A Two Day FDP on "Biology for Engineers"

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Course material

Organized By

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MODULE 1

Module - 1

BIOMOLECULES AND THEIR APPLICATIONS (QUALITATIVE)

Carbohydrates (cellulose-based water filters, PHA and PLA as bioplastics), Nucleic acids (DNA Vaccine for Rabies and RNA vaccines for Covid19, Forensics – DNA fingerprinting), Proteins (Proteins as food – whey protein and meat analogs, Plant based proteins), lipids (biodiesel, cleaning agents/detergents), Enzymes (glucose-oxidase in biosensors, lignolytic enzyme in bio-bleaching).

BIOMOLECULES AND THEIR APPLICATIONS:

What is a biomolecule?
Biomolecule, also called biological molecule, any of numerous substances that are produced by cells and living organisms.

Biomolecules have a wide range of sizes and structures and perform a vast array of functions. The four major types of biomolecules are carbohydrates, lipids, nucleic acids, and proteins. Among biomolecules, nucleic acids, namely DNA and RNA, have the unique function of storing an organism's genetic code—the sequence of nucleotides that determines the amino acid sequence of proteins, which are of critical importance to life on Earth.

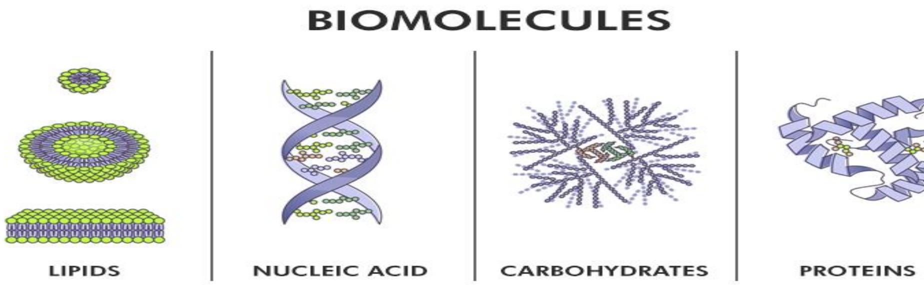
There are 20 different amino acids that can occur within a protein; the order in which they occur plays a fundamental role in determining protein structure and function. Proteins themselves are major structural elements of cells.

They also serve as transporters, moving nutrients and other molecules in and out of cells, and as enzymes and catalysts for the vast majority of chemical reactions that take place in living organisms. Proteins also form antibodies and hormones, and they influence gene activity.

Carbohydrates, which are made up primarily of molecules containing atoms of carbon, hydrogen, and oxygen, are essential energy sources and structural components of all life, and they are among the most abundant biomolecules on Earth. They are built from four types of sugar units—monosaccharides, disaccharides, oligosaccharides, and polysaccharides.

Lipids, another key biomolecule of living organisms, fulfill a variety of roles, including serving as a source of stored energy and acting as chemical messengers. They also form membranes, which separate cells from their environments and compartmentalize the cell interior, giving rise to organelles, such as the nucleus and the mitochondrion, in higher (more complex) organisms. Examples include **cytidine, uridine, adenosine, guanosine, and thymidine**. Nucleosides that are phosphorylated become nucleotides. Apart from serving as a structural unit of nucleic acids, nucleotides may also serve as sources of chemical energy (e.g. adenosine triphosphate or ATP).

The main applications of biomolecules are:
The biomolecules may involve in several processes such as energy storage (carbohydrates), catalyzing the biochemical reactions (hormones), storing/transmitting the genetic codes (RNA/DNA), or altering biological and neurological activities (neurotransmitter/hormones).



COURTESY: *GEEKSFORGEEKS*

CARBOHYDRATES:

What are carbohydrates?
Carbohydrates, or carbs, are sugar molecules. Along with proteins and fats, carbohydrates are one of three main nutrients found in foods and drinks. Body breaks down carbohydrates into glucose. Glucose, or blood sugar, is the main source of energy for your body's cells, tissues, and organs. Glucose can be used immediately or stored in the liver and muscles for later use.

