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ML 201 – Science of Living Systems

Unit 1 : Understanding Basics (6L)

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1. Engineering perspectives of biological sciences: Where engineering meets biology and where biology meets engineering. Biology as an integrated Science; Case studies on integrating biology with engineering.
2. Biopolymers and macromolecules – Structure and Function: Organic and inorganic molecules; Unique Properties of Carbon; Carbohydrates, Amino Acids and proteins, Lipids, Nucleic Acids, Vitamins and Minerals; The Rise of Living Systems.
3. Levels of organization of life : Cell as basic unit of life, prokaryotic and eukaryotic cells, microbes, plant and animal cells; Cell organelles – structure and function; Levels of organization of life - tissues, organs, systems and organism.

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1) ENGINEERING PERSPECTIVES OF BIOLOGICAL SCIENCES

Bioengineering or Biomedical Engineering is a discipline that advances knowledge in engineering, biology, and medicine -- and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. Bioengineering/Biomedical Engineering combines engineering expertise with medical needs for the enhancement of health care. It is a branch of engineering in which knowledge and skills from the existing methodologies in such fields as molecular biology, biochemistry, microbiology (study of microorganism), pharmacology (study of drugs and medicines), cytology (cell biology), immunology (study of immune system) and neuroscience (neurology) are utilized and applied to the design of medical devices, diagnostic equipment, biocompatible materials, and other important medical needs.

Bioengineering is not limited to the medical field. Bioengineers have the ability to exploit new opportunities and solve problems within the domain of complex systems. They have a great understanding of complexity within the living systems which can be applied to many fields including entrepreneurship. Those working within the bioengineering field are of service to people, work with living systems, and apply advanced technology to the complex problems of medical care.

Bioengineering may be categorized as:

- Biomedical engineering;
- Biomedical technology
- Biomedical Diagnosis
- Biomedical Therapy
- Biomechanics
- Biomaterials.
- Genetic engineering
- Cell engineering

Biomedical engineering (BME): By combining biology and medicine with engineering, biomedical engineers develop devices and procedures that solve medical and health-related problems. Biomedical engineers may be called upon to design instruments and devices, to bring together knowledge from many sources to develop new procedures, or to carry out research to acquire knowledge needed to solve problems. Many do research, along with life scientists, chemists, and medical scientists, to develop and evaluate systems and products for use in the fields of biology and health, such as artificial organs, prostheses (artificial devices that replace missing body parts), instrumentation, medical information systems, and health management and care delivery systems. Bioengineers design devices used in variety of medical procedures, such as the computers used to analyze blood or the laser systems used in corrective eye surgery. They develop artificial organs, imaging systems such as magnetic resonance, ultrasound, and x-ray, and devices for automating insulin injections or controlling body functions. Most engineers in this specialty require a sound background in one of the basic engineering specialties, such as mechanical or electronics engineering, in addition to specialized biomedical training. Some specialties within bioengineering or biomedical engineering include biomaterials, biomechanics, medical imaging, rehabilitation engineering, and orthopedic engineering.

Examples of work done by biomedical engineers include:

• designing and constructing cardiac pacemakers, defibrillators, artificial kidneys, blood oxygenators, hearts, blood vessels, joints, arms, and legs.

• designing computer systems to monitor patients during surgery or in intensive care, or to monitor healthy persons in unusual environments, such as astronauts in space or underwater divers at great depth.

• designing and building sensors to measure blood chemistry, such as potassium, sodium, 0_2, CO_2, and pH.

• designing instruments and devices for therapeutic uses, such as a laser system for eye surgery or a device for automated delivery of insulin.

developing strategies for clinical decision making based on expert systems and artificial intelligence, such as a computer-based system for selecting seat cushions for paralyzed patients or for, managing the care of patients with severe burns or for diagnosing diseases.

• designing clinical laboratories and other units within the hospital and health care delivery system that utilize advanced technology. Examples would be a computerized analyzer for blood samples, ambulances for use in rural areas, or a cardiac catheterization laboratory.
• designing, building and investigating medical imaging systems based on X-rays (computer assisted tomography), isotopes (position emission tomography), magnetic fields (magnetic resonance imaging), ultrasound, or newer modalities.
• constructing and implementing mathematical/computer models of physiological systems.
• designing and constructing biomaterials and determining the mechanical, transport, and biocompatibility properties of implantable artificial materials.
• implementing new diagnostic procedures, especially those requiring engineering analyses to determine parameters that are not directly accessible to measurements, such as in the lungs or heart.
• investigating the biomechanics of injury and wound healing.

Specialty Areas

By combining biology and medicine with engineering, biomedical engineers develop devices and procedures that solve medical and health-related problems. Many do research, along with life scientists, chemists, and medical scientists, to develop and evaluate systems and products for use in the fields of biology and health, such as artificial organs, prostheses (artificial devices that replace missing body parts), instrumentation, medical information systems, and health management and care delivery systems. Some of the well established specialty areas within the field of biomedical engineering are bioinstrumentation, biomechanics, biomaterials, systems physiology, clinical engineering, and rehabilitation engineering.

Bioinstrumentation

Bioinstrumentation is the application of electronics and measurement principles and techniques to develop devices used in diagnosis and treatment of disease. Computers are becoming increasingly important in bioinstrumentation, from the microprocessor used to do a variety of small tasks in a single purpose instrument to the extensive computing power needed to process the large amount of information in a medical imaging system.

Biomechanics

Biomechanics is mechanics applied to biological or medical problems. It includes the study of motion, of material deformation, of flow within the body and in devices, and transport of chemical constituents across biological and synthetic media and membranes. Efforts in biomechanics have developed the artificial heart and replacement heart valves, the artificial kidney, the artificial hip, as well as built a better understanding of the function of organs and musculoskeletal systems. Biomaterials describes both living tissue and materials used for implantation. Understanding the properties of the living material is vital in the design of implant materials. The selection of an appropriate material to place in the human body may be one of the most difficult tasks faced by the biomedical engineer. Certain metal alloys, ceramics, polymers, and composites have been used as implantable materials. Biomaterials must be nontoxic, noncarcinogenic, chemically inert, stable, and mechanically strong enough to withstand the repeated forces of a lifetime.

Systems Physiology

Systems physiology is the term used to describe that aspect of biomedical engineering in which engineering strategies, techniques and tools are used to gain a comprehensive and integrated understanding of the function of living organisms ranging from bacteria to humans. Modeling is used in the analysis of experimental data and in formulating mathematical descriptions of physiological events. In research, models are used in designing new experiments to refine our knowledge. Living systems have highly regulated feedback control systems which can be examined in this way. Examples are the biochemistry of metabolism and the control of limb movements.

Clinical Engineering

Clinical engineering is the application of technology for health care in hospitals. The clinical engineer is a member of the health care team along with physicians, nurses and other hospital staff. Clinical engineers are responsible for developing and maintaining computer databases of medical instrumentation and equipment records and for the purchase and use of sophisticated medical instruments. They may also work with physicians on projects to adapt instrumentation to the specific needs of the physician and the hospital. This often

involves the interface of instruments with computer systems and customized software for instrument control and data analysis. Clinical engineers feel the excitement of applying the latest technology to health care.

Rehabilitation Engineering

Rehabilitation engineering is a new and growing specialty area of biomedical engineering. Rehabilitation engineers expand capabilities and improve the quality of life for individuals with physical impairments. Because the products of their labor are so personal, often developed for particular individuals or small groups, the rehabilitation engineer often works directly with the disabled individual. These specialty areas frequently depend on each other. Often the bioengineer, or biomedical engineer, who works in an applied field will use knowledge gathered by bioengineers working in more basic areas. For example, the design of an artificial hip is greatly aided by a biomechanical study of the hip. The forces which are applied to the hip can be considered in the design and material selection for the prosthesis. Similarly, the design of systems to
electrically stimulate paralyzed muscle to move in a controlled way uses knowledge of the behavior of the human musculoskeletal system. The selection of appropriate materials used in these devices falls within the realm of the biomaterials engineer. These are examples of the interactions among the specialty areas of biomedical engineering.

Major Advances in Bioengineering

Artificial Joints

In 1994, a National Institutes of Health Consensus Panel declared that total hip replacement (THR) is one of the most successful surgical procedures, providing immediate and substantial improvement in a patient's pain, mobility, and quality of life. THR involves removing diseased or damaged bone in the upper end of the thigh bone (femur) and the section of the lower pelvis into which the femur fits. The bone is then replaced with prosthesis, usually made of a metal alloy or polyethelene (plastic) components. Successful replacement of deteriorated, arthritic, and severely injured hips has contributed to enhanced mobility and comfortable, independent living for many people who would otherwise be substantially disabled.

