytoplasm (cytokinesis) only occurs in the last phase of cell division. It must be remembered, however, that cell division is a continuous phenomenon and there are no sharp and definite demarcations between the phases. We can only sum up general characteristics, therefore, for each stage of a flowing process. The description of
mitosis which follows is confined to the division process of animal cells. Plant cells conform generally to the same description with a few minor variations.

INTERPHASE: A cell which does not visibly display any activity of cell division is said to be in interphase. This stage of cellular existence has often been referred to as the "resting" state, a term which is very misleading. The cell is only resting from cell division, but is still accomplishing all the intricate aspects of metabolism and protein synthesis necessary for maintenance, repair, and growth. An increase in the size of the cell due to an excess production of protein will continue until a critical point is reached in the relationship of cell surface to volume. At this point, a cell must either cease to grow or divide into two smaller units which will return the surface to volume relationship to a more favorable ratio.

The chromatin material, the active elongated form of chromosomes, are composed of protein and DNA, the nucleic acid which contains the genetic information for controlling the cell. The DNA, for a reason not yet understood, is somehow triggered to replicate itself (Unit 8) in the latter stage of interphase. The fact that this has occurred is apparently the signal which sets the next four stages into operation, and is the beginning of karyokinesis.

PROPHASE: The first visible signs of cell division occur during the second stage known as prophase. One of the earliest signs that a cell is about to reproduce itself is found in the activity of the organelles known as centrioles. Centrioles are organelles that appear as pairs (Unit 3) lying close to the nucleus and are composed of
microtubules. The centrioles duplicate themselves, separate and begin to migrate away from each other toward the opposite sides of the nucleus. As they move they begin to form aster rays, protein filaments, which radiate away from the nucleus into the cytoplasm. The chromosomes become visible as the chromatin material thickens and shortens into rod shaped structures due to the elimination of water molecules. The chromosomes are actually doubled structures, due to the duplication of DNA in interphase, and each identical half is held together with its partner by an area known as a centromere. Each half of the chromosome is called a chromatid, a term used to designate them until they separate in a later stage.

The centrioles begin to form additional protein filaments which radiate toward the center of the nucleus. These filaments, or traction fibers, attach themselves individually to each chromosome at the centromere. Thus each chromosome, or pair of chromatids, is firmly held in place between the centrioles by a pair of traction fibers radiating from each. The nucleolus, or nucleoli if more than one is present, disappears and the nuclear membrane dissolves. The cytoplasm and the nucleoplasm consistency shifts to a gel state to hold all organelles more permanently in position for the events which will follow. During the latter stages of prophase, the chromosomes, each attached to traction fibers, move toward a mid-line between the centrioles known as an imaginary equatorial plate. The entire structure, the centrioles complete with aster rays and traction fibers, is known as the mitotic apparatus, or spindle apparatus.

METAPHASE: When the chromosomes are lined up along the equatorial plate, the stage is known as metaphase. This phase is completed when a simultaneous division of all the centromeres occurs.
Figure 1. Schematic view of mitosis in animal cells. Interphase (A), prophase (B and C), metaphase (D), anaphase (E) and telophase (F and G).
ANAPHASE: Once the centromeres have divided the chromatids, known now as daughter chromosomes, begin to separate and migrate away from each other. Scientists do not know for sure if this movement is due to a molecular repulsion or an actual pulling by the traction fibers, or a combination of the two factors. No matter how the movement of chromosomes is accomplished, the result is that they migrate away from each other toward the opposite centrioles. Karyokinesis is now completed.

TELOPHASE: During the last stage of mitosis, the daughter chromosomes, each set clustered near the opposite centrioles, begin to disappear as they reform the chromatin material, the nuclear membrane reappears, the nucleoli reform and the cytoplasm and nucleoplasm return to a sol consistency. Each new nucleus contains a complete set of the genetic blueprint in the form of identical DNA molecules. The process of cell division is completed during this stage as the cytoplasm divides by forming a cleavage plane, or furrow, along the imaginary equatorial plate by a pinching in process of the cell membrane.

The time required to complete the mitotic cycle varies from cell to cell. Bacteria may divide in fifteen to twenty minutes, whereas the process spans several days in certain mammalian cells. Embryonic, undifferentiated, cells divide rapidly, whereas highly differentiated cells, such as neurons, often lose their ability to self-reproduce once they have become specialized. Prophase and telophase are generally the longest stages, whereas metaphase and anaphase are the shortest.

Mitosis is necessary in unicellular organisms, as previously mentioned, as a means of asexual reproduction. In multicellular organisms, the mitotic process is a means of replacement and growth. It
Figure 2. Mitosis in animal cells. (Whitefish blastula @ 430x.)
has been estimated that an adult human is composed of $10^{14}$ number of cells, each of which was derived from a single cell by mitosis, and each of which contains an exact replica of the original DNA composing the chromosomes.

The number of chromosomes contained within a cell is characteristic of the species (46 in man) and may involve one or more sets of chromosomes. A chromosome set includes a given number of chromosomes that are different from each other, or nonhomologous, and an organism, or cell, which contains only one set of chromosomes is referred to as haploid (n). Most cells usually possess two complete sets of nonhomologous chromosomes and are referred to as diploid (2n). A diploid cell, therefore, contains two chromosomes of each kind, or a pair of homologous chromosomes for each kind. For example, man has a diploid number of chromosomes which equals 46 (2n) or 23 pairs of homologous chromosomes. Each kind of chromosome exhibits certain characteristics such as the location of the centromere and therefore may be classified in a linear order of homologous pairs to form a karyotype (Figure 3). The condition of polyploidy, more than two sets of chromosomes, usually exists only in the plant world.

In organisms which reproduce by sexual mechanisms, or the union of two gametes to form a new individual, there must be a process capable of reducing the number of chromosomes from a diploid to a haploid state. This process is known as meiosis and occurs only in cells destined to differentiate into reproductive gametes, or sperms and ova. The new individual produced from the union of gametes, both of which are haploid, will contain the diploid number of chromosomes.
Figure 1. Human chromosomes before and after being arranged into a karyotype.
Meiosis is similar to mitosis in that the same five stages are recognized and both involve karyokinesis and cytokinesis. Meiosis differs from mitosis in that two nuclear divisions occur and the number of chromosomes is reduced in half instead of being maintained. The two divisions of meiosis are referred to as Meiosis I and Meiosis II. The actual division of the cytoplasm, or cytokinesis, which occurs in telophase of mitosis may not occur during Meiosis I.

INTERPHASE OF MEIOSIS I: This phase is identical in regards to characteristics as the interphase of mitosis. DNA is replicated to trigger the ensuing stages.

PROPHASE OF MEIOSIS I: As in mitotic prophase, the spindle apparatus is formed, the chromosomes become visible, the cytoplasm changes in consistency, and the nuclear membrane and nucleoli disappear. The significant difference between the prophase stage of mitosis and meiosis I is confined to the behavior of the chromosomes themselves. In meiosis I, the pairs of homologous chromosomes move together and unite lengthwise (synapsis) to form a structure known as a tetrad, a unit of two homologous chromosomes or four chromatids. Thus, the number of tetrads formed will be equal to the haploid number characteristic of a species, or in the case of man, equal to 23.

METAPHASE OF MEIOSIS I: During metaphase, the tetrads line up along the equatorial plate. This differs from the mitotic process in which the individual chromosomes, each composed of two chromatids, lined up along the equatorial plate. A simultaneous separation of the tetrad, or of the homologous chromosomes, into two dyads signals the end of this stage of meiosis.
ANAPHASE OF MEIOSIS I: The dyads begin to migrate toward the opposite poles formed by the centrioles. This division of the nuclear material has now reduced the number of chromosomes in half that will move toward each new nuclear region.

TELOPHASE OF MEIOSIS I: This stage may be partially or totally eliminated in the process of meiosis I. Each new nuclear region is preparing for the second nuclear division, meiosis II, and cytokinesis may be apparent only in the initial state. There is no interphase stage between meiosis I and meiosis II as both of the two new nuclear regions enter into the prophase stage of meiosis II.

MEIOSIS II: The second nuclear division of meiosis is actually a normal mitotic division of the chromosomes involving the stages of prophase, metaphase, anaphase and telophase. Cytokinesis does occur in the telophase stage of meiosis II and once this has been accomplished there is the formation of four haploid daughter cells from the original parent cell. These haploid cells will mature into gametes, or sex cells, which will fuse during fertilization and restore the diploid number of chromosomes for the development of the new individual.

The process of producing mature gametes, sperm and ova, is known as gametogenesis and involves the meiotic sequence listed above. The formation of sperm, or spermatogenesis, and the formation of ova, or oogenesis, do differ, however, in one important respect. The process is identical but the viable gametes produced are different in number. Spermatogenesis leads to the formation of four haploid sperms, whereas oogenesis leads to the formation of one viable ova and three polar bodies which disintegrate.
Figure 4: Part A demonstrates the general process of meiosis. Part B schematically shows the differences between male and female gametogenesis. Note that only one viable egg, or ovum, is produced from a primary oocyte and not four as in the case of spermatogenesis.
GLOSSARY

Anaphase A stage of cell division characterized by the migration of the daughter chromosomes toward the poles.