There are three main types of carbohydrates:

1) Sugars: They are also called simple carbohydrates because they are in the most basic form. They can be added to foods, such as the sugar in candy, desserts, processed foods, and regular soda. They also include the kinds of sugar that are found naturally in fruits, vegetables, and milk.
Starches. They are complex carbohydrates, which are made of lots of simple sugars strung together. Your body needs to break starches down into sugars to use them for energy. Starches include bread, cereal, and pasta. They also include certain vegetables, like potatoes, peas, and corn.
Fiber. It is also a complex carbohydrate. Your body cannot break down most fibers, so eating foods with fiber can help you feel full and make you less likely to overeat. Diets high in fiber have other health benefits. They may help prevent stomach or intestinal problems, such as constipation. They may also help lower cholesterol and blood sugar. Fiber is found in many foods that come from plants, including fruits, vegetables, nuts, seeds, beans, and whole grains.
Just like starches, **cellulose** is another best example for carbohydrates.

2) Cellulose: a complex carbohydrate, or polysaccharide, consisting of 3,000 or more glucose units.
It is extremely abundant, easily renewable, and biodegradable. Due to inter- and intramolecular hydrogen bonding between the hydroxyl groups of the neighboring cellulose chains, cellulose is insoluble in water, despite being hydrophilic, and is difficult to dissolve with common organic solvents.

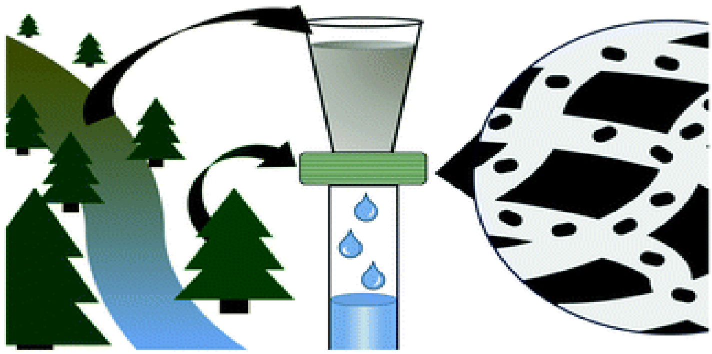
Taking benefit of these advantages of cellulose, we have a best application of cellulose, that is, **Cellulose-based water filters.**

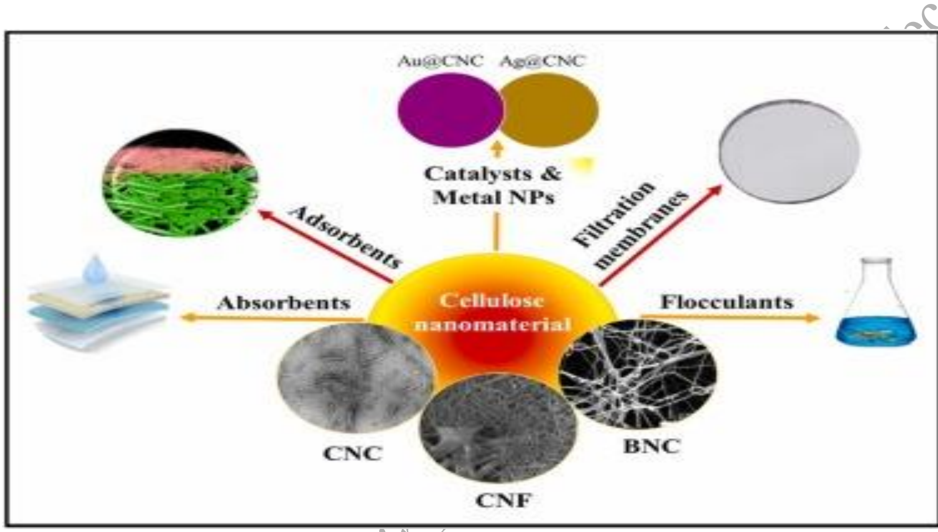
The interest in the use of biobased filters for water purification has increased in recent years, as such filters have the potential to be affordable, lightweight and biodegradable. Research has been focused on creating biobased membranes for micro- and ultrafiltration from cellulose nanofibrils (CNFs).
Filters based on cellulose pulp fibers do usually have large pores that facilitate water percolation but they do not sufficiently remove bacteria through size exclusion; other techniques are therefore needed to achieve a bacteria-reducing effect. Several groups have addressed this issue by incorporating antibacterial metal nanoparticles into cellulose-based water filters; both silver nanoparticles (AgNPs) and copper nanoparticles (CuNPs) are known to have good antibacterial effects.
An alternative method to physically remove bacteria from water, while keeping the filter pore size larger than bacteria, is to use positively charged filters that adsorb negatively charged bacteria onto the surfaces of the filters.