Magnetic Resonance Imaging (MRI)

In 1952, the Nobel Prize in Physics was awarded for the discovery of nuclear magnetic resonance, which laid the groundwork for one of the most unique and important inventions in medical imaging since the discovery of the X-ray. Magnetic resonance imaging (MRI) is a method of looking inside the body without using surgery, harmful dyes or radiation. The method uses magnetism and radio waves to produce clear pictures of the human anatomy. Although MRI is used for medical diagnosis, it uses a physics phenomenon discovered in the 1930s in which magnetic fields and radio waves, both harmless to humans, cause atoms to give off tiny radio signals. Different kinds of animal tissue emit response signals of differing length e.g. response signals between cancerous and non-cancerous tissue, and among the response times of other kinds of diseased tissue.

Heart Pacemaker

The invention and development of the heart pacemaker illustrates the merging of medicine and engineering. The device is a result of the collective efforts and collaboration of people and organizations from both engineering and medicine, and both public and private institutions. The pacemaker was the first electronic device ever surgically implanted inside a human. First developed in the 1960s, pacemaker typically refers to a small, battery-powered device that helps the heart beat in a regular rhythm. Small electrical charges travel to one or multiple electrodes placed next to the heart muscle. Originally pacemakers sent one steady beat to the heart through a single electrode. Today's pacemakers can sense when a heart needs help and delivers just the right amount and duration of impulse---sometimes through multiple electrodes- --that maintain steady heart rate, even during physical activity. While most pacemakers today

are permanent implants, some are used as temporary therapy for recovering heart patients.

Arthroscopy

Arthroscopy is a surgical procedure orthopedic surgeons use to visualize, diagnose and treat problems inside a joint. The word arthroscopy comes from two Greek words, "arthro"

(joint) and "skopein" (look), and literally means "to look within the joint." In an arthroscopic examination, an orthopedic surgeon makes a small incision in the patient's skin and then inserts pencil-sized instruments that contain a small lens and lighting system to magnify and illuminate the structures inside the joint. Light is transmitted through fiber optics to the end of the arthroscope that is inserted into the joint. By attaching the arthroscope to a miniature television camera, the surgeon is able to see the interior of the joint through this very small incision. The camera attached to the arthroscope displays the image of the joint on a television screen, allowing the surgeon to look, for example, throughout the knee -- at cartilage and ligaments, and under the kneecap. The surgeon can determine the amount or type of injury, and then repair or correct the problem, if necessary.

Angioplasty

Insertion of a catheter into a patient's coronary artery and inflated a tiny balloon, opening a blockage and restoring blood flow to a human heart is known as coronary angioplasty. It accounts a most common medical intervention in the world. Although this procedure was first envisioned as simply an alternative to open heart bypass surgery in only a handful of patients, today angioplasty accounts for more than half of the treatments for coronary artery disease. Biomedical engineering and advances in technology have not only optimized basic balloon angioplasty, but also added the use of stents, lasers and other interventional devices that restore normal blood flow while minimizing damage to the heart muscle.

Bioengineered Skin

The burgeoning field of tissue engineering promises to be one of the most significant biomedical areas of the new century. The hope is that, eventually, whole organs could be manufactured to replace those that are injured or diseased. The field's first contribution to health care took a big step toward fulfilling these promises by producing artificial version of the body's largest organ, skin. Skin is a difficult organ to transplant because of its inherently strong immune defense system. Nevertheless, it has a relatively simple structure, making it a good testing ground for the talents of tissue engineers. Patients can

have skin made to order that combines collagen as a binder with living human cells. This is placed onto a wound, usually a chronic ulcer or a burn, and its cells become activated and gradually integrate with those of the patient.

Kidney Dialysis

Considerable human population on the Earth currently lives with chronic kidney failure resulting from disease, birth defect or injury. Virtually all these patients would die if not for the aid of ongoing kidney dialysis. Kidney dialysis artificially filters and removes waste products and excess water from blood, a process normally performed by the kidneys. Although often referred to as an artificial kidney, kidney dialysis is not a cure. The procedure can, however, give damaged kidneys a rest and a chance to recover normal function, or be used until the patient receives a transplant. For many patients, kidney dialysis is a way of life. Kidney dialysis was first developed by a Dutch physician, Willem Kolff, M.D., Ph.D. In the early 1940s, he began searching for a way to use dialysis, the process by which particles pass through a membrane, to treat patients with kidney failure. A sever shortage of materials due to the war forced Kolff to improvise, especially when it came to a suitable membrane, the key component to the filtering process.

Today, research to find more efficient, low-cost methods of treatment remains a priority for biomedical engineers. Current efforts include not only improving the components of dialysis, such as better dialysates and membranes, but also developing alternatives to dialysis, such as a true artificial kidney, xenotransplantation and replacement kidneys through tissue engineering.

Heart-lung Machine

One of the truly revolutionary pieces of medical equipment has been the invention and development of the heart-lung machine. Before its introduction to medicine in the 1950s, heart surgery was unheard of; there was no way to keep a patient alive while working on the heart. During an open-heart surgery, such as bypass surgery, the heart-lung machine takes over the functions of the heart and lungs and allows a surgeon to carefully stop the heart while the rest of the patient's body continues to receive oxygen-rich blood. The surgeon can then perform delicate work on the heart without interference from bleeding or

the heart's pumping motion. Once the procedure is over, the surgeon restarts the heart and disconnects the heart-lung machine.

A typical biomedical engineering department does the corrective and preventive maintenance on the medical devices used by the hospital, except for those covered by a warranty or maintenance agreement with an external company. All newly acquired equipment is also fully tested. That is, every line of software is executed, or every possible setting is exercised and verified. Most devices are intentionally simplified in some way to make the testing process less expensive, yet accurate. Many biomedical devices need to be sterilized. This creates a unique set of problems, since most sterilization techniques can cause damage to machinery and materials. Most medical devices are either inherently safe, or have added devices and systems so that they can sense their failure and shut down into an unusable, thus very safe state. A typical, basic requirement is that no single failure should cause the therapy to become unsafe at any point during its life-cycle.

2) BIOPOLYMERS & MACROMOLECULES

A living organism's body is built of and run by thousands of different types of molecules. As these are made chiefly by the living organisms they are known as biomolecules. Biomolecules have distinct properties and functions responsible for their selection and continuation in the course of evolution.

Many of the small molecules with low molecular weight, simple structure and high solubility are known as **micromolecules** (or monomers e.g. water, mineral, simple sugars, nucleotide etc.) form the building units for larger **macromolecules** (or polymers.e.g. protein, lipids etc.). The biomolecules are classified into organic and inorganic types based on their composition.

Thus, all cells are made up of biomolecules, these are organized in physico-chemical organizations and in isolation they do not have living characteristics. Biomolecules produce, maintain and perpetuate the living state and are continuously transformed i.e. synthesized and broken down.

Water, minerals and gases are important groups of inorganic bimolecules while lipids, carbohydrates, proteins and nucleic acids are the four important classes of organic compounds.

WATER

Physical & Chemical Properties of Water:

- Water is cohesive & adhesive
- Water has high specific heat
- Water has high thermal conductivity
- Water has high boiling point
- Water is good evaporative coolant
- Water has high freezing point and is less dense as a solid than liquid

In the biological reactions, two important features are observed,

- **polarity** (+ ve charge for H and – ve for O extend polarity to water molecule; water molecules form cluster around electrically charged molecules like PO_4 or COOH, that are

water soluble hence known as **hydrophilic** while water does not react with non charged molecules like lipids that are insoluble known as **hydrophobic**) and

- **ionization ability** (water molecule dissociates to form H and OH ions)

Significance of water in living system

- Life has doubtless origin from the water.
- Water is the most abundant substance in living system making up more than 70% of the weight for most of the living organisms.
- Water provides liquid medium for colloidal protoplasm for chemical reactions and transport mechanism in the cell.
- The water molecule and its ionization products, H and OH influence the structure, properties and self assembly of all cellular components.
- Aqueous solutions of weak acids & bases with their salts act as buffer in pH change in biological system. It facilitates chemical reactions in the cells.
- The non covalent interactions responsible for the strength & specificity of biomolecules are decisively influenced by the solvent property of water. It is known as Universal solvent for most of the organic & inorganic molecules.
- It absorbs heat and maintains body temperature.
- In green plants, it is a source for H + ve ions as a source of energy.
- Removal of waste material thus helps in maintaining **homeostasis**

MINERALS

Minerals are the nutrients required especially for the growth of plants that are absorbed from the soil. Some of these minerals are required in larger quantity and some in trace levels for the plant growth. Accordingly they are known as **micro** or **macronutrients** respectively. The role of some minerals in the cell metabolism is as follows,

Mineral	Function	Mineral	Function
N, S	Synthesis of Amino acids, proteins	**P**	Present in compounds like phospholipids, ATP, nucleotides etc.
K, Na	Constituents of Body fluids, nerve cells, blood plasma	**Ca**	Plays significant role in Blood coagulation & cell wall formation, propulsion of nerve impulses
Fe	Formation of haemoglobin	**Mg**	Formation of chlorophyll, enzymes, structural integrity of ribosomes
I	Functioning of thyroid glands	**Cu, Mo**	Activation of enzymes

Ions are required to maintain osmotic concentration of cellular as well as extra cellular fluids.

Gasses are significant for the basic cellular processes.