Asexual Independent of sexual processes.

Aster rays Protein filaments formed by centrioles which radiate away from the nuclear regions.

Centrioles Organelles of animal cells which are involved in the process of cell division.

Centromere A region of the chromosome which holds two chromatids together and attaches to the traction fibers.

Chromatid A duplicated half of a chromosome.

Chromatin The elongated, active form of chromosomes.

Chromosome Rod-shaped visible forms of chromatin; composed of DNA molecules surrounded by a protein coat.

Cleavage The act of cleaving or splitting.

Cytokinesis Division of the cytoplasm during cellular reproduction.

Diploid Double; containing two similar sets of chromosomes.

Dyad A term used to designate a chromosome that consists of two chromatids.

Equatorial plate An imaginary line upon which the chromosomes line up during the divisional stage of metaphase.

Gamete A haploid sex cell.

Gametogenesis The meiotic process of developing mature sex cells.

Growth An increase in the number and/or size of cells.

Haploid Single; containing only one set of chromosomes.

Homologous Similar in structure and function.

Interphase A stage of cellular existence between stages of cellular division; growth stage during which DNA duplicates.

12
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karyokinesis</td>
<td>Division of the nuclear material.</td>
</tr>
<tr>
<td>Karyotype</td>
<td>The sum total and classification of the chromosomes of a cell.</td>
</tr>
<tr>
<td>Meiosis</td>
<td>The process of cell division during the development of haploid gametes from diploid germ cells.</td>
</tr>
<tr>
<td>Metaphase</td>
<td>A stage of mitosis characterized by the chromosomes lining up along the equatorial plate.</td>
</tr>
<tr>
<td>Microtubules</td>
<td>Protein filaments which may exist by themselves or in a definite arrangement found in centrioles.</td>
</tr>
<tr>
<td>Mitotic apparatus</td>
<td>The apparatus formed by the centrioles to prepare for the division of the nuclear material and includes the aster rays and traction fibers.</td>
</tr>
<tr>
<td>Mitosis</td>
<td>A form of cell division which retains the chromosome number from parent to daughter cells; asexual reproduction.</td>
</tr>
<tr>
<td>Nonhomologous</td>
<td>Dissimilar in structure and function.</td>
</tr>
<tr>
<td>Nucleolus</td>
<td>Organelle within the nucleus that seems to be responsible for the synthesis of ribosomes.</td>
</tr>
<tr>
<td>Oocyte</td>
<td>An immature sex cell; primary oocytes are diploid and secondary oocytes are haploid.</td>
</tr>
<tr>
<td>Oogenesis</td>
<td>The process of developing mature ova by meiotic division.</td>
</tr>
<tr>
<td>Ootid</td>
<td>An ovum just before it matures.</td>
</tr>
<tr>
<td>Ovum</td>
<td>The female reproductive gamete; ova is pleural.</td>
</tr>
<tr>
<td>Polyploid</td>
<td>More than two sets of chromosomes.</td>
</tr>
<tr>
<td>Prophase</td>
<td>A stage in cell division in which the mitotic apparatus is formed.</td>
</tr>
<tr>
<td>Sperm</td>
<td>The male reproductive gamete.</td>
</tr>
<tr>
<td>Spermatocyte</td>
<td>An immature male sex cell.</td>
</tr>
<tr>
<td>Spermatogenesis</td>
<td>The process of developing mature sperm by meiosis.</td>
</tr>
<tr>
<td>Spermatotid</td>
<td>A sperm just before it matures.</td>
</tr>
<tr>
<td>Spindle apparatus</td>
<td>See mitotic apparatus.</td>
</tr>
<tr>
<td>Synapsis</td>
<td>The pairing of homologous chromosomes into a tetrad.</td>
</tr>
</tbody>
</table>
Telophase  The final stage of cell division involving cytokinesis.

Tetrad  Two homologous chromosomes, or four chromatids together.

Traction fibers  Protein filaments which attach to chromosomal centromeres.

PROGRAMMED SELF TEST - UNIT 9

The form of cellular reproduction fundamental to all cells

mitosis  page 1

Mitosis in unicellular organisms results in

asexual reproduction  page 1

Mitosis in multicellular organisms results in

growth  page 1

The division of the nuclear material is called

karyokinesis  page 1

The division of the cytoplasm is called

cytokinesis  page 1

The five stages of mitosis are called

interphase, prophase, metaphase, anaphase, telophase page 1

A cell not visibly undergoing cell division is in the phase

interphase  page 1

DNA duplication, or replication occurs in the phase

interphase  page 1

Are chromosomes visible during interphase

No  page 1

The first visible signs of cell division are in the phase

prophase  page 2

14
The organelles which build the spindle apparatus are **centrioles**.

Visible chromosomes are doubled with each half called a **chromatid**.

The chromatids are held together by a region called a **centromere**.

The traction fibers attach to the chromosomes at the **centromere**.

The aster rays, traction fibers and centrioles are called the **mitotic or spindle apparatus**.

The nuclear membrane and nucleolus disappear during **prophase**.

The stage in which the chromosomes line up around the **equatorial plate** is called **metaphase**.

Just before the chromatids separate what divides is the **centromere**.

The migration of daughter chromosomes toward opposite poles occurs in the phase of **anaphase**.

Karyokinesis involves what stages of mitosis are **interphase, prophase, metaphase, anaphase**.

Cytokinesis involves the phase of **telophase**.

The pinching in process of cytokinesis is called **cleavage**.
The normal number of chromosomes in man is

46

The number of homologous pairs of chromosomes in man is

23

The number 46 is said to be \(2n\) or
diploid

Gametes contain one set (\(n\)) of chromosomes and are

haploid

Cells destined to become gametes undergo division called

meiosis

How many nuclear divisions occur in meiosis

two

Prophase of Meiosis I differs from mitosis in the formation by homologous chromosomes of a
tetrad

The union of homologous chromosomes is known as

synapsis

A tetrad is composed of two homologous chromosomes or four

chromatids

What arrangement of chromosomes line up during meiotic metaphase
tetrad

Meiosis I or II is the actual reduction division

Meiosis I

Meiosis II involves the separation of

chromatids
The process of producing gametes by meiotic division is

**gametogenesis** page 7

The female gamete is called

**ova, ovum** page 7

The male gamete is produced by

**spermatogenesis** page 7

The germ cell which undergoes oogenesis is called an

**oocyte** page 8

Polar bodies are produced during the process of

**oogenesis** page 8

Gametes contain what number of chromosomes in man

**haploid, or 23** page 5

Fertilization of an ovum by a sperm will produce an individual with what number of chromosomes

**diploid, or 46** page 5
OBJECTIVES

To identify by name or description from a list or diagram
a) the genotypic and phenotypic ratios of a monohybrid cross
b) the phenotypic ratio of a dihybrid cross
c) the concept of lethal genes
d) the concept of gene collaboration and complementation
e) the genotypic and phenotypic ratios of incomplete dominance
f) the law of dominance and recessive
g) the law of independent assortment and segregation
h) the concept of linked genes
i) the process of crossing over
j) basic gene and chromosome mutations

To be able to work genetic problems involving
a) monohybrid crosses
b) dihybrid crosses
c) linked genes
d) multiple alleles
e) Mendelian inheritance
GENETICS

The reproduction of an organism through the mechanism of mitosis (Unit 9) will result in the production of offspring identical to the parent. In the process of sexual reproduction, however, both parents will transmit chemical code instructions through DNA to the offspring. Thus, each new individual will resemble each of the parents in some ways, but vary from them in other ways. These variations, resulting from the union of two haploid gametes, form the basis for genetic change through time by natural selection. This concept is included in that characteristic of life known as adaptability.

Each new individual, or organism, produced is influenced by two types of factors throughout its development and life span. The first factor is heredity, or the development of traits controlled by the inherited DNA code. The study of genetics deals with this influence. The second factor is that of environment, or all external forces which influence the expression of the inherited genetic code.

As an example of how the two factors, genetics and environment, will together influence a trait, let us look at the characteristic of body size. The basis for bone structure, body build and height are found in genetic inheritance. Environment, however, will influence the expression of these genes through diet, amount of exercise, injuries and/or medical problems. This interdependence has often been stated: "heredity determines what you can become, but what you do become depends on environment".

1
You, as an individual, have inherited two types of genetic characteristics. Species characteristics, such as a highly developed nervous system or the ability to walk erect, are those which classify you as a member of the human family. Individual characteristics are those which make you unique within the human species. Species and individual characteristics are both controlled through the mechanism of protein synthesis (Unit 8) which translates the DNA code into proteins, the biological molecules responsible for structure and activity as metabolic regulators.

MENDELIAN GENETICS

The basic principles of genetics were first discovered by Gregor Mendel in the last half of the nineteenth century. He accomplished this feat without any knowledge of chromosomes, genes, or their behavior. Much of his work was based on mathematical ratios and the laws of probability. Mendel used garden peas for much of his experimental work as these plants had a number of contrasting traits which were pure breeding. Or in other words, tall pea plants always produced tall offspring and short pea plants always produced short offspring due to the fact that these plants reproduced sexually by self-pollination.