This allows negatively charged particles much smaller than the filter pore size to be efficiently removed from water and this is an interesting approach for removing bacteria from water without adding any toxic chemicals or reducing the flow by reducing the pore size. Both Gram-positive and Gram-negative bacteria have a negative net surface charge on the cell envelope, due to peptidoglycans, liposaccharides and proteins in the cell wall, and this makes their removal non-selective and efficient for most types of bacteria.
Methods used for the same are:

- LBL [Layer By Layer] MODIFICATION
- NITROGEN ANALYSIS
- SEM [Scanning Electron Microscope]
- FLOW RATE FOR FREE FLOW FILTRATION
- BACTERIAL REMOVAL EFFICIENCY OF FILTRATION
- FILTRATION OF NATURAL WATER SAMPLES
- FLOURESCENCE MICROSCOPY

Cellulose filter papers are versatile and diverse tools for microfiltration, that work by trapping particulates within a random matrix of cellulose fibers. Cellulose filter papers can be categorized as quantitative or qualitative, depending on their application.





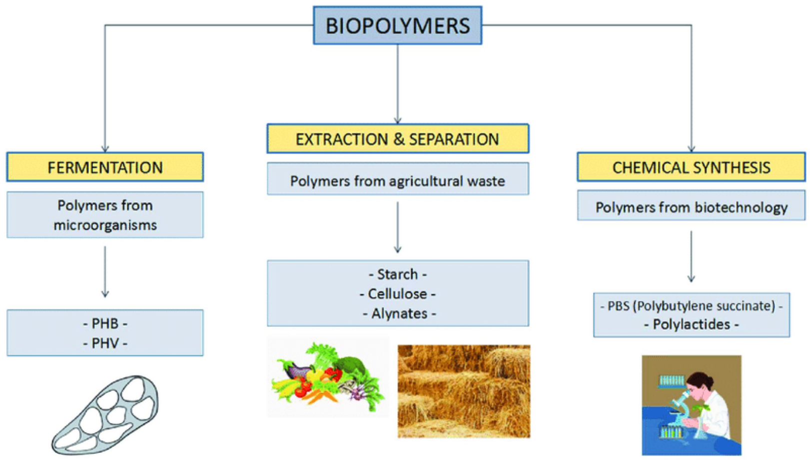
Cellulose based nanomaterials for water treatment

POLY LACTIC ACID [PLA] AND POLYHYDROXYALKANOATES [PHA]:

Just like, how we introduced biodegradable water treatment plant from cellulose, we also have a replacement for toxic, non-biodegradable plastics which we are using in our daily life. That is, Bioplastics.

Bioplastics are one type of plastic which can be generated from natural resources such as starches and vegetable oils. Bioplastics are basically classified as bio based and/or biodegradable. Not all bio-based plastics are biodegradable and similarly not all biodegradable plastics are bio based. Bioplastics are referred to as bio based when the focus of the material is on the origin of the carbon building block and not by where it ends up at the end of its cycle life. Bio plastics are said to be biodegradable if they are broken down with the effect of the right environmental conditions and microbes which in turn use them as a food source. The bioplastics are considered compostable if within 180 days, a complete microbial assimilation of the fragmented food source takes place in a compost environment.

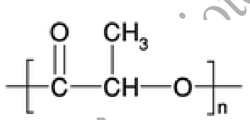
Based upon this, we have PHA and PLA.



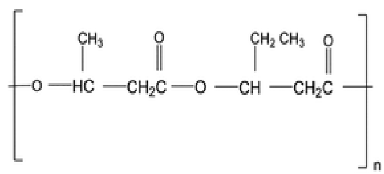
Production of biopolymers

PLA is both: biobased and biodegradable under industrial composting conditions (at a high temperature, around 58 °C). Because of its good mechanical properties, processability, renewability, and non-toxicity, PLA is considered today as one of the most commercially promising bioplastics. When compared with most other biodegradable polymers, PLA has better durability, transparency, and mechanical strength.