Gas	Function
O_2	Essential for respiration for all aerobic bacteria, combustion process, photosynthesis byproduct
N_2	Constituents of proteins, nucleic acid, fixation & release of nitrogen by bacteria for plants
CO_2	Used in photosynthesis, excess is dissolved in water

Carbohydrates –These are hydrates of carbon made up of C, H, O

Reducing sugars – Sugars with free aldehyde / ketone group

Non- reducing sugars- e.g. aldehyde region of glucose reacting with ketone region of fructose – form glycosidic bond – non – reducing sugar as free aldehyde / ketone groups are masked.

Aldoses: Glucose, Ribose, Deoxiribose, Mannose, Galactose etc.

Ketoses: Fructose, Ribulose, Xylulose etc.

According to number of monomers present in carbohydrate molecule

Monosaccharide**: Water soluble**

- Trioses (Dihydroxy acetone, glyceraldehydes)
- Tetroses (Threose, Erythrose)
- Pentoses (Ribose, Deoxyribose, Xylose, Ribulose, Arabinose)
- Hexoses (Glucose – also called blood sugar, grape sugar and Dextrose can be polymerized in to glycogen in animals and starch in plants; Fructose – Fruit sugar; Galactose, Mannose)
- Heptose (Sedoheptulose)

Oligosaccharides: 2-9 monomers

- Disccharides (Maltose, Sucrose, lactose etc)
- Trisaccharides (Raphinose, Pectin, Innulin)
- Polysaccharides (Starch, Cellulose, Glycogen, Chitin, Agar)

Homo-polymers: All the monomers same in given polysaccharides (Starch, Hemicellulose, Cellulose, Glycogen)

Hetero-polymers: Two or more monomers in given polysaccharides (Agar, Chitin)

Monomers are linked by glycosidic bond during polymerization

Types & Function of Polysaccharides:

Storage polysaccharides: *Starch*, *inulin* stored in roots, tubers of plants; *Glycogen*: In animals and bacteria

Inulin is the smallest polysaccharide: not metabolized in human body filtered through kidney. ⟶ used in kidney testing.

Structural polysaccharides: *Cellulose, Hemicellulose, Pectin* – (in plants), Chitin (plant fibres & animal exoskeleton like insects, spiders, crabs etc.)

Chondrin sulphate in cartilage, tendon ligament

Hyaluronic acid – (glucoronic a.+ acetyl glucosamine) cementing subs. between animal cells. In diff body fluid – vitreous humor of eye,

sinusoidal fluid CSF e.g. *Keratan Sulphate* in cornea, skin, cartilage, bone, hair, nail

Mucopolysaccharide – slimy substances e. g. *Hyaluronic acid*

Agar – used in culture media, medicine, capsules and chromatography

Algin –used in Ice creams, cosmetics.

Carrageenin – used as a emulsifier, clearing agent – fruit juice.

Funori –used as adhesilve in hair curling

Heparin – used in blood bank as blood anti-coagulant

Husk of *Plantago ovata* – used as purgative / laxative

Aloegel – used as inflammation - relief, in hand lotion, shampoo, hair conditioner, sunscreen lotion.

PROTEINS:

Proteins make up more than 50 % of the dry mass of animals and bacteria and perform important functions in living organisms. They contain the elements carbon, oxygen, hydrogen, nitrogen and usually sulfur that makes a monomer of protein i.e. amino acid. All organisms contain 20 common amino acids as biological molecules.

Essential amino acids: can not be synthesized by animals, so must be taken in diet. In man such amino acids are 8, in other animals are 7.

Non Essential Amino acids: Can be synthesized by animals, so may not be taken in diet

Each amino acid (AA) has a carboxyl group (-COOH), amino group (-NH2) and a hydrogen atom bounded to a central carbon atom. The sequence of amino acids (linked by peptide bond) determines the overall shape and properties of proteins. Depending on number of amino acids in a chain oligopeptide (1-10 AA), Polypeptides (11-50 AA) and protein (>50 AA).

Various categories made for the classification of proteins based on the composition, structure etc. are as follows;

Structural organization of proteins:

PrimaryProteins: two dimensional, simple chain of AA with peptide (covalent) bond e.g. Insulin

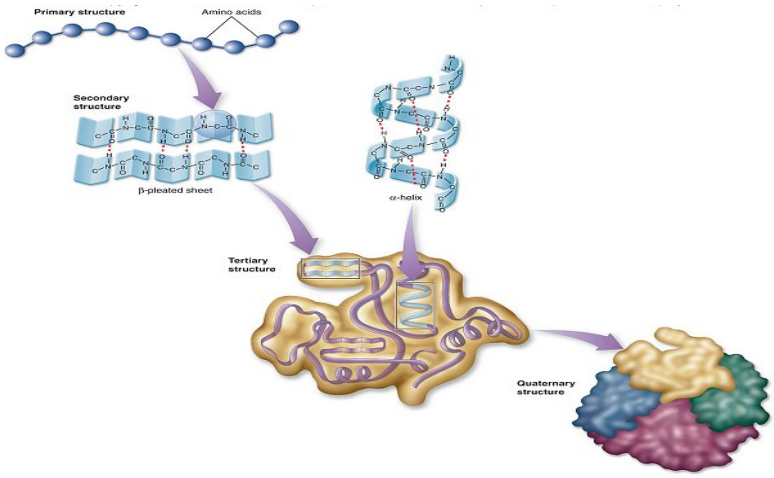
Secondary Proteins: Various functional groups exposed on outer surface interact with hydrogen bonds

- α- helix – e.g. keratin, hair, fur, clans, hooves
- β– pleated – B. keratin of feathers, silk fibroin
- Collagen helix – 3 α – helices coiled around one another

Tertiary Proteins: Additional bonds between functional groups, twisting of secondary protein, weak covalent and high energy disulphide bonds are formed e.g. Myoglobin

Quaternary P**roteins**: Formed as a result of 2-more

polypeptide chain and have specific orientation



Types of proteins according to structure:

Fibrous – collagen fibres, keratin, elastin, fibrin, fibroin, actin, myosin, bl. clot.

Globular – glutelin, protemine, globulin, albumin, glutenin, orygemin.

Intermediate – (myosin), fibrinogen.

Types of proteins according to chemical nature

Simple – only a.a. Albumin, globulin, protanine, fish, prolamine (corn, pl, wheat), histone (corn, wheat), glutelin (glutenin), keratin.

Conjugated – protein + non protein (prosthetic group) e.g. **Nucleoprotein** (nucleic acid), **chromoprotein** (Hb, cytochrome), **metallo** (with metals Zn, Fe), **lipoprotein**, **glycoprotein** etc.

Properties of proteins:

- Number: According to length,, number & types of polypeptides – thousands of proteins
- Specificity: High specificity in the individual but shared with related species or group
- Molecular weight – ACTH (4500 daltons) to Pyruvate Dehydrogenase (4,600,000 daltons)
- Solubility: Some are insoluble due to large size, many form colloidal solution with water
- Amphoteric nature: Show both acidic & basic properties.
- Electrical reaction: Isoelectric point at which pH is neutral (Curdling of milk at pH 4.7 due to isoelectric point at acidic pH 4.7)

- Denaturation: Permanent or temporary loss of three dimensional structure caused due to UV, heat, strong acid & alkali, high salt concentration; within limit renaturation occur.

Role of protein:

Type of protein	**Example**	**Function**
Enzymes	Amylase	Converts starch into sugar
Structural	Keratin, Collagen Haemoglobin	Hair, wool, nail, horn, hoofs, tendons, cartilage Blood clotting
Hormones	Insulin, glucagons	Regulate glucose metabolism
Contractile	Actin, myosin	Contractile filaments in muscle, cilia & flagella (in lower organisms)
Amphoteric	All proteins	Maintain acid-base equilibrium
Storage	Ferritin, albumin Casin	Stores iron in spleen & egg yolk Milk
Transport	Haemoglobin Serum albumin	Carried oxygen in blood Carries fatty acid in blood
Energy	All proteins	Provides energy stored in peptide bonds
Metaloprotein	Cytochrome	Electron transport
Receptor	Adrenalin	Conduction of nerve stimulus
Nucleoprotein	Histones & non-histone	Stabilization of DNA coiling
Immunological	Antibodies	Forms complexes with foreign proteins
Toxins	Venum (Neurotoxin)	Blocks the nerve function

Proteins are masterpieces of molecular engineering and they are tailored to their functions by millions of years of natural selection.

LIPIDS:

Lipids are the organic compounds that share a distinguishing property of non polarity and so do not dissolve in water. They mostly contain carbon and hydrogen with very small portion of oxygen compare to carbohydrates. Some of them also incorporate phosphorus and nitrogen. Basically they are polymers of fatty acids & glycerol.

As lipids are insoluble in water they are vital components of the membrane that separate living cells from each other and their surrounding.

Lipids offer unique way to store energy as they possess very high proportion of energy rich carbon-hydrogen bonds in a concentrated form within the cells. They contain six times more energy than the carbohydrates and have become increasingly important as food reserves for organisms. (e.g. migratory birds).