Mendel cross-fertilized two pure-breeding plants with contrasting traits by eliminating any chance of their reproducing by self-pollination. To use the previous example of tallness and shortness as contrasting traits regarding plant height, he cross-fertilized the gametes of a tall and short plant to produce a new generation. The original plants
were designated as the parent plants (P) and the offspring as the first filial generation, or F₁. The F₁ generation consisted of all tall plants, resembling the tall parent in regards to height. Were the tall F₁ plants identical to the tall parent? If they were identical they would be pure-breeding if allowed to reproduce by self-pollination to produce the F₂ generation. The F₁ plants did, however, produce an F₂ generation which contained some tall and some short plants. Mendel concluded from these results that "something" within the plant controlled the characteristic of height. He name this something a factor, which is today known as a gene, and formulated the hypothesis of unit characters which states: "the various hereditary characteristics are controlled by factors (genes) and that these factors occur in pairs".

Chromosomes are composed of DNA and protein and the genetic code is found within the sequence of nucleotides which make up the DNA molecule (Unit 8). A gene is that segment of DNA which carries the code for the primary sequence of one protein. Each diploid individual contains two homologous chromosomes, and therefore, contains two genes for the expression of each inherited trait. During the process of gametogenesis (Unit 9) the homologous chromosomes are separated and segregated and only one of each pair is found in a haploid gamete. Therefore, only one of the genes controlling a particular trait is found within the DNA of each gamete.

Let us now return to the above example and follow the crosses made by Mendel in terms of the genes involved. The parents were pure-breeding and therefore must contain identical genes in regards to height. The F₁ generation appeared exactly like the tall parent, with no plants resembling the short parent. Tallness, therefore, must be able to mask or prevent the expression of the gene for shortness.
The trait which appears in the F₁ generation is designated as dominant over the trait which reappears in the F₂ which is recessive. The parents then may be considered as pure dominant for tallness, or T T, and pure recessive for shortness, or t t. When an individual contains identical genes for a particular trait they are said to be homozygous for that trait. The parent homozygous dominant, T T, can produce only haploid gametes containing T, a gene for tall, and the parent homozygous recessive, t t, can produce only gametes containing t, the gene for short. Upon the fertilization of these two gametes, a new individual will be produced with the combination of T and t to restore the diploid number. When an individual contains two contrasting alleles (T is the allele of t) they are said to be heterozygous.

\[ P = TT \times tt \quad \text{(homozygous individuals)} \]

Gametes = \( \frac{0}{\text{T}} \) \( \frac{t}{0} \)

Fertilization = Tt \quad \text{(heterozygous individuals)} \quad (F₁)

The F₁ plants (Tt) appear tall like the dominant parent (TT) even though the plants are not alike genetically. The phenotypic expression of the genes are identical, both are tall, but their genotypes, or the actual genetic make-up are different. Let us now see what occurred when Mendel allowed the F₁ plants (Tt) to self-pollinate to produce the next, or F₂ generation. This cross is known as the monohybrid cross, or a cross between two heterozygous individuals in regard to one trait.

Each parent (Tt) can now produce two types of gametes in equal number, or haploid cells with either T or t. Upon the fertilization of these gametes definite ratios of inherited characteristics will be seen to be a result of considering all possible combinations.
Parents:

Gametes:

Possibilities:

\[
\begin{array}{c|cc}
\text{T} & \text{Tt} & \text{Tt} \\
\text{t} & \text{tt} & \text{tt} \\
\end{array}
\]

Ratios:

\[
\begin{array}{c|cc}
\text{T} & \text{TT} & \text{Tt} \\
\text{t} & \text{tt} & \text{tt} \\
\end{array}
\]

Genotypic: 1:2:1
Phenotypic: 3:1

Three different genotypes are produced in the following ratio:

one homozygous dominant (TT) to two heterozygous individuals (Tt) to one homozygous recessive (tt). Three of the plants will appear identical, or tall, to one plant appearing short. The phenotypic ratio for a monohybrid cross in which there is a dominant trait over a recessive trait will be 3 appearing dominant to 1 recessive. It can be seen from this cross that for a recessive trait to appear, it must be homozygous recessive, or tt.

When a cross involves two pairs of traits, both of which are heterozygous, it is known as a dihybrid cross. If we add the contrasting trait of seed color in which yellow (Y) is dominant over green (y) to the above example of tallness dominant over shortness, a dihybrid would be TtYy. In crossing two dihybrids, a very important concept will be demonstrated concerning Mendel's law of independent assortment. Or in other words, which haploid gamete receives T, or t, has nothing to do with which gamete receives Y or y. They are segregated during meiosis and gametogenesis independent of each other. A dihybrid such as TtYy can, therefore, produce four different types of gametes in equal numbers; TY, Ty, tY, and ty haploid cells are the four possible combinations. Work through the dihybrid cross which follows to see exactly how the phenotypic ratio of 9:3:3:1 is derived. Nine of the individuals will
be tall and yellow in appearance, three will be tall and green, three will be short and yellow, and only one will be homozygous recessive in both traits, or short and green. A dihybrid cross complicates the genotypic ratio considerably and will not be taken up in this discussion.

Parents: \( TtYy \times TtYy \)

Gametes:

Possibilities:

\[
\begin{array}{c|cc|cc}
TY & Ty & tY & ty \\
\hline
TY & TTYY & TTyy & TtYY & TtYy \\
Ty & TTYY & TTyY & TtYY & Ttty \\
tY & TtYY & TtYy & ttYY & ttYy \\
ty & TtYy & Ttyy & ttYy & tttY \\
\end{array}
\]

Much of Mendel's work was ignored until after the turn of the century when it was rediscovered and scientists began testing many types of crosses. Some of the genetic crosses experimented with did not yield the expected Mendelian ratios, and today the reasons for unexpected results can be explained in the following ways.

LETHAL GENES: A number of genes bring about the death of the individual produced if they are homozygous. For example, a gene in plants, such as corn, is responsible for the pigment chlorophyll. The dominant form of the gene (G) will produce chlorophyll and the plant will be green, whereas the recessive form (g) will not produce the green pigment and the plant will be white. The expected ratio of a monohybrid cross would be 1GG: 2Gg: 1gg. The pure recessive plant, gg, would not be able to live as chlorophyll is essential for the process of photosynthesis.

GENE COLLABORATION: Many traits are determined by two pairs of genes working together. The shape of combs in chickens is an example
of this type of gene interaction. A dominant P will result in a pea shaped comb, a dominant R in a rose comb, a pure recessive in a single comb and both a dominant P and R in a walnut comb. If two dihybrids, PpRr, and crossed the phenotypes produced will consist of nine walnut combs, three pea combs, three rose combs, and one single combed chicken. Work this problem through by using the chi square and you will see that it is a variation of Mendel's 9:3:3:1 phenotypic ratio of a dihybrid cross.

COMPLEMENTARY GENES: Genes which depend on more than one set to be expressed are said to be complementary genes. An example of this type of genetic interaction would be found in regards to color in sweet peas. A dominant C is necessary for the development of a colorless pigment, and a dominant E is necessary to produce the enzyme capable of turning the colorless pigment to purple. A dihybrid cross between two individuals (CcEe) will produce nine purple sweet pea plants to seven white ones. This also can be seen as a variation of the 9:3:3:1 phenotypic ratio.

INCOMPLETE DOMINANCE: Figure 1 demonstrates a cross between two plants which appear to have a contrasting trait in regards to color of flowers. The allele for red (R) is not completely dominant over the allele for white (r), however, and the offspring combination of Rr produces pink flowers as a result of the blending influence of both alleles. The phenotypic and genotypic ratios for a monohybrid cross involving incomplete dominance, therefore, are both 1:2:1 as each allele influences the expression of the trait.
Figure 1: Schematic representation of the incomplete dominance of blended inheritance. Note that the genotypic and phenotypic ratios are identical as $1:2:1$. 

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MULTIPLE ALLELES: All of the crosses which have been discussed up to this point have involved only two forms of a gene, or two allelic possibilities. Frequently, three or more different forms of alleles occur in regards to a particular gene. The major blood groups found in the human race are determined by three forms of alleles. \( I^A \) and \( I^B \) are both dominant over \( i \) but lack dominance to each other. Any individual can have any combination of one or two of the three allelic forms.