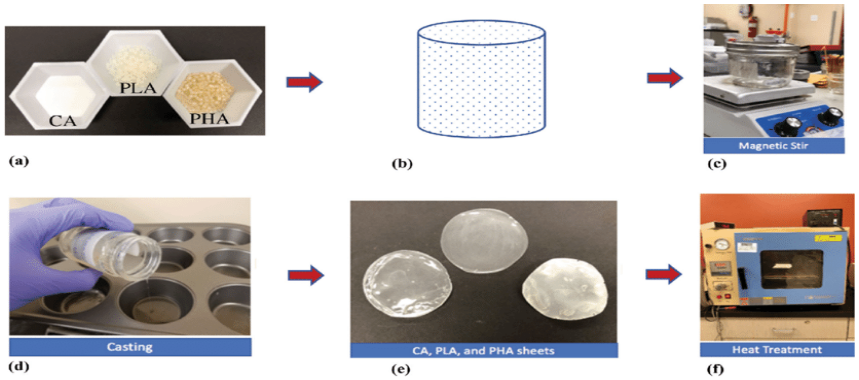
PHAs are a significant polymer family that are 100% bio-based and bio-degradable. PHAs are microbiologically produced polyesters that have tunable physical and mechanical properties. This is accompanied by low environmental impact due to their biodegradability and non-toxicity nature. Therefore, they are promising candidates for a sustainable future manufacturing. Ranging from brittle thermoplastics to gummy elastomers, PHAs' properties can be altered by the selection of bacteria, fermentation conditions, and substrate. Due to their flexible properties, PHAs can eventually substitute PP, polyethylene (PE), and polystyrene (PS), which are the main polymers of today's global polymer market.



PLA



PHA



STEPS IN PRODUCING BIOPLASTIC FROM PHA AND PLA

NUCLEIC ACID:

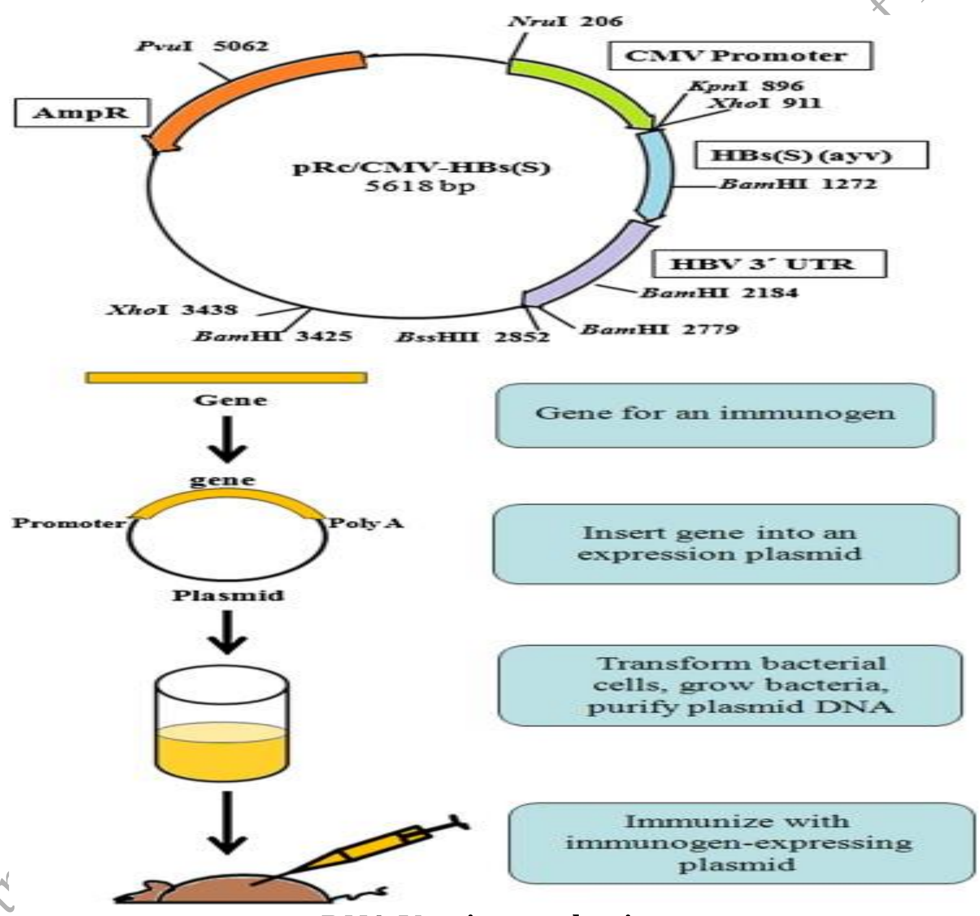
Nucleic acids are biopolymers, macromolecules, essential to all known forms of life.They are composed of nucleotides, which are the monomers made of three components: a 5-carbon sugar, a phosphate group and a nitrogenous base. The two main classes of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). If the sugar is ribose, the polymer is RNA; if the sugar is the ribose derivative deoxyribose, the polymer is DNA.