Fatty Acids: Simplest form of lipids consisting of a long hydrocarbon chain (non polar hydrophobic) with a carboxyl group at the end (which is hydrophilic). Because of this characteristic orientation, fatty acids significantly contribute in the structure of cell wall.

Fats & Oils: These are the energy store reserves for the plant & animal cells. Fats are formed by the condensation of fatty acid molecules and are characteristically non polar. They are classified into **saturated** (butter, coconut oil) which are solid at room temperature and without double bond and **unsaturated** (from olive, corn, safflower, peanut etc.) which are liquid at room temperature and with double bond. Usually, animals use saturated fatty acids against the plants with unsaturated fatty acids.

Phospholipids: These are similar to fats except one or two fatty acids are replaced by phosphate group which in turn are linked to nitrogen containing group.

Steroids: They differ from lipids in structure but insoluble in water. Cholesterol is most commonly known steroid forming essential component of animal cell membrane. It also served as a raw material for the production of vitamin D and steroid hormones.

In general the steroids carry chemical messages between the cells.

Properties:

- Saturated & unsaturated
- Insoluble in water and soluble in organic solvents like alcohol
- Low specific gravity hence float on water

- On hydrolysis give fatty acids and glycerol
- Neutral fats or triglycerides are colour less, odder less, taste less
- Rancidity: Naturally occurring unsaturated fats undergo partial hydrolysis by the action of enzyme lipase. Oxidation at double bond produces aldehydes and carboxylic acids. This develops foul test and odder to the fats.**Types of Lipids –**

1. Simple Lipids – These are neutral or true fats. Solid at room temperature, on hydrolysis give three faty acids and one glycerol e.g. waxes

R C O R ← esters of fatty acids with different alcohols.

e.g. tripalmitin, diplamitin are hard fats, solid at room temp.

2. Compound / Conjugated lipids –

Phospolipids – Cephalin – act as insulation for nerves
Lecithin – cell permeability

Glycolipds – Cerebrosides – brain cells – cell mem. gangliosides – grey matter.
Sphingomyelins –in myelin sheath.
Sphingosine ⟶ amino alcohol.

Lipoproteins – found in milk, egg yolk, blood plasma, tissues, cell surfaces.
Cutin – from cuticle.
Suberin – due to it cell wall impermeable to H_2O.
Chromolipds – e.g. carotenoids.

3. Derived Lipids –Formed from hydrolysis of simple & comp. lipids, Include f.a., steroids, prostaglandins, terpenes.

Prostaglandins – Hormone – like unsaturated fatty acids / local hormones, present in amniotic and tissue fluid

- Circulate in blood
- Cause acid production in stomach
- Stimulate contraction of smooth muscles.

Steroids – solid wax like alcohols e.g. ergosterol – yeast. Cholesterol - animal cell mem., blood, bite. When bl. level of chole. rises – Cholesterol and its esters form bond with fats secreted by endothelium of arteries. And thus deposited on wall of arteries.

It is precursor for hormone progesterone, testosterone, cortisol, estradiol, androsteron

Produces bile salts, vitamin D by action of U V rays of sunlight.

- React with protein in nucleus
- Trigger changes in gene expression and metabolism

Role of lipids:

- Reserved food: In plants oilseeds like groundnuts, mustard, coconut are the stores of fats. Animals contain adipocytes which are the cells containing the fat droplets as stored food.
- Structural component: Phospholipids, glycolipids and sterols are the structural components of the cell membranes.
- Synthesis: Take part in the synthesis of steroids, hormones, Vit D etc.
- Energy source: Rich source of energy. 9.3 kcal/gram
- Insulation: Provide electrical and thermal insulation. Deposited below the skin and around the internal organs to lessen the heat loss. Also work as shock absorbers.
- Solvent: Fats are the solvents for fat soluble vitamins like A, D, K, E.
- Waxes are water proof agents e.g. fur, feathers, insect exoskeleton, bee wax, ear wax (cerumen), skin wax (sebum), paraffin wax & plant waxes

NUCLEIC ACIDS :

1st reported by Friedrich Miescher. from pus cells nuclei. Called them nuclein. Altman called N.A. Feulgen developed staining tech. of N.A. with fusch.

DNA – Deoxyribo nucleic acid

Made up of three components –

i) Deoxyribose sugar – (pentagonal shape with 5 C atoms)

ii) Nitrogen containing bases –

Purine – Adenine (A), Guanine (G).

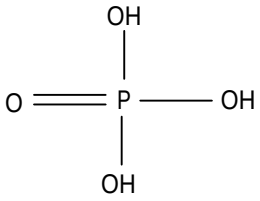
Pyrimidine – Cytosine (C), Thymine (T)

Pentose suger + N base ⟶ nucleoside

Glycosidic bond between 1st C of sugar and nitrogen at 3rd position in pyrimidine base and 9th position in purine base.

iii) Phosphoric acid –

OH – 3 acid groups.

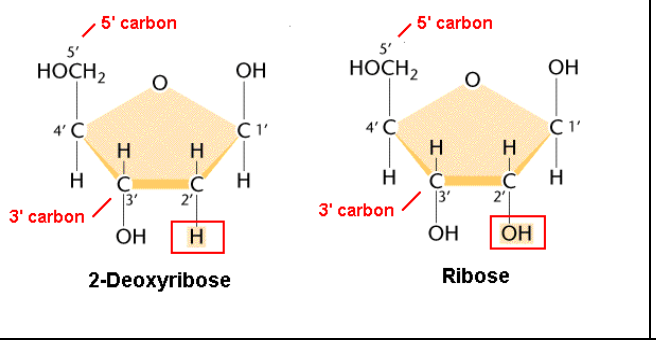


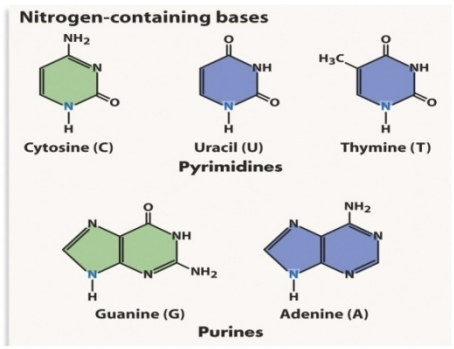
Nucleoside + P group at 5' position by **phosphor-diester bond**.

Nucleoside + Phosphate group ⟶ nucleotide.

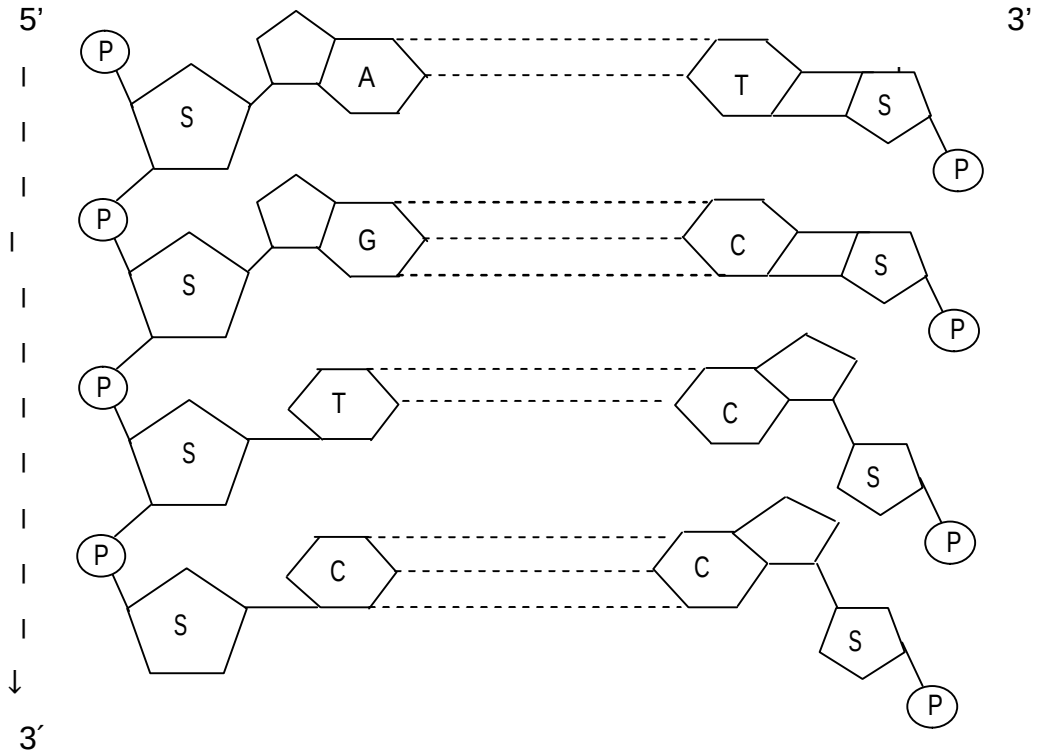
Amount of DNA measured by picogram = 10^{-12} g., 1 Pg DNA has 31 cm length.

Human cell – contains 5.6 Pg DNA – 174 cm long.