<table>
<thead>
<tr>
<th>Phenotypes:</th>
<th>A</th>
<th>B</th>
<th>AB</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible</td>
<td>A_A</td>
<td>B_B</td>
<td>A_B</td>
<td>i</td>
</tr>
<tr>
<td>Genotypes:</td>
<td>( I^A )</td>
<td>( I^B )</td>
<td>( I^A _B )</td>
<td>( i )</td>
</tr>
</tbody>
</table>

LINKAGE: Mendel stated that genes are independently assorted during gametogenesis and segregated into haploid gametes. This concept was shown in the dihybrid cross in which the allele of \( T \) was segregated independent of the allele \( Y \). During meiosis of gametogenesis, it is the homologous chromosomes which are segregated to the gametes, not the individual genes. Therefore, those genes which are contained within the DNA of the chromosome will be inherited together, and are said to be linked. For example, if the genes controlling the two traits of eye color and hair color are both located within the same chromosome, and for simplicity, let us assume that dark hair and brown eyes are dominant over light hair and blue eyes, then the tendency will be that dark haired individuals will also have brown eyes, and vice versa. It was fortunate for Mendel that the contrasting traits with which he did his experiments were located on different chromosomes as linked genes do not separate independent of each other. A typical cross of two dihybrids concerning linked genes would be as follows:
Parents: AaBb x AaBb (no independent assortment)

Gametes:  

<table>
<thead>
<tr>
<th>AB</th>
<th>ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>ab</td>
</tr>
</tbody>
</table>

(no gametes formed of Ab or aB)

Possibilities:  

<table>
<thead>
<tr>
<th>AB</th>
<th>Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>AABb</td>
<td>Aabb</td>
</tr>
<tr>
<td>ab</td>
<td>Aabb</td>
</tr>
</tbody>
</table>

A special type of gene linkage involves the sex chromosomes. Man has forty-six chromosomes, or twenty-three pairs of homologous chromosomes. Twenty-two pairs are known as autosomal chromosomes, and one pair are sex chromosomes. The sex-chromosomes of a female are referred to as XX, whereas the male contains the sex-chromosomes of XY. A female can produce gametes containing only an X chromosome, whereas a male will produce two types of gametes pertaining to the sex chromosomes, or either an X or a Y. Thus, the male parent is going to determine the sex of the new individual. Characteristics which are determined by sex-linked genes, such as color-blindness and hemophilia, will involve those genes located on the X chromosome and are normally recessive if abnormal.

In the abnormality of red-green color blindness, the defective gene is carried on the X chromosome and is recessive to the gene for normal color vision. A female could be one of three different categories concerning this defect. She could be normal in both X chromosomes (XX), she could be a carrier of the defect without showing it (XXc), or she could be colorblind by being homozygous recessive (XcXc). A male, however, can be only normal (XY) or demonstrate color blindness (XcY). As a male contains only one X, the trait will be present with only one recessive allele as there is no normal X to cancel its effects. A
typical problem would be: a normal male marries a carrier female in regards to color blindness; what are their chances in producing color blind offspring?

Parents: \( XXc \times XY \)

Gametes: \( \begin{array}{c} X \ \ Xc \ \ X \ \ Y \\ Xc \end{array} \)

Possibilities: \[
\begin{array}{c|c|c}
 & X & Y \\
\hline
X & XX & XY \\
Xc & XcX & XcY \\
\end{array}
\]

It is shown above that the probabilities are fifty percent that the boys will be color blind, and fifty percent that the girls will be carriers.

CROSSING OVER: To introduce the concept of cross-overs between chromosomes, let us look at a typical genetic problem. Purple flowers (P) are dominant over red flowers (p) and elongated pollen grains (E) are dominant over round pollen grains (e). A plant homozygous for both traits, PPEE, is crossed with a plant homozygous recessive for both traits, or ppee. The \( F_1 \) generation produced is exactly as predicted, or PpEe, and the plants are all phenotypically purple with elongated pollen grains. The \( F_1 \) plants are crossed with the following results.

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple and elongated</td>
<td>4,831</td>
</tr>
<tr>
<td>Purple and round</td>
<td>390</td>
</tr>
<tr>
<td>Red and elongated</td>
<td>393</td>
</tr>
<tr>
<td>Red and round</td>
<td>1,338</td>
</tr>
</tbody>
</table>

The \( F_2 \) generation did not result in the expected ratio of a dihybrid cross, or 9:3:3:1. If the genes had been inherited through independent assortment the expected results should have been close to:

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Expected Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple elongated</td>
<td>3,910.5</td>
</tr>
<tr>
<td>Purple round</td>
<td>1,303.5</td>
</tr>
<tr>
<td>Red elongated</td>
<td>1,303.5</td>
</tr>
<tr>
<td>Red round</td>
<td>434.5</td>
</tr>
</tbody>
</table>
The F2 generation did not result in the expected ratio of linked genes if the dominant P was always inherited with the dominant E, and recessive p always inherited with recessive e. The expected ratio if the genes were linked would be close to:

Purple elongated: \( \frac{12}{16} \) of 6,952 = 5,214
Red round: \( \frac{4}{16} \) of 6,952 = 1,738

The actual results obtained in the cross agree more closely with the hypothesis that the genes are linked. However, if the genes are linked and inherited together, how is the limited number of purple round offspring and red and elongated offspring explained? The results can only be explained if the genes are linked on the same chromosome and if homologous chromosomes sometimes exchange parts during meiosis.

During prophase of meiosis I the tetrad of homologous chromosomes is formed. The chromatids often become twisted about each other, and when they are pulled apart a break often occurs with an exchange of segments. The schematic portrayal of this process is shown in Figure 2. In that example, a normal segregation of chromosomes would have produced gametes containing either AB or ab, but due to the process of crossing over the four gametes produced are AB, Ab, aB and ab. In the example of the purple and elongated pollen given above, it can be seen from the actual results that approximately 390 chromosomes did indeed exchange segments, thereby exchanging genes that are normally inherited together due to linkage.

![Figure 2: Schematic portrayal of crossing over during Meiosis I.](image)
The previous examples of varying forms of inheritance are the normal mechanisms for increasing the variable of genetic combinations. Any change within the nucleotide sequence of a gene is going to result in a mutation of that gene. Mutations are the only means known whereby new types of genes can arise. Spontaneous mutations occur at a slow rate in nature and they usually are recessive in influence. Induced mutations can be caused by a variety of mutagenic agents such as X-ray, ultra-violet light, excessive temperature and chemical base analogs, or molecules which resemble the nitrogenous bases used as a component of DNA. Most mutations are disadvantageous and may impair cell functions or lead to cell death. Gene changes generally are somatic mutations and affect a patch of tissue at most. Mutations which take place within the germ cells, or the cells destined to become gametes, however, will affect an entire new individual.

Chromosome aberrations, or mutations, can be of several types. Entire segments of a chromosome can be accidentally eliminated in the following example of a deletion, in which genes E and D are lost.

The abnormality known as an inversion is very similar to a deletion except that the broken segment reattaches in an inverted manner. The position of the gene on the chromosome can be of vital importance in regards to its functional operation.
The segment eliminated in a deletion can be attached to another chromosome. If it is attached to a homologous chromosome, it is known as a duplication, and if it is attached to a non-homologous chromosome it is called a translocation.

Another form of chromosome aberration is that of non-disjunction, an abnormal distribution of chromosomes during meiosis. This is an extremely serious defect as it affects an entire new individual produced from gametes that are abnormal in terms of chromosome number. In this instance, the homologous chromosomes fail to separate during metaphase and both chromosomes migrate to the same pole, a process which produces 22 chromosomes in one gamete and 24 in the other in humans.

Turner's syndrome in humans is a result of the non-disjunction of sex chromosomes and produces an individual with only one sex chromosome, an X. These are phenotypic females that are under developed and not capable of reproductive activity. Klinefelter's syndrome also results from non-disjunction and produces an individual with three sex chromosomes, or XXY. The latter are phenotypic males incapable of reproduction due to abnormal development. Downs syndrome, more commonly known as Mongolian idiocy, is the result of non-disjunction in regards to the autosomal chromosome numbered twenty-one. These individuals contain a total of 47 chromosomes, due to the fact they possess three
instead of the normal two for chromosome numbered 21.

GLOSSARY

Aberration  Deviation from the normal course.

Allele  An alternate form of a gene.

Autosomal  Any chromosome other than a sex chromosome.

Chromosome  The organelle responsible for genetic information and composed of DNA surrounded by a protein coat.

Deletion  A genetic aberration involving the removal of genes from a chromosome.

Dihybrid  An individual heterozygous for two particular traits.

Diploid  Containing two sets of chromosomes; 2n.

DNA  Deoxyribonucleic acid, the macromolecule containing the genetic code of inheritance.

Dominant  Any trait in genetics which masks the expression of a recessive gene.

Duplication  A chromosomal aberration in which a deleted portion of a chromosome adheres to a homologous chromosome.

Filial  Pertaining to the sequence of generations from a parent.

Gamete  A mature sexual reproductive cell such as a sperm or ovum.

Gametogenesis  The process involving meiosis that produces gametes.

Gene  A segment, or unit, of DNA which controls an inherited characteristic.

Genetics  The study of inherited characteristics.

Genotype  The actual gene combination regarding a particular trait.

Haploid  A single set of nonhomologous chromosomes.