Nucleic acids are naturally occurring chemical compounds that serve as the primary information-carrying molecules in cells and make up the genetic material. Nucleic acids are found in abundance in all living things, where they create, encode, and then store information of every living cell of every life-form on Earth. In turn, they function to transmit and express that information inside and outside the cell nucleus to the interior operations of the cell and ultimately to the next generation of each living organism. The encoded information is contained and conveyed via the nucleic acid sequence, which provides the 'ladder-step' ordering of nucleotides within the molecules of RNA and DNA. They play an especially important role in directing protein synthesis.
Strings of nucleotides are bonded to form helical backbones—typically, one for RNA, two for DNA—and assembled into chains of base-pairs selected from the five primary, or canonical, nucleobases, which are: adenine, cytosine, guanine, thymine, and uracil. Thymine occurs only in DNA and uracil only in RNA.
The two main nucleic acids are DNA and RNA,which is the fundamental unit of any living organisms. Based on these factors, there are many applications for the same, some of which are explained below:

1) DNA VACCINE FOR RABIES:

Rabies is a preventable viral disease most often transmitted through the bite of a rabid animal. The rabies virus infects the central nervous system of mammals, ultimately causing disease in the brain and death. Most rabies cases reported to the Centers for Disease Control and Prevention (CDC) each year occur in wild animals like bats, raccoons, skunks, and foxes, although any mammal can get rabies.

A DNA vaccine, using a pCl-neo plasmid encoding the glycoprotein gene of a Mexican isolate of rabies virus, was developed to induce long-lasting protective immunity against rabies virus in dogs. The worldwide incidence of rabies and high rates of therapy failure, despite availability of effective vaccines indicate the need for timely and improved prophylactic approaches. DNA vaccination based on optimized formulation of lysosome-targeted glycoprotein of the rabies virus provides potential platform for preventing and controlling rabies. A range of parameters including physical, physiological, clinical, immunological, hematological along with histopathology profiles of target organs was monitored to assess the impact of vaccination. There were no observational adverse effects despite high dose administration of the DNA vaccine formulation. Thus, this study indicates the safety of next generation of vaccines as well as highlights their potential application.