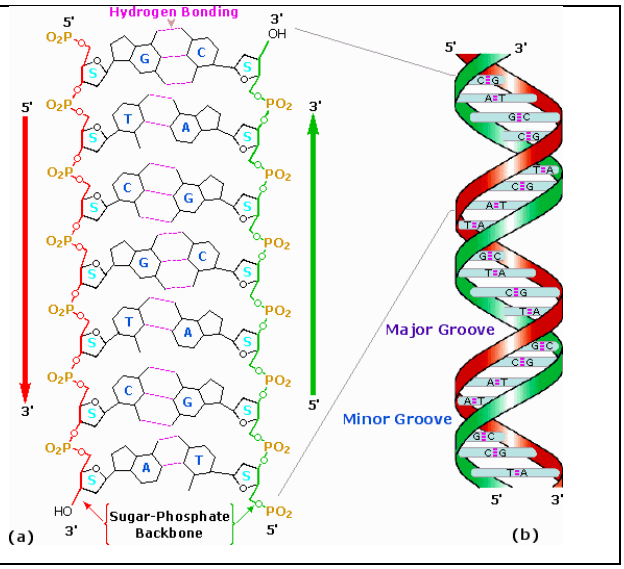
Chain of nucleotides – **poly nucleotide chain**



Characteristics / Properties – DNA

- It has several thousand Nucleotides.
- Back bone of it by alternate d sugar and PO_4 gr.
- Nitrogen bases are inside at right angle to longitudinal axis.
- PO_4 gr. Attached 5^{th} , 3^{rd} C atom.
- By phosphodiester bond.
- 2 chains joined by weak H bond – A = T, G = C specific pairing. H of one base linked to O_2 / N_2 of another base.
- 2 strands anti parallel i.e. 3', 5' phosphor ------- link in opp. direction.
- Pairing specific — 2 chain complementary.
  i.e. sequence of N_2 bases in one chain will decide it on other chain.
- Diameter of DNA – 20 A°

- **Erwin Chargaff's rule** – regardless of source - purine, pyrimidine components occur in equal amounts in a DNA mole.

1) A = T, G = C from this it is also seen 2) $\frac{A}{T} = \frac{C}{G} = 1$ 3) A +G = T + C 4) A + C = G + T but 5) A + T not always G + C necessarily.	

James Waston & Francis Crick – suggested three dimensional molecular model based on X ray crystallography technique; according to this model DNA comprises of

1) 2 right Handed helices.
2) Each turn has – 10 nitrogen base pairs
3) One spiral each 3.4 A°
4) Distance between 2 nitrogen bases 3.4A°

Denaturation and Renaturation of DNA –

1) If DNA solution heated / exposed to alkaline PH or acidic PH, H bonds break and 2 strands uncoil this is known as **denaturation** or **DNA melting**.
2) If above solution gradually cooled / neutralized – new base pair formation begins, it becomes thermally / chemically stable finally double stranded DNA formed which is called as **renaturation**.

Linear DNA with ends free **with histones** (eukaryotes) and circular DNA 2 ends covalently linked **without histones (**prokaryots).

Repetitive DNA –

- The part of DNA which contains same sequence of N bases repeated several times in tandem (one behind another)
  e.g. A A T C G G A A T C G G A A T C G G
- It occurs specifically near telomeres (ends), centromeres,
- Area with long sequence of repetitive DNA is called satellite DNA as it separates out during density gradient ultra centrifugation.
- Microsatellite DNA — 1 – 10 base pairs repeat units
  Minisatellite DNA — 11 – 60 base pairs repeat units, it is hypervariable (it is known as VNTR variable Number of Tandom Repeats discovered by Jeffreys et al., specific for each individual therefore used in DNA finger printing.

Palindromic DNA –

DNA duplex has areas with sequence of nucleotides same reading forward or backward from central axis of symmetry G A C T G C G T C A G

AND MADAM DNA

(Restriction endo-nuclease commonly recognize DNA sequences that are palindromes.

RNA – Ribo Nucleic Acid –

It is also made up of three components;

i) Ribose sugar – Pentose sugar

ii) Nitrogen containing bases – **Purine** – Adenine, Guanine & **Pyrimidine** – Cytosine, Uracil.

Sugar + N. B. ⟶ Nucleoside

Genetic in some pl. viruses TMV yellow MV animal viruses – influenza, poliomyelitis, HIV;

Animal, Plant viruses ⟶ single stranded

Reovirus of some plant ⟶ Double stranded.

Non- genetic RNA –

Mainly in nucleolus, cytoplasm, ribosome, mitochondria, chloroplast, in association with chromo.

Found both in pro & eukaryots

Synthesis in N on one of the DNA strand by transcription.

Thus carries genetic inf. from DNA.

Structure – Single stranded. Hence does not follow Chargaff's rule.

Types – three types of RNA - all are synthesized in nucleus

1) m – RNA / messenger / template: linear, longest molecule with 900 – 1500 nucleotides

Function: To carry genetic information in the form of codons from DNA to site of protein synthesis i.e. ribosomes.

2) r – RNA / ribosomal RNA – folded.

Function:

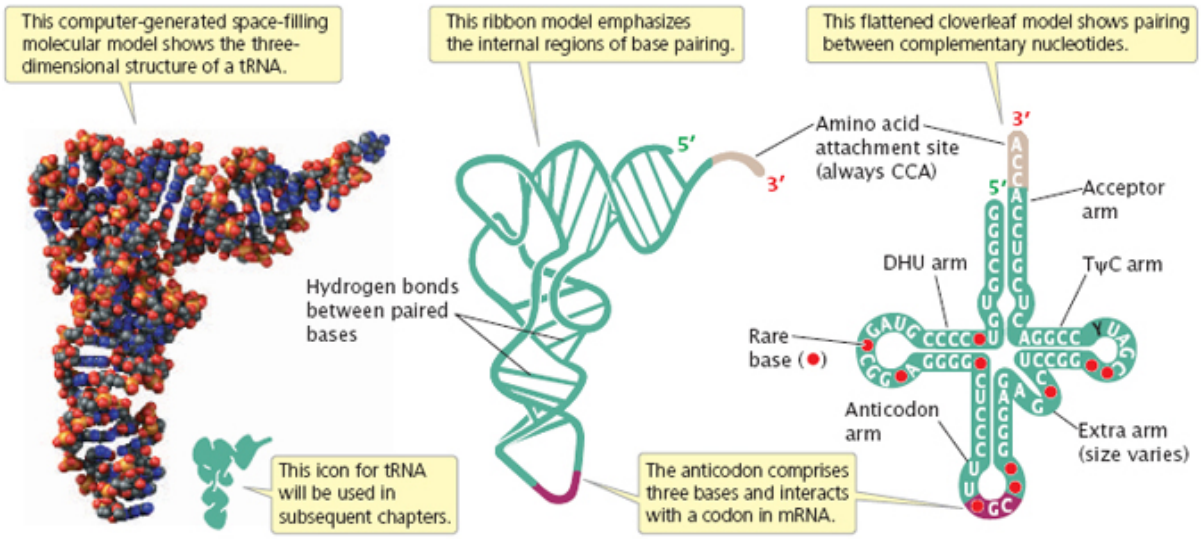
- Proper orientation of m RNA
- Formation of ribosomal complex by the attachment of smaller & larger subunit and further ribosomal complex with m RNA
- relese of t RNA from ribosome complex after transfer of AA to polypeptide chain

3) t - RNA / transfer RNA / soluble RNA (can't be precipitated by ultracentrifugation)

Structure: According to shape two models are explained viz. clover leaf and hair pin

Function:

- To bring AA at the site of protein synthesis
- Transfer of AA to polypeptide chain



3) LEVELS OF ORGANIZATION OF LIFE

Cell as basic unit of life, prokaryotic and eukaryotic cells, microbes, plant and animal cells;

CELL ORGANELLES

Present in all eukaryotic cells. Absent in prokaryotic cells, secondarily lost in mammalian RBC.

MITOCHONDRION

Also called as power houses, energy coins. Present in all eukaryotic cells, except mammalian RBC where secondarily lost.

No. per cell variable, 1 in primitive eukaryotes, 5,00,000 insect flight muscles.

Size 1.5—10 μm in length, 0.25 μm in diameter.

Shape cylindrical common, may be spherical, tubular, branched, discoidal.

Ultrastructure :--

1) 2 membranes : **Outer** – limiting, permeable, smooth, **Inner** – selectively permeable thrown into folds called cristae / trabeculae.

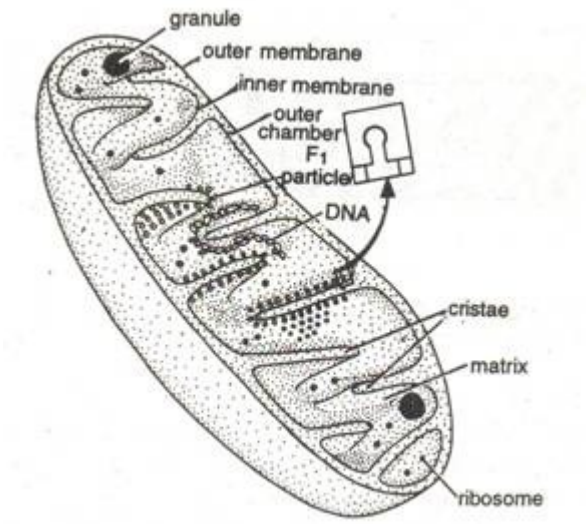


Fig. 2 Structure of mitochondrion cut longitudinally.