Heredity  The transmission of genetic characteristics from parents to offspring.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterozygous</td>
<td>Having dissimilar genes in regard to a particular trait.</td>
</tr>
<tr>
<td>Homologous</td>
<td>State of being fundamentally similar, or corresponding to each other as structural units.</td>
</tr>
<tr>
<td>Homozygous</td>
<td>Having identical genes in regard to a particular trait.</td>
</tr>
<tr>
<td>Inversion</td>
<td>Change in position of genes such that the linear order is reversed.</td>
</tr>
<tr>
<td>Meiosis</td>
<td>A process of cell reproduction which reduces the number of chromosomes from diploid to haploid number.</td>
</tr>
<tr>
<td>Mitosis</td>
<td>A process of cell reproduction which retains the original number of chromosomes; asexual reproduction.</td>
</tr>
<tr>
<td>Monohybrid</td>
<td>An individual that is heterozygous for a particular trait.</td>
</tr>
<tr>
<td>Multiple alleles</td>
<td>When a gene can exist in more than two forms even though a single individual only can possess one or two forms.</td>
</tr>
<tr>
<td>Mutation</td>
<td>A change in the base sequence of DNA or a change in the chromosome.</td>
</tr>
<tr>
<td>Nucleotide</td>
<td>The sub-unit of nucleic acids (DNA or RNA) composed of a pentose, a nitrogenous base, and a phosphate group.</td>
</tr>
<tr>
<td>Phenotype</td>
<td>The expression of a genetic trait.</td>
</tr>
<tr>
<td>Primary sequence</td>
<td>The order of amino acids in a protein.</td>
</tr>
<tr>
<td>Somatic</td>
<td>Cells which are not germ, or reproductive, cells.</td>
</tr>
<tr>
<td>Tetrad</td>
<td>A formation of two homologous chromosomes, each of which is composed of two chromatids, that appears in meiosis.</td>
</tr>
<tr>
<td>Translocation</td>
<td>Abnormal behavior of a segment of chromosome that has attached to a nonhomologous chromosome.</td>
</tr>
</tbody>
</table>
The study of inherited characteristics is known as genetics. Inherited characteristics may be influenced by factors in the environment. Both parents in sexual reproduction contribute chemical code instructions to the offspring through the meiotic development of gametes. Genetic information is translated by the mechanism of protein synthesis. Chromosomes are composed of DNA molecules and protein. A gene is a segment of DNA. The information in one gene codes for the production of one protein. A diploid cell contains how many nonhomologous sets of chromosomes? two or 2n. A diploid individual contains how many genes for each trait? two. Haploid cells produced by meiotic division contain how many sets of homologous chromosomes? one or N. Haploid cells contain how many genes for each trait? one. An individual that contains identical genes for a particular trait is said to be homozygous.
An individual which contains unlike genes for a particular trait is said to be heterozygous.

A cross between two individuals that are both heterozygous in regards to one particular trait is called monohybrid cross.

A gene that can mask the expression of its allele is said to be dominant.

A monohybrid cross involving dominance results in a phenotypic ratio of three to one, 3:1.

A dihybrid cross involves two individuals heterozygous for what number of particular traits?

A phenotypic ratio of a dihybrid cross is 9:3:3:1.

An alternate form of a gene is called an allele.

A diploid parent with the genotype of Aa can produce what types of gametes in regard to this trait?

A heterozygous individual (Aa) is crossed with a homozygous (aa), what will be the genotype of the offspring in regards to this trait?

Genes that are carried on the same chromosome are said to be linked.

Linked genes have a tendency to be inherited together.

The sex chromosomes of a female are XX.
The sex chromosomes for a male are

XY

page 7

Most sex linked characteristics that are abnormal are recessive and carried on what chromosome

X

page 7

For a female to show a sex linked abnormal trait she must be homozygous recessive

page 7

A male will show a sex linked abnormality by possessing how many recessive genes

one

page 7

A normal female marries a colorblind male. What probability exists that their offspring will be colorblind.

boys normal, girls carriers

page 7

The process of crossing over occurs between chromosomes that are homologous

page 8

The actual change of nucleotide sequence in DNA is called a gene mutation

page 9

An individual that possesses 45 or 47 chromosomes is a result of non-disjunction

page 10
DEVELOPMENT AND DIFFERENTIATION

UNIT 11

OBJECTIVES

To identify from a list by name or description:

a) the contributions of male and female gametes
b) the role of yolk in determining cell division
c) the principle stages of development
d) the function of extra-embryonic membranes
e) the major systems derived from primary germ layers
f) the five types of tissues and their functions
g) the basic organ systems and their functions
All living things die and the ability to reproduce is therefore a vital characteristic of organisms and allows for the perpetuation of a species through time. Asexual reproduction, or mitosis (Unit 9), results in the production of identical offspring, whereas the process of sexual reproduction allows for offspring which vary from parental prototypes due to a recombination of genetic codes within the individual produced. Thus, both parents will transmit a set of chemical instructions by contributing a haploid set of chromosomes contained within the gametes that fuse during fertilization. Before undertaking a general look at developmental, or embryological, concepts, let us first consider the haploid gametes and the role they will play in determining future events.

**SPERM:** The process of gametogenesis in males will produce four mature haploid sperm from each primary spermatocyte by meiotic cell division (Unit 9). Sperms are generally the smallest cell of a species and consist of a head containing the haploid set of chromosomes, a middle piece which is tightly packed with mitochondria, and a tail which allows for movement. On the front of the head is an acrosome which contains lysosomes and associated enzymes (Figure 1-A).

**OVA:** The process of gametogenesis in females will produce only one viable ova from each primary oocyte by meiotic cell division, the remaining three products of oogenesis being reduced to polar bodies which are reabsorbed. Ova are generally the largest cell of a species.
A: Components of the male sperm.

B: A schematic portrayal of three ovum which differ according to the amount of yolk material and its dispersion. An isolecithal ovum is shown in B:1, a telolecithal ovum in B:2, and a highly telolecithal ovum in B:3. Note that the amount of yolk has forced the active cytoplasm to concentrate nearer to animal (A) pole and away from the vegetal (V) pole.

Figure 1: Part A demonstrates the components of human sperm.
and contain a haploid set of chromosomes, the usual cytoplasmic organelles and a varying amount of a lipoprotein substance known as yolk. The quantity of yolk found in the ovum depends upon the amount required for development, and therefore, will vary from species to species. Ova are classified according to the amount of yolk present and how it is distributed as granules throughout the cytoplasm.

Ova which contain a small amount of yolk evenly distributed throughout the cytoplasm are classified as isolecithal. Ova which contain a great amount of yolk which is concentrated toward one end of the cell are known as telolecithal. The amount of yolk is going to play a vital role in determining the stage of development at emergence and the form of early cell division.

Ova possess polarity and are nearly spherical in form. The animal pole is the area where the polar bodies were pinched off and is the general region of highest activity due to the presence of the haploid nucleus. The vegetal pole is at the other end of the polar axis and tends to be more sluggish due to the concentration of yolk and will be concerned with the development of nutrient organs. (Figure 1:B).

FERTILIZATION: Fertilization of the ovum by a sperm is a process which encompasses two stages and requires that both male and female gametes are in a proper state of maturity to ensure union. In humans the ovum must have extruded the first polar body (Meiosis I) and the second polar apparatus (Meiosis II) should be in a state of arrest. Random movement brings contact between the gametes and a thigmotaxic response by the sperm allows it to penetrate the ovum membrane. This first stage of fertilization is the stimulus needed to extrude the
second polar body and to initiate cell division. The second stage of fertilization is the union of the male and female nuclei which is completed as the chromosomes line up in a metaphase sequence of the first cellular division.

Ova may be stimulated to divide by other means than sperm penetration, a process known as parthenogenesis, and will result in the development of ova without the haploid set of chromosomes contributed by the sperm.

DEVELOPMENT

Once fertilization has occurred, three general categories of development are recognized in all organisms:

1) cleavage or early cell division leading to morphogenesis
2) gastrulation as the initial stage of differentiation
3) organogenesis or the formation of organs by varying tissues

CLEAVAGE: Cleavage is the initial process of mitotic cell division which is going to result in an increase of the number of cells and reduce the individual cell size. This is a fractional process to provide the building blocks of a convenient size with a more favorable surface to volume relationship (Unit 1). Even though this division is mitotic, the cells produced do not separate and remain together as a total unit. The size of the total mass remains the same as cell division proceeds, and each cell is identical to the others as the DNA contained within each is an exact copy of the original chromosomes brought together at fertilization.
The first cleavage plane occurs through the poles and divides the zygote, or fertilized ovum, into two cells. The second divisional plane also occurs through the animal and vegetal poles and creates a four-celled stage of early development. The third cleavage plane, however, is horizontal to the previous divisions and its exact location will be dependent upon the amount of yolk present and its distribution. Yolk is a sluggish, inert, substance and in a telolecithal ovum, the third cleavage plane will be forced toward the animal pole. Further cell division results in the production of a solid mass of cells known as the morula. Each cell within the morula is identical to every other cell and will differ, if at all, only in size according to the amount of yolk initially present. Figure 2 demonstrates the initial mitotic divisions, or cleavage, and illustrates the effect of yolk in impeding equal cell division.