DNA Vaccine production

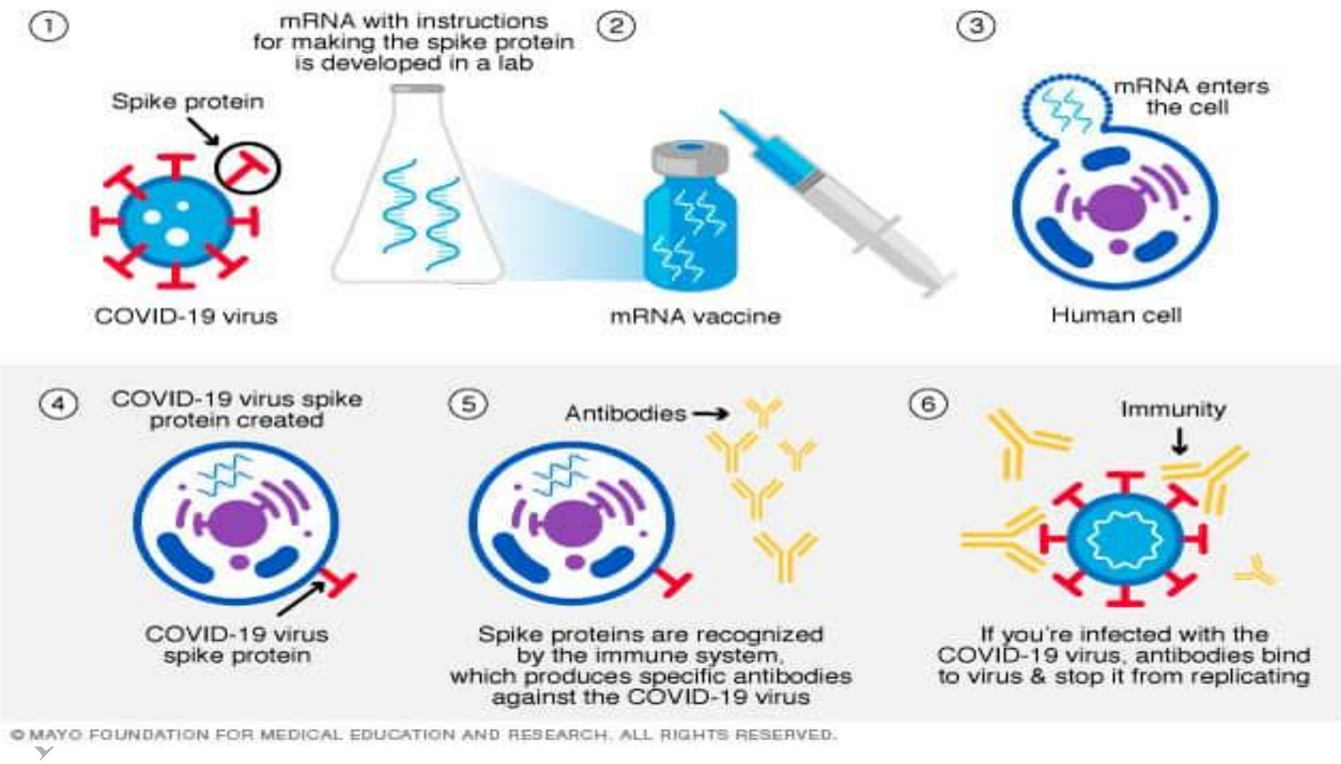
COURTESY: *BABIUK*

2) RNA VACCINES FOR COVID-19:

Coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus. Messenger RNA, or mRNA technology, instructs cells to make a protein that generates an immune response in the body, thus producing the antibodies that provide protection against a disease.
It is the basis for the Pfizer/BioNTech and Moderna COVID-19 vaccines being used by governments worldwide, and in the UN-supported COVAX global vaccine solidarity initiative. Messenger ribonucleic acid (mRNA) is a molecule that provides cells with instructions for making proteins. mRNA vaccines contain the instructions for making the SARS-CoV-2 spike protein. This protein is found on the surface of the virus that causes COVID-19.

The mRNA molecule is essentially a recipe, telling the cells of the body how to make the spike protein. COVID-19 mRNA vaccines are given by injection, usually into the muscle of the upper arm. After the protein piece is made, the cell breaks down the instructions and gets rid of them. The mRNA never enters the central part (nucleus) of the cell, which is where our DNA (genetic material) is found. Your DNA can't be altered by mRNA vaccines.

The cell then displays the protein piece on its surface. Our immune system recognizes that the protein doesn't belong there and begins building an immune response and making antibodies.



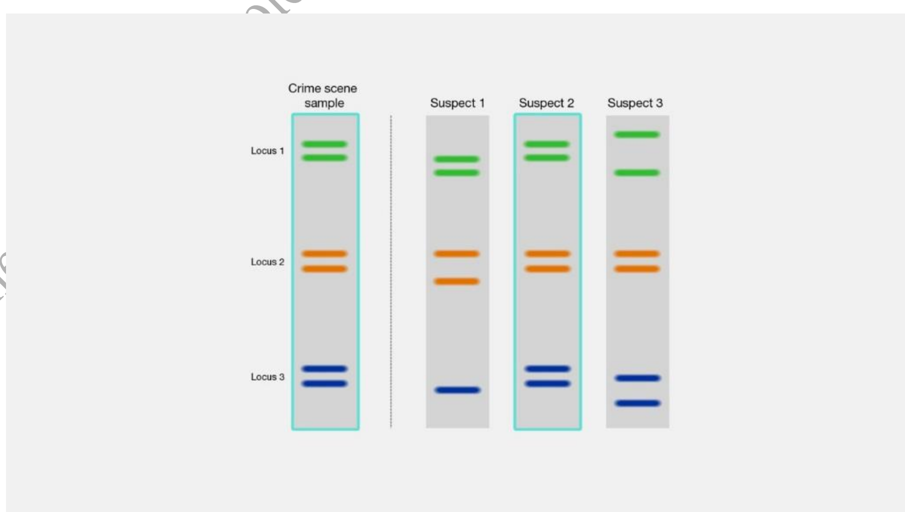
3) FORENSIC-DNA FINGERPRINTING:

DNA fingerprinting, also called DNA typing, DNA profiling, genetic fingerprinting, genotyping, or identity testing, in genetics, method of isolating and identifying variable elements within the base-pair sequence of DNA (deoxyribonucleic acid).

The procedure for creating a DNA fingerprint consists of first obtaining a sample of cells, such as skin, hair, or blood cells, which contain DNA. The DNA is extracted from the cells and purified, the DNA was then cut at specific points along the strand with proteins known as restriction enzymes. The enzymes produced fragments of varying lengths that were sorted by placing them on a gel and then subjecting the gel to an electric current (electrophoresis): the shorter the fragment, the more quickly it moved toward the positive pole (anode).