2) In between two membranes peri – mitochondrial space, filled with homogenous fluid called cytosol, contains H_2O, minerals.

3) Inner mitochondrial cavity has dense, homogenous gel like matrix with high conc. of soluble proteins, nucleotides, lipids, circular DNA called mitochondrial/mt DNA, ribosomes of 70s type, K^+, HPO_4, Mg^{++}, Mn^{++}, Cl^-, SO_4^-, RNA (3 types), riboflavin vitamin.

4) Inner cavity divided into many compartments due to cristae, which are more in active cells. Inner membrane has 2 faces, outer face called C/cytosl face, inner M/matrix face. On inner surface of inner membrane i.e. at M face, numerous knob like elementary particles / F_1 paticles / oxysomes / Fernandez – Moran subunits.

Oxysome :- composed of base, stalk, head piece.

Head piece – contains F_1 – subunit, spherical, contains enzyme ATPase / ATP synthatase

Function – oxidative phosphorylation, oxidation of food, ATP release.

Base – contains Fo – particle / subunit , rectangular ,embedded in inner mitochondrial membrane, contains coezymes of ETC.

Stalk – contains F5, F6 subunit.

Mitochondria:- self duplicating, New one formed by division of existing one.

Semi autonomous organelle –

Mitochondria – have own genetic information, in mitochondria DNA is independent of cell's nuclear DNA., capable of self replication, capable of forming 3 types of RNA. Mitochondria has its own ribosomes. Hence can, form its own structural proteins. Few subunits of mitochondria & enzymes are formed by itself from ribosomes. Remaining subunits from cytosol. Hence mitochondrion is a semiautonomous organelle.

Functions:-

1) Power house / storage batteries / ATP mills of cells.
2) Bring about oxidation of carbohydrates, fats., proteins.
3) Capable of self – replication.
4) Site for synthesis of haemoglobin(protein in blood), myoglobin (protein in muscles).
5) Site for thermiogenesis (heat production).

PLASTIDS – FOOD FACTORIES & STORE HOUSES

On the basis of colour pigments plastids are classified in to chloroplasts (green), chromoplast (Yellow, orange etc.) and amyloplasts (White)

Chloroplast: Present in green parts of plant like leaves, skin of raw fruits, flower in bud condition, young stem.

Shape – Cup shaped, Spiral ,Girdle,Branched,Starlike ,Reticulate, Spherical, Oval, Discoidal in higher plants. **Number** –1 to several hundreds. Size – 4 – 6 μm.

Ultra structure –

1) Covered by 2 membranes. Outer one permeable with less proteins. Inner one semi permeable with more proteins.

2) Periplastidial space of 25 – 75 A° between 2 membranes.

3) Matrix / stroma **–** Ground substance, colourless, granular with proteins, lipids, 70 s ribosomes, circular DNA, (called as chloroplast/ct – DNA), RNA (3types), enzymes.

4) In stroma no. of membranous sheets called lamellae. Lamellae form closed oval sacs called thylakoids.

5) Each thylakoid has intra thylakoid space / loculus. In loculus no. of para crystalline rounded bodies called quantosomes present which trap quantum of light. Each quantosome contains 230 chlorophyll pigment molecules. In higher plants quantosomes contain chlorophyll a & b, carotene, xanthopyll. Thylakoids also contain various electron carriers like cytochrome f, b, ferredoxin, plastocyanin, plastoquinone.

In eukaryotes – thylakoids are superimposed like a pile of coins and form granum. In each granum 10 – 100 (average 20 – 50) thylakoids. In each chloroplast about 40 – 60 grana . Adjacent grana interconnected by stroma lamellae / frets / intergranal lamellae.

Semi – autonomous organelles

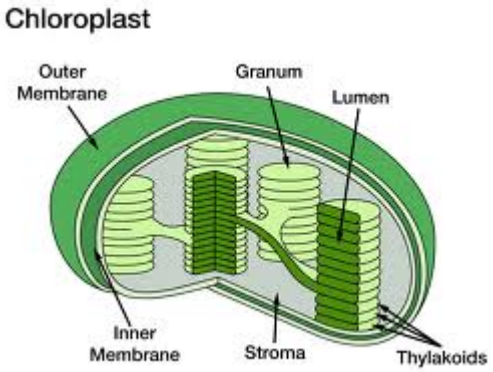
Circular DNA, 70 S ribosome, RNA (3 types) present, hence can form another chloroplast using some enzymes from cytoplasm.

Functions- 1. Photosynthesis.

2. O_2 replenished in atmosphere.

3.Starch storage.

4.Natural greenery



Endoplasmic Reticulum – (ER)

ER has inter connected membrane bound vacuoles / cavities , concentrated in endoplasmic portion of cytoplasm (Cytoplasm has 2 regions – outer homogenous--ectoplasm, inner granular – endoplasm), hence called ER,

Occurrence –

Well developed in fully differentiated, metabolically active eukaryotic cells – e.g. liver, pancreas. Absent in prokaryotic cells, secondarily lost in matured mammalian erythrocytes (RBC).

Ultra structure –Composed of 3 shapes

1) Cisternae – Near nucleus. Long, flattened, saclike, unbranched tubules. Lie one upon the other, interconnected & studded with ribosomes.

2) Vesicles – oval / rounded, vacuolar structures, scattered in cytoplasm.

3) Tubules – branched, form reticular structure along with cisternae and vesicles. Near cell membrane. .

Types:-

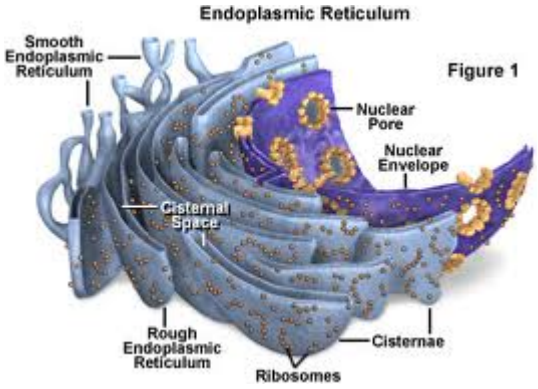


Figure 1

1) Agranular / Smooth ER – SER

Ribosomes absent on outer membrane. Present near cell membrane. Generally in the form of tubules.

2) Granular / Rough ER / RER –

Ribosomes attached to outer membrane. Generally in the form of cisternae.

Functions of Endoplasmic Reticulum–

2) Fluid filled vacuolar system. Acts as endoskeleton; gives support to colloidal protoplasm.
3) Active, passive transport of material.
4) Divides cytoplasm into many compartments, thus cell activities take place separately in each compartment. Various organelles remain stationed.
5) Increase surface area for absorption / chemical reactions within cell.
6) Contain variety of enzymes.

Golgi Complex: Molecular sorting & finishing area

Ultrastructure -

Present in three shapes / forms --

a) Cisternae **-** Flat / curved , piled up one above other, with swollen ends. Outer convex surface associated with nuclear membrane/ ER. It is called – forming / cis / entry face

Inner concave surface, called maturing / trans / exit face.

b) Vacuoles –Formed by fusion of small vesicles / large parts of broken cisternae. Generally associated near concave surface.

c) Vesicles – Pinched off from edges of cisternae hence near edges / concave surface.

Chemical composition – Proteins – 60%, Phospholipids – 40% , Enzymes.

Origin – mostly from SER as cisternae connected to E.R.

Functions –

1) Secretion – Mainly secretion of enzymes, hormones, glycoprotein, Ab(antibody).

2) Storage and Synthesis – Store proteins, lipids in the form of glycoprotein & glycolipid.

3) Packing and forwarding center for enzymes, mucus, hormones in small vesicles.

4) Cell plate formation in cell division.

5) Formation of primary lysosomes – Hydrolytic enzymes are formed in ER, then come to cisternae, packed and budded off as primary lysosome.

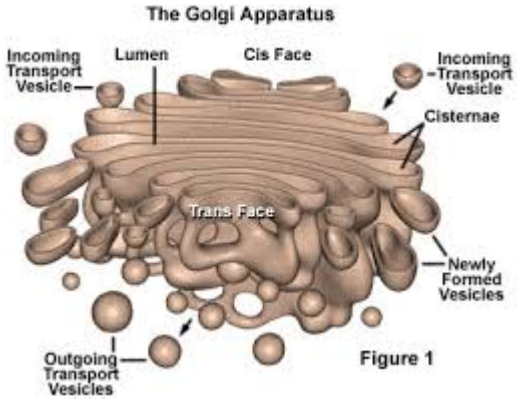


Figure 1

Lysosomes : Sacs of hydrolytic enzymes

Structure – These are small membrane bound (unit membrane) vesicles. Contain hydrolytic enzymes.