The morula faces the same disadvantageous surface to volume relationship as did the original zygote. The inner cells of this mass must receive nutrients and eliminate wastes efficiently in order to survive and all substances must pass through the outer cells during their transport. The inner cells begin to push outward to overcome this disadvantage and thus create a hollow ball of cells which surround a central fluid filled cavity. The structure produced is known as a blastula and demonstrates the beginning of form, or morphogenesis, as the cells become arranged in a spacial relationship. The fluid filled central cavity is known as the blastocoel and each individual cell is known as a blastomere. The blastomeres are still identical to each other as differentiation between them has not yet occurred.
Figure 2: Cleavage in an isolecithal zygote (A), in an amphibian
telolecithal ovum (B), and in a highly telolecithal organism (C). Note
the differences in blastula formation due to the amount of yolk. The
final cleavage formation, or blastula, will be determined by the amount of
yolk. Morphogenesis, or the formation of spacial arrangements, which deter-
mine form and size will thus be influenced by the type of ovum which was
originally fertilized.
GASTRULATION: The next stage of development consists of an infolding or movement of cells and is a key stage in the embryology of organisms. The total mass of the embryo has remained the same throughout the process of cleavage and blastula organization, and only the number of blastomeres has increased. To explain the process of gastrulation an isolecithal ovum will be used. The process will differ in other organisms due to the amount of yolk and the presence of extra-embryonic membranes, but the basic concepts of germ layer formation and spacial orientation are similar.

If one considers the blastula to be a hollow ball of cells similar to a hollow tennis ball, then one can conceive of pushing in one side until eventually it reaches the internal wall opposite the site of pressure. This can be demonstrated in the following way:

Those cells which now lie on the inside differ in environmental conditions that those which form the outer surface of the involuted blastula. The opening through which these cells moved, or were pushed, is called the **blastopore** and aids in establishing an anterior and posterior orientation in the developing embryo. Those cells which line the new cavity, or **archenteron** (the blastocoel has been obliterated) are now beginning to undergo differentiation and form the primary germ layer of **endoderm**. The cells which remained on the external area of the **gastrula** are designated as **ectoderm**. A third primary germ layer of **mesoderm** will form between the other two in those species which are triploblastic, or naturally are composed of three primary germ layers.
Differentiation has now begun in the process of gastrulation and no longer are all cells of the embryo alike in terms of future capabilities. Differentiation is under the control of the inherited DNA molecules and the chemical code for the synthesis of proteins (Unit 8) and it is during this stage of development that the amount of RNA produced becomes significant. The key stage of gastrulation has thus determined the following variables:

- the establishment of the primary germ layers
- the orientation of anterior and posterior positions
- the orientation of ventral and dorsal positions
- the establishment of body cavities

The three primary germ layers established during gastrulation will ultimately form specialized tissues which will function together as organs and organ systems. The following chart designates the germ-layer origin of human development: (Major designations only)

<table>
<thead>
<tr>
<th>ECTODERM</th>
<th>MESODERM</th>
<th>ENDODERM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Epidermis</td>
<td>1. Muscle</td>
<td>1. Epithelium of:</td>
</tr>
<tr>
<td>2. Epithelium of</td>
<td>2. Connective</td>
<td>a) pharynx</td>
</tr>
<tr>
<td>a) sense organs</td>
<td>3. Blood</td>
<td>b) larynx</td>
</tr>
<tr>
<td>b) nasal cavity</td>
<td>4. Lymphoid tissue</td>
<td>c) digestive tube</td>
</tr>
<tr>
<td>c) mouth</td>
<td>5. Epithelium of:</td>
<td>d) bladder</td>
</tr>
<tr>
<td>d) anal canal</td>
<td>a) blood vessels</td>
<td>e) lungs</td>
</tr>
<tr>
<td></td>
<td>b) body cavities</td>
<td>f) vaginal canal</td>
</tr>
<tr>
<td>3. Nervous tissue</td>
<td>c) kidney</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) gonads</td>
<td></td>
</tr>
</tbody>
</table>

**EXTRA-EMBRYONIC MEMBRANES**

Until the evolution of land laid eggs, all embryos developed within a fluid environment which aided in protecting against mechanical injury,
allowed a buoyant surrounding to ensure development without pressure, and afforded the developing organism a means of eliminating wastes by diffusion. With the advent of organismic development external to a body of water, there was the concurrent development of extra-embryonic membranes to protect the embryo and to simulate a water environment. Four extra-embryonic membranes are recognized and serve a definite function in the embryological development of species.

The egg of a bird will be used to demonstrate the functions of the extra-embryonic membranes.

1. Chorion: a membrane formed by the embryonic mass to prevent dehydration of the embryonic environment. Water is an essential component of all protoplasm and its retention will, therefore, be vital to a developing organism.

2. Amnion: a membrane formed by the embryonic mass to hold a bathing fluid, the amniotic fluid, to protect the embryo from mechanical injury and to keep a moist atmosphere.

3. Allantois: a membrane developed which functions as an embryonic lung for the exchange of gases and to store nitrogenous waste products. This membrane is present in the human species for only a short time and becomes a component of the umbilical cord.

4. Yolk sac: This membrane forms as a nutritive covering surrounding the mass of yolk needed to sustain the developing organism until it emerges as a free living individual. In humans, this membrane is not as significant as there is an attachment for nutrients through the umbilical cord.

Figure 3 shows the extra-embryonic membranes and their involvement with both a bird's egg and a developing human organism.
A. Extra-embryonic relationships in birds.

B. Human relationships of extra-embryonic membranes.

Figure 3: The relationship of extra-embryonic membranes in the bird (A) and in the human species during development (B).
TISSUES

The level of complexity (Unit 2) which follows the cellular level is that of tissues. Tissues are groups of cells which function together for a common purpose. Five major tissues are recognized according to physiological purposes and are composed of cells derived from the primary germ layers.

1. Epithelium: Closely packed cells which are arranged in flat sheets and line the various cavities and tubes of the body as well as forming skin are components of the epithelium system of tissues. They are classified according to the relative thickness of the individual cells:
   a) squamous, or very flat cells. An example is that of skin cells.
   b) cuboidal, or cubed shaped cells. The tubules of kidneys are composed of cube shaped epithelial cells.
   c) columnar, or long column shaped cells. The intestinal lining is composed of columnar epithelial cells.

The function of epithelial tissue includes protection against dehydration, abrasion, radiation and bacterial invasion. Epithelial tissue is always found at the boundary of a cell mass and a cavity or space, and is therefore, important in the process of transporting substances to and from the cell masses and the cavities which they separate. A specialized form of germinal epithelium will give rise to gametes through the process of meiosis.

2. Connective: Cells which are embedded in extracellular materials give support and strength to human organisms and are known as connective tissues. Those tissues which directly support and give strength to soft parts are known as supporting connective tissue and includes cartilage and bone. Another form of connective tissue is known as binding connective tissue. Tendons and ligaments fall into this class as they bind body parts together. Fascia is a fibrous form of connective tissue which is utilized as a packing material for internal organs as well as providing pathways for blood vessels and nerves to reach these organs. Fascia also binds muscular tissue to epidermal layers of cells and becomes the site of deposition for excess oil and fats.

3. Muscle: Cells which function together and possess contractile proteins are known as muscle tissues. Three types of muscle fibers are recognized on the basis of structure and function. Skeletal, or voluntary, muscles are those which are attached to bones and are involved with conscious movement. Involuntary, or smooth, muscles are associated with internal vital organs and are generally under unconscious control. Cardiac muscle is found only in the heart and is unique in the fact that it has its own intrinsic rhythm of contraction.

4. Nervous: Cells which possess the ability to pass impulses are components of the nervous tissue. A nerve is composed of many individual cells, or neurons, which are bundled together in a single structure.
5. Vascular: The circulating internal environmental fluids are composed of various types of vascular tissue, including red blood cells, lymphocytes, platelets, etc., which contribute to the homeostasis of the internal but extracellular environment.

ORGANS

Tissues which function together for a similar specific purpose form organs. Organs may be composed of one tissue, or may be composed of all five tissues working for a common goal. For example, the stomach is an organ involved with the process of digestion and is composed directly of smooth muscle, connective, and epithelial tissue which are indirectly influenced by vascular and nervous tissues. In this example, all five tissues are functioning together for the purpose of digestion and therefore together form an organ.

ORGAN SYSTEMS

Organs which have a common overall functional relationship form organ systems. Organ systems often are involved with more than one functional goal and even though they are separated by major contributory actions, it must be remembered that they often are interrelated and interdependent in servicing the total organism. The ten commonly recognized organ systems are classified as:

1. The integumentary system which includes the protective covering, or skin, and those derivatives which arise from the epidermal layers such as feathers, scales, etc.
2. The skeletal system is composed of cells and cell products which give support to the soft parts of the organism and affords a degree of protection for vital organs. The skeletal system also provides leverage for movement.
3. The muscle system is involved with movement in conjunction with the skeletal system and the contractions associated with internal organs.

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4. The nervous system brings coordination to the organism by receiving and interpreting stimuli gathered both internally and externally.

5. The endocrine system is composed of ductless glands which secrete chemical messengers, or hormones, to bring about a chemical coordination by neural stimulation.

6. The digestive system is involved with the procurement of nutrients and those processes associated with extracellular degradative events.

7. The respiratory system is composed of organs and tissues necessary for the exchange of gases to facilitate cellular respiratory processes.