The sorted double-stranded DNA fragments were then subjected to a blotting technique in which they were split into single strands and transferred to a nylon sheet. The fragments underwent autoradiography in which they were exposed to DNA probes—pieces of synthetic DNA that were made radioactive and that bound to the minisatellites. A piece of X-ray film was then exposed to the fragments, and a dark mark was produced at any point where a radioactive probe had become attached. The resultant pattern of marks could then be analyzed.
The DNA testing process is comprised of four main steps, including **extraction, quantitation, amplification, and capillary electrophoresis.**

DNA fingerprinting is a laboratory technique used to determine the probable identity of a person based on the nucleotide sequences of certain regions of human DNA that are unique to individuals. **Forensic genetic fingerprinting** can be defined as the comparison of the DNA in a person's nucleated cells with that identified in biological matter found at the scene of a crime or with the DNA of another person for the purpose of identification or exclusion. The application of these techniques introduces new factual evidence to criminal investigations and court cases.



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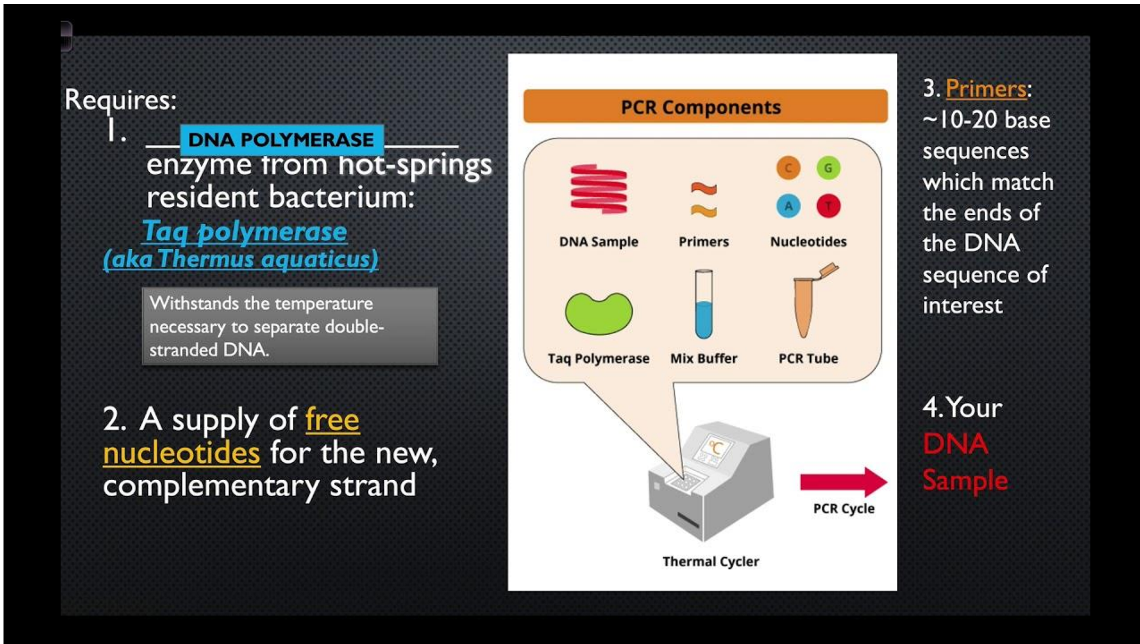


COURTESY: *FORENSIC SCIENCE*

DNA FINGERPRINTING

So, this is all about nucleic acids, considering the two main nucleic acids, that is, DNA and RNA, discussing about some of the most important applications of these nucleic acids.

PROTEINS:

Protein is found throughout the body—in muscle, bone, skin, hair, and virtually every other body part or tissue. It makes up the enzymes that power many chemical reactions and the hemoglobin that carries oxygen in your blood.

Talking more about proteins based on biomolecule concept, **Proteins** are large biomolecules and macromolecules that comprise one or more long chains of amino acid residues. Proteins perform a vast array of functions within organisms, including catalysing metabolic reactions, DNA replication, responding to stimuli, providing structure to cells and organisms, and transporting molecules from one location to another. Proteins differ from one another primarily in their sequence of amino acids, which is dictated by the nucleotide sequence of their genes, and which usually results in protein folding into a specific 3D structure that determines its activity.

Proteins are assembled from amino acids using information encoded in genes. Each protein has its own unique amino acid sequence that is specified by the nucleotide sequence of the gene encoding this protein. The genetic code is a set of three-nucleotide sets called codons and each three-nucleotide combination designates an amino acid.