*** Hydrolytic enzymes are stored in crystalline / fluid form. Membrane of lysosome is impermeable to enzyme. But ruptures during O_2 deficiency / exposure to poisonous substances. Then enzymes are released and cell itself is destroyed. Hence lysosomes are also known as suicidal bags of cells.***

Types of Lysosomes

1) Primary lysosome - / storage granules – Derived from G.C. Contain only hydrolytic enzymes in inactive form. In the form of small vesicles.
2) Secondary lysosome / Digestive vacuoles / Heterophagosomes – Pinosome (vacuole with liquid) / phagosome (vacuole with solid) fuse with primary lysosome. Hence contain enzyme + material to be digested.
3) Residual Bodies / Tertiary lysosome / Telolysosome – Undigested mateial remain in. Now called residual body. Come near plasma membrane, throw out their contents out side thro' ephagy / exocytosis. If contents not discharged, the cells are loaded with it, cause nephritis, hepatitis, arthritis, gout, lung fibrosis.
4) Autophagosomes / Autolysosomes **–** Cell organelles like ER, Mitochondria get worn out. Its degradation by lysosome called as autophagy. Primary lysosome + worn out cell organelle form autophagosomes.

Function –

1) Digestion – by hydrolytic enzymes.

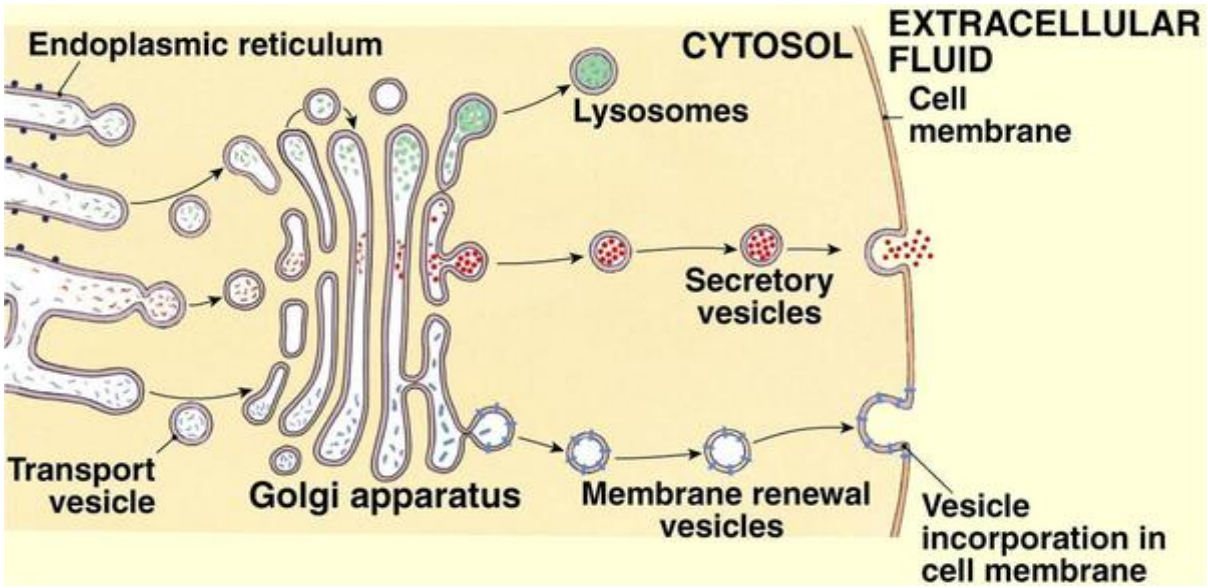
Extracellular – enzymes are released in surrounding medium by exocytosis.

Intracellular – by formation of secondary lysosomes or autophagosomes. E.g. phagocytes in higher animals, degeneration of tail in tadpole larva of frog by enzyme cathepsin.

Heterophagy – digestion of foreign substance,

Autophagy – digestion of self substances. Thus lysosomes are self disposal units, also bring about physiological rejuvenation. Digestion of reserve food during starvation is also called as Autophagy.

2) Initiate cell division by removing repressors of this process.
3) By breaking thyroglobulins, thyroid hormone(thyroxin) is produced.
4) In joint disorder like gout, arthritis -- macrophages come here & release lysosomes which causes inflammation.
5) Accidental / pathological release of lysosome enzyme causes chromosome breakage, abnormal distribution of chromosomes during mitosis, which may lead to blood cancer.



Ribosomes: Work benches for protein analysis

Occurance -- both in pro and eukaryotic cells, except mature RBC.

Types of Ribosomes – According to size, sedimentation coefficient ($S = 1 \times 10^{-13}$ cm /sec /dyne / gm) 2 types.

1) 70 S ribosoms –found in mitochondria, chloroplast of eukaryotic & prokaryotic cells
2) 80 S ribosomes – " in eukaryotic plant & animal cells.

Structure – Not covered by unit membrane, but porous, hydrated, 2 subunits. Larger & smaller. 70 S ribosome has 50 S and 30 S subunits & 80 S ribosome has 60 S and 40 S subunits which are separated by a narrow cleft. 2 subunits remain separated, join only

during protein synthesis. In high conc. of Mg^{++} ions $\longrightarrow$ 2 subunits remain united & called as dimmer. Smaller sub unit fits like a cap on larger subunit. Larger subunit – dome – shaped, 2 binding sites Peptidyl / P site / donar site, Amino – acyl / A site / acceptor site. It has protuberance, ridge and stalk. Smaller subunit – ellipsoidal shape, cap like. It has a platform, cleft, head & base.

Polyribosome / polysomes – It is chain of ribosomes as formed during protein synthesis on m-RNA.

Functions –

1) Protein factories / engines of cell as site of protein synthesis.
2) Free ribosome produce non – secretary proteins like enzymes for intra cellular use (e.g. in muscle cells, skin cells)
3) Bound ribosome like present on RER synthesize secretory proteins e.g. enzymeA

After synthesis of proteins, proper folding of proteins is assisted by specific proteins **chaperons** which also assist transport of proteins into organelles like mitochondria

Nucleus: Genetic message centre

Ultrastructure-

Contains nuclear membrane, nucleolus, nucleoplasm, chromatin

Nuclear membrane / karyotheca / Nuclear envelop / Nucleolemma.

- It is an outer envelop
- Present in all eukaryotic N Absent during late cell division.
- Consists of 2 unit membrane, between them perinuclear space of 75 A°.
- Outer membrane continuous with RER, studed with ribosome on outer side.
- Nuclear openings or pores in it to maintain nucleo – cytoplasmic connection.
- Outer membrane called as ectokaryotheca, inner called as endokaryotheca.
- Each nuclear pore has cylindrical annulus with pore complex.
- Through pore complex / basket movement of substances takes place.
- mRNA come out through them into cytoplasm.
- Dissociates during early cell division, reappears at end of cell division.

Nucleous –

Appears spherical, dense, colloidal, no limiting membrane. No. 2 -- 5

Parts – i)Granular region -- protein granules ii)Fibrillar region – proteinaceous fibrils iii)Amorphous matrix – less dense called 'pars amorpha'. iv)Chromatin fibres are perinucleolar and intranucleolar.

Nucleoplasm – nuclear sap / nucleoplasm / karyolymph.

Transparent., semi – solid, granular, acidophilic.Composed of – Nucleic acids, enzymes, minerals.

Chromatin –

Hereditary part. Network of fibres. During cell division organizes as chromosome.

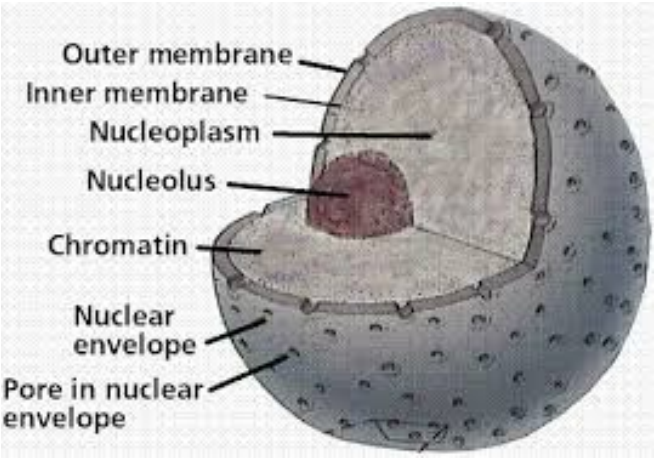
.Heterochromatin **–** Show thick regions, darkly staining where DNA is condensed. Lies near nuclear membrane. Contain late replicating genes. Inactive genetically.

Euchromatin – Thin regions, less darkly staining, DNA loose, genetically active.

Chromatin thread composition – DNA, RNA, proteins (histones., non – histones.)

Functions --

1) Contain hereditary material in the form of chromosomes
2) Transfer genetic characters from one generation to another
3) Control cell division
4) Control all physiological activities of the cell.