8. The circulatory system provides a means of circulating nutrients and gases throughout the organism and serves as a means of transporting waste materials to elimination outlets.

9. The excretory system is utilized as a means of excreting metabolic wastes to the outside environment.

10. The reproductive system consists of those organs which function for the perpetuation of the species.

The above ten organ systems function toward the common goal of maintaining the organism and represents the highest level of complexity within a single living system.

GLOSSARY

Acrosome Cap located on the sperm head containing lysosomes.

Allantois Extra-embryonic membrane that functions as bladder and site of gas exchange.

Amnion Extra-embryonic membrane that holds the amniotic fluid in which the embryo is suspended.

Animal pole That area of an ovum which is nearest the nucleus and contains the highest concentration of active cytoplasm.

Anterior Situated toward the front.

Archenteron Primitive gut or cavity of a gastrula.

Blastocoel Cavity of the blastula that is fluid filled.

Blastomere Any cell of the blastula.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blastopore</td>
<td>The opening into the blastula through which cells move during gastrulation.</td>
</tr>
<tr>
<td>Blastula</td>
<td>A stage of development in which a layer of cells surround a central cavity or blastocoel.</td>
</tr>
<tr>
<td>Cleavage</td>
<td>The act of cleaving or splitting; early cell division.</td>
</tr>
<tr>
<td>Chorion</td>
<td>The extra-embryonic membrane that functions to prevent dehydration; aids in forming the placenta in mammals.</td>
</tr>
<tr>
<td>Dorsal</td>
<td>Area of the backside of an organism.</td>
</tr>
<tr>
<td>Embryology</td>
<td>The science dealing with development of organisms.</td>
</tr>
<tr>
<td>Endoderm</td>
<td>A primary germ layer formed during gastrulation.</td>
</tr>
<tr>
<td>Exoderm</td>
<td>A primary germ layer formed during gastrulation.</td>
</tr>
<tr>
<td>Extra-embryonic</td>
<td>Developed by the embryo without being a part of it.</td>
</tr>
<tr>
<td>Gametogenesis</td>
<td>The process of developing sex cells or gametes.</td>
</tr>
<tr>
<td>Gastrula</td>
<td>An embryo in the early stage of germ layer development.</td>
</tr>
<tr>
<td>Gastrulation</td>
<td>The process of producing a gastrula in development.</td>
</tr>
<tr>
<td>Isolecithal</td>
<td>An ovum which contains little yolk evenly dispersed.</td>
</tr>
<tr>
<td>Lipoprotein</td>
<td>Chemical substances composed of both lipids and proteins.</td>
</tr>
<tr>
<td>Mesoderm</td>
<td>A primary germ layer developed during gastrulation.</td>
</tr>
<tr>
<td>Morphogenesis</td>
<td>The structural development of an organism; form.</td>
</tr>
<tr>
<td>Morula</td>
<td>A solid ball of cells resulting from cleavage.</td>
</tr>
<tr>
<td>Organogenesis</td>
<td>The formation of organs from primary germ layers.</td>
</tr>
<tr>
<td>Parthenogenesis</td>
<td>The development of an ovum without fertilization.</td>
</tr>
<tr>
<td>Posterior</td>
<td>Situated behind or at the rear of an organism.</td>
</tr>
<tr>
<td>Prototype</td>
<td>The original on which something is based.</td>
</tr>
<tr>
<td>Telolecithal</td>
<td>An ovum which contains more yolk concentrated at the vegetal pole.</td>
</tr>
<tr>
<td>Thigmotaxic</td>
<td>Movement toward a substance or object upon contact.</td>
</tr>
<tr>
<td>Triploblastic</td>
<td>Having three primary germ layers.</td>
</tr>
</tbody>
</table>
Vegetal pole: That area of an ovum which contains the highest concentration of yolk.

Ventral: Pertaining to the abdominal side of an organism.

Yolk sac: Extra-embryonic membrane which forms around the yolk.

Zygote: A fertilized ovum.

PROGRAMMED SELF TEST - UNIT 11

The male and female gametes are known as sperm, ovum

Reproductive cells, or gametes, contain how many chromosomes haploid, or 23 in man

Sperms contribute mainly a set of chromosomes

Ovum contribute a haploid set of chromosomes, cytoplasmic organelles as well as the nutritive material known as yolk

The amount of yolk is going to determine the form of early cell division

The nucleus of an ovum lies nearest which pole animal

The yolk of an ovum lies nearest which pole vegetal

An isolecithal ovum contains yolk which is evenly distributed

Development of ovum without fertilization is parthenogenesis

The union of sperm and ovum is known as fertilization
The initial process of cell division within an ovum is cleavage page 3.

The type of cell division in cleavage is mitotic page 3.

The solid mass of cells resulting from cleavage is a morula page 4.

A zygote is a fertilized ovum page 4.

The hollow structure formed as cells of the morula push out is the blastula page 4.

The cavity of the blastula is called the blastocoel page 4.

The blastula has demonstrated a definite form or morphogenesis page 4.

Each undifferentiated cell of the blastula is called a blastomere page 4.

The stage of development involving a movement of cells is gastrulation page 4.

The movement or infolding of cells occurs through the opening blastopore page 4.

The three primary germ layers established during gastrulation are ectoderm, mesoderm, and endoderm page 6.

The cells of the gastrula have become specialized or differentiated page 6.

The outer covering and nervous system will arise from the germ layer ectoderm page 7.
<table>
<thead>
<tr>
<th><strong>The blood and muscle systems will be derived from</strong></th>
<th><strong>mesoderm</strong></th>
<th><strong>page 7</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The digestive tube will arise from the germ layer</strong></td>
<td><strong>endoderm</strong></td>
<td><strong>page 7</strong></td>
</tr>
<tr>
<td><strong>The extra-embryonic membrane which functions as a bladder</strong></td>
<td><strong>allantois</strong></td>
<td><strong>page 9</strong></td>
</tr>
<tr>
<td><strong>The extra-embryonic membrane which holds the bathing fluid</strong></td>
<td><strong>amnion</strong></td>
<td><strong>page 8</strong></td>
</tr>
<tr>
<td><strong>The tissue which separates cells from cavities</strong></td>
<td><strong>epithelial</strong></td>
<td><strong>page 9</strong></td>
</tr>
<tr>
<td><strong>Tissues which contain cells that contract</strong></td>
<td><strong>muscle</strong></td>
<td><strong>page 10</strong></td>
</tr>
<tr>
<td><strong>Tissues composed of cells which transmit electrical impulses</strong></td>
<td><strong>nervous</strong></td>
<td><strong>page 10</strong></td>
</tr>
<tr>
<td><strong>The organ system that secretes hormones, or chemical messengers to influence target cells.</strong></td>
<td><strong>endocrine</strong></td>
<td><strong>page 11</strong></td>
</tr>
<tr>
<td><strong>What system is composed of cells which function to support</strong></td>
<td><strong>skeletal</strong></td>
<td><strong>page 11</strong></td>
</tr>
<tr>
<td><strong>The outer protective covering of organisms is the system of</strong></td>
<td>** integumentary**</td>
<td><strong>page 11</strong></td>
</tr>
</tbody>
</table>
OBJECTIVES

To identify from a list by name or description:

a) the term cybernetics
b) the essential abilities of a control system
c) the components of a control system
d) the concept of negative feedback
e) the concept of positive feedback
f) the components of a neuro-muscular system
g) the components of a neuro-endocrine system
h) the components of a cellular system
CYBERNETICS

All living organisms are constantly responding to a variety of stimuli continually being received from both their internal and external environment. The human organism must coordinate activities on each level of complexity (cell, tissue, organs, etc.) as well as between the various levels, in order to maintain an appropriate internal environment, or homeostasis, while seeking an optimal external environment in the midst of change.

The term cybernetics is used to designate a science concerned with control mechanisms and communication systems which are based on the concept of feedback information. In living systems, the homeostatic mechanisms involved with the regulation of structure and function due to environmental changes are self-regulating cybernetic systems that operate on all levels of complexity. It is through these control mechanisms that any change within the environment, or stress, is continually interpreted and either removed or counteracted. Therefore, it is essential that such a control system has the ability to:

1) recognize a stress, and
2) respond to the stress.

Three components of any cybernetic system are necessary to ensure a rapid flow of information, the interpretation of that information, and a means of responding to the original stress in the altered environment. These three components are designated as:

1) receptors
2) moderators, or modulators
3) effectors
In a self-regulating system the effectors return corrective information to the moderator for re-evaluation once the effectors have carried out the appropriate response. If the response reinforces the original stress, it is known as positive feedback, whereas a negative feedback system returns the situation back to an optimal condition and lowers the effects of the original stress. To exhibit regulation, a system must contain a negative feedback route and, therefore, most biological mechanisms are of the latter type.

Three general control systems will be examined in this unit, each of which operates on a negative feedback mechanism. The first two are concerned with regulatory controls on the organismic level, and the third is a homeostatic control of cellular existence.