The process of synthesizing a protein from an mRNA template is known as translation. The mRNA is loaded onto the ribosome and is read three nucleotides at a time by matching each codon to its base pairing anticodon located on a transfer RNA molecule, which carries the amino acid corresponding to the codon it recognizes. The enzyme aminoacyl tRNA synthetase "charges" the tRNA molecules with the correct amino acids. The growing polypeptide is often termed the nascent chain. Proteins are always biosynthesized from N-terminus to C-terminus.

Proteins are the chief actors within the cell, said to be carrying out the duties specified by the information encoded in genes. With the exception of certain types of RNA, most other biological molecules are relatively inert elements upon which proteins act. Proteins make up half the dry weight of an Escherichia coli cell, whereas other macromolecules such as DNA and RNA make up only 3% and 20%, respectively. The set of proteins expressed in a particular cell or cell type is known as its proteome.

PROTEIN AS FOOD:

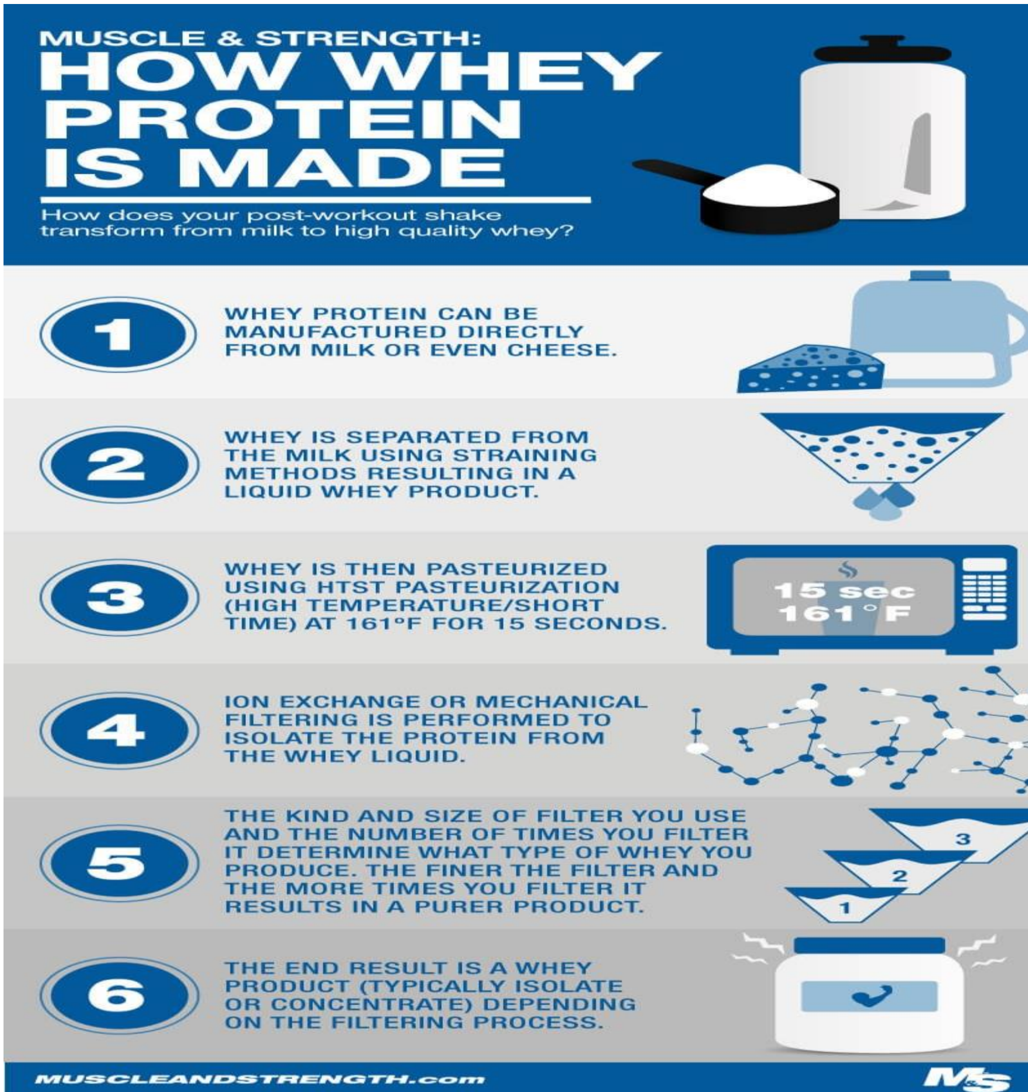
Protein is a key part of any diet. The average person needs about 7 grams of protein every day for every 20 pounds of body weight. Because protein is