EVOLUTION OF BIOLOGICAL MACHINES

Major changes that occurred when prokaryotes gave rise to eukaryotes -

- Cells acquired more DNA.
- DNA folded compactly into discrete complexes with specific proteins to divide it equally between daughter cells at cell division.
- Specialized proteins stabilize folded DNA (chromosomes).
- A system of intracellular membranes and a double membrane surrounding the DNA was developed.
- Early eukaryotic cells enveloped aerobic bacteria or photosynthetic bacteria to form endosymbiotic associations that became permanent. Some aerobic bacteria evolved into mitochondria of modern eukaryotes and some photosynthetic bacteria became plastids like chloroplasts and likely ancestors of modern plant cells.
- It was advantageous to cluster together for acquiring greater motility, efficiency, or reproductive success than their free-living, single-celled competitors.
- Specialization within the colony – to cellular differentiation.
- It led to even more complex and highly differentiated organisms, in which some of them carried out the sensory functions, others the digestive, photosynthetic or reproductive functions so forth.

Principles of generating diverse body plans and design in nature:

The major events include the changes in

a. Size of organisms
b. Form and complexity
c. Expansions in diversity
d. Production of many shapes of macroscopic life.

The evidences for the process of evolution are usually obtained from fossil records which is also the data at the time of origin.

Inferences about direction of evolution:

a. Multicellularity evolved independently many times and in all parts of life i.e. plants, animals and microorganisms.
b. Multicellularity evolved from different unicellular ancestors.
c. These multicellular organisms have new body plans and physiologies
d. They represented more complex features.

These complex forms then diversified so that varied kinds appeared over a long period.

Figure: Evolution of eukaryotes through endosymbiosis:

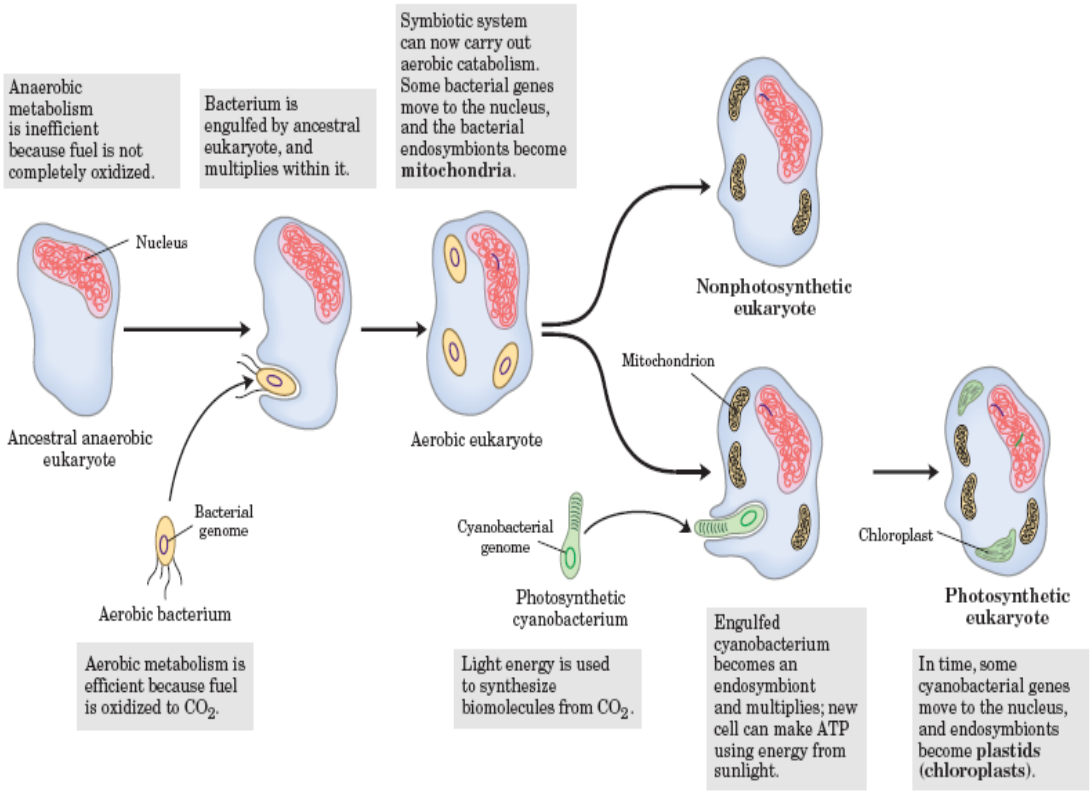


FIGURE 1-36 **Evolution of eukaryotes through endosymbiosis.** The earliest eukaryote, an anaerobe, acquired endosymbiotic purple bacteria (yellow), which carried with them their capacity for aerobic catabolism and became, over time, mitochondria. When photosynthetic cyanobacteria (green) subsequently became endosymbionts of some aerobic eukaryotes, these cells became the photosynthetic precursors of modern green algae and plants.

Size and multicellularity:

For first 2500 million years of life on the earth, most species were generally much smaller and rarely exceeded 1mm in size. The bacterial microfossils obtained from 3500 million years had 5mm diameter.

The early microfossils of eukaryotes were 40-200 mm in size for first 600-800 million years

Cellular dimension are limited by oxygen diffusion:

A bacterial cell is 1-2 mm long and animal/plant cell is 5-100 mm long. The upper limit of cell size is set by the rate of diffusion of solute molecules in aqueous system.

Consider the example of a bacterial cell-

It depends upon oxygen consuming reactions for energy production. So it has to obtain molecular oxygen by diffusion across its plasma membrane. The cell is small and the ratio of its surface area to its volume is large hence every part of its cytoplasm is easily receiving the diffused oxygen.

But as cell size increases, surface-to-volume ratio decreases. The rate of consumption of oxygen is faster than that of its diffusion because if the metabolism of the cell. So when the cell size goes on increasing, the oxygen demand for metabolism increases to such a point that the metabolism becomes impossible. This puts a theoretical upper limit for the cell size and cell cannot increase above this point.
Complexity: It is referred to as number of different cell types or the no./ functional specialization of parts.

There are four types of complexity –

1. the number of different physical parts e.g. genes, cells, organs and organisms in a system..
2. the no. of different interactions between the above mentioned parts
3. the no. of levels
4. the no. of parts or interactions in a specific condition

Diversity: Actually the diversity of life has expanded from its origin but it doesn't cause continuous increase. For the organisms those are made entirely of soft tissues or of small size, it cannot be said whether the total diversity increased or decreased over a long period of time.

Levels of Organization

Within multi-cellular organisms there is division of labor. Division of labor means that the work (labor) of keeping the organism alive is divided (division) among the different parts of the body. Each part has a job to do and as each part does its special job, it works in harmony with all the other parts.

The arrangement of specialized parts within a living thing is referred to as levels of organization.

First Level :-Cells

Cells of course, are the first level of organization

Second Level:- Tissues

Tissues are the second level of organization. In any multi-cellular organism, cells rarely work alone. Cells that are similar in structure and function are usually joined together to form tissues. There are four basic/major types of tissues in the human body: Muscle tissue (skeletal, smooth, cardiac muscles), nerve tissue (brain, spinal nerves, cranial nerves), connective tissue (bone, cartilage, blood), and epithelial tissue (skin, other body parts coverings).

Third Level :- Organs

Organs are the third level of organization.

When a bunch of different types of tissues work together, they form an organ. E.g. Brain, liver, stomach, heart etc.

Fourth Level :- Organ System

Organ systems are the fourth level of organization.

Each organ in human body is a part of an organ system, a group of organs that work together to perform a major function. E.g. heart, blood vessels are parts of circulatory system, likewise digestive, excretory, respiratory systems.

Fifth Level :-- Organism/Individual

Organisms with many systems form fifth level of organization.

Single cell to multi cellular organism

- Unicellular organisms formed colonies by remaining together after each cell division.
- Division of labor, made it possible to exploit resources in better way.
- For formation of multicellular organism, cells remain bound together. In animals extracellular organic matrix binds cells together as cell wall, plasmodesmata are absent.
- Such fundamental arrangement is seen in epithelial tissue sheets.
- From a group of cells, some cells differentiated from others and adopt different structure, chemistry, function usually in response to cues from neighbouring cells.
- Cells have memory i.e. cell and its progeny usually persist in their differently specialized state even after disappearance of original stimuli.
- Final character of animal not determined by its final environment but entire sequences of influences to which cells are exposed during development.
- As body grows and matures, progressively finer details of the adult body pattern become specified, complex organisms are formed in long developmental history.
- Though more and more complex organisms are formed, early developmental stages very similar though adult stage radically different.
- Specialization of cells depend on gene expression and not on loss or acquisition of genes. As specialization also involves loss of genetic material. E.g. RBC – lost nucleus during differentiation.
- In eukaryotes sophisticated mechanisms for controlling gene expression has evolved.
- Groups of genes activated or repressed in response to external and internal signals.
- Radical differences of character between cell types reflect stable changes in gene expression.