NEURO-MUSCULAR

The neuro-muscular system generally triggers short term responses, and in this regard is a contributor to the characteristic of life designated as irritability. Man possesses a complex nervous system that permits the various parts of the body to communicate with each other and allows them to function as a coordinated whole. The receptors of a neuro-muscular cybernetic system consist of neurons which receive information concerning a stress in the form of a stimulus which is transported to the central nervous system. The information is interpreted by the central nervous system and an appropriate response chosen on the basis of learning and experience. The central nervous system thus serves as the moderator of the neuro-muscular cybernetic system. Simple integration of information often occurs in the spinal cord and results in simple responses, whereas more complex activities require an interpretation and integration of incoming information and these decisions will be moderated in the brain.
Once a course of action, or determination of response, has been chosen, it will be sent to the proper effectors, or muscles, to execute the moderator's decision.

An example of the simple reflex arc will demonstrate a neuro-muscular cybernetic system. If you place your hand on a hot object, the following sequence of reactions will occur:

The receptors receive the stress, or stimulus, that the object is hot and sends this information to the spinal cord which chooses an appropriate response (move the hand away from the hot object). The directive is sent to the effectors, or muscles, which will carry out the moderators order. This is a negative feedback system as the response attempts to reduce the effect of the stress and return the environmental condition to an optimum state. If this had been a positive feedback system, the response would have reinforced the stress, or the hand would have been ordered closer to the hot object.

A more complex integration of information utilizes the brain as the moderator and not the spinal cord. A constant flow of information is received by this organ in various forms of transported stimuli, interpreted, and responses selected. Once the response to an incoming stimulus has been selected, the appropriate orders are transported by neural connections to those muscles concerned with their execution, or to the effectors of the neuro-muscular system.
The endocrine system, also controlled by negative feedback systems, triggers long term responses in reaction to neural stimulation. The endocrine glands are ductless and secrete chemical messengers, or hormones, into the circulating body fluids. Hormones stimulate certain target cells to alter their metabolic activities by influencing protein synthesis or enzyme production. One significant difference between a neuro-endocrine and neuro-muscular cybernetic system is that of effector response. In a neuro-muscular system, the effector, or muscle, reacts if stimulated, whereas the target cell, or effector, of the neuro-endocrine system determines the competency of reaction. Neuro-muscular systems accomplish effector response by altering membrane potentials and neuro-endocrine systems alter the enzymatic machinery of the target cells.

To demonstrate a neuro-endocrine system, the sequence of reactions involving the release of the hormone thyroxine by the thyroid gland will be followed. Thyroxine is an important hormone which stimulates the oxidative phosphorylation processes of target cells via the blood circulatory route.
In the previous example of a neuro-endocrine system, the sensory input (receptors) stimulates the hypothalamic neurosecretory center to secret TRF, a moderator. TRF is a thyrotrophic releasing factor which in turn stimulates the pituitary gland to release a thyroid stimulating hormone, or TSH. This hormone circulates within the body fluids until it reaches the target cells of the thyroid gland (effector) which will then increase the production and secretion of thyroxine. Once the level of thyroxine contained within the body fluids reaches a critical level, the action of the hypothalamic center will be inhibited from further production of TRF. When the levels of thyroxine fall below an optimal concentration, the cycle will again be initiated by a re-activation of TRF secretion.

Both the receptors and moderators of the above cybernetic system are neural, whereas the effectors are glands of the endocrine system. In this manner, communication can be completed with and between cells of the various parts of a multicellular organism and direct neural contact, as in the neuro-muscular system, is not necessary for interaction.

CELLULAR SYSTEMS

Regardless of what type of stress exists, it usually affects one or more metabolic reactions, and the response is ultimately a metabolic cellular one. Homeostasis, or steady state, can therefore be maintained if, in response to a stress or stimuli, a cell can adjust and re-adjust the pattern of its chemical reactions. Chemical reactions are determined by the presence of enzymes, and enzymes are determined by protein synthesis. Cells maintain steady states, therefore, by adjusting rates
of protein synthesis, which is controlled by the DNA contained within the chromosomes.

In a cellular cybernetic system, the receptor is the plasma membrane, the moderator is DNA and the effectors are the proteins, or enzymes, produced. One such system is known as enzyme induction. A series of genes, or segments of DNA, may normally be inhibited from producing mRNA by a regulator substance \( r \) which is a protein product controlled by a regulator gene. The site at which the regulator substance inhibits the genes is called the operator area \( o \). Any substance \( A \) enters the cell and ties up the regulator substance \( r \), and \( r \) is therefore no longer able to inhibit mRNA synthesis by tying up the \( o \) region. The \( o \) region is free, the genes produce enzymes to metabolize \( A \) through protein synthesis and the stimulus is removed by inducing the enzymes that can metabolize it. This can be shown schematically as:

Before induction:

\[
\text{Regulator gene} \quad \xleftarrow{\text{mRNA}} \quad \text{Operator} \quad \text{Gene}_1 \quad \text{Gene}_2 \quad \text{Gene}_3
\]

\( (\text{No mRNA production}) \)

After induction:

\[
\text{Regulator gene} \quad \xleftarrow{\text{mRNA}} \quad \text{Operator} \quad \text{Gene}_1 \quad \text{Gene}_2 \quad \text{Gene}_3
\]

\( (\text{mRNA production present}) \)

Before induction, the genes (1, 2, and 3) are not producing mRNA and therefore the proteins (enzymes) are not being synthesized. After substance \( A \) enters the cell, it induces these genes to be turned "on"
by inhibiting the r protein which had been inhibiting the gene activity. In this way, substance A induces the production of the proteins, or enzymes, that are necessary for the metabolism of itself. Once substance A is no longer present the regulator protein (r) will again tie up the operator region and turn that portion of the DNA molecule (genes) "off" as the enzymes will no longer be necessary without a substrate.

As multicellular organisms became more complex and developed organs and organ systems from tissues and cells, each level of organization became more specialized and therefore, less independent. Some form of communication between cells, tissues, organs, and organ systems was required to maintain homeostasis on all levels. The three examples of control systems mentioned in this unit are merely models of many such cybernetic systems that coordinate responses to stimuli and are necessary for:

1) the development of one cell (zygote) \[\rightarrow\] multicellular organism in which differentiation proceeds by means of tissue and cell communication.
2) the coordination of the organism as it responds "in total" to environmental factors, or stresses, as an organized unit.

GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cybernetics</td>
<td>Study of self-regulating control systems.</td>
</tr>
<tr>
<td>Effectors</td>
<td>A cell or tissue that carries out a response to a nerve impulse.</td>
</tr>
<tr>
<td>Moderators</td>
<td>That which moderates or selects a response.</td>
</tr>
<tr>
<td>Modulator</td>
<td>See moderator.</td>
</tr>
<tr>
<td>Neuron</td>
<td>A cell that is the functional basis of nerve tissue.</td>
</tr>
<tr>
<td>Neuro-endocrine</td>
<td>A combined coordinated system in which the receptors and the moderator is nervous tissue and the effectors are endocrine glands.</td>
</tr>
</tbody>
</table>
Neuro-muscular  A combined coordinated system in which the receptors and the moderator is nervous tissue and the effectors are muscle fibers.

Receptor  End organs of sensory neurons specialized to receive stimuli.

PROGRAMMED SELF TEST - Unit 12

Any change in the environment, external or internal, is a stress  

The stress is relayed to a moderator as a stimulus  

A term that designates a self-controlled system is cybernetic  

Most biological cybernetic systems operate on a negative feedback  

Once a system has recognized a stress it must be able to respond  

That which receives the initial stimuli is called a receptor  

That which interprets the stimuli is called a moderator  

That which carries out the moderator's order is called an effector  

A system which reinforces the stress is called a system of positive feedback  

In a neuro-muscular system, what cells are receptors neural, neurons  

In a neuro-muscular system, the effectors are muscles
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a neuro-endocrine system, the effectors are</td>
<td>glands</td>
<td>3</td>
</tr>
<tr>
<td>In a neuro-endocrine system, the receptors are</td>
<td>neural</td>
<td>3</td>
</tr>
<tr>
<td>In both neuro-muscular and neuro-endocrine the moderator is</td>
<td>neural</td>
<td>2, 3</td>
</tr>
<tr>
<td>The moderator of a cellular cybernetic system is</td>
<td>DNA</td>
<td>4</td>
</tr>
<tr>
<td>The effectors of a cellular system are</td>
<td>enzymes</td>
<td>4</td>
</tr>
<tr>
<td>The receptor of a cellular system</td>
<td>plasma membrane</td>
<td>4</td>
</tr>
<tr>
<td>Enzyme induction belongs to what class of control systems</td>
<td>cellular</td>
<td>4</td>
</tr>
<tr>
<td>What class of molecules are secreted by endocrine glands</td>
<td>hormones</td>
<td>3</td>
</tr>
<tr>
<td>The competency of reaction is decided by what component in a neuro-endocrine system</td>
<td>effectors, target cells</td>
<td>3</td>
</tr>
<tr>
<td>Homeostasis on all levels of complexity is maintained by</td>
<td>cybernetic systems</td>
<td>1</td>
</tr>
</tbody>
</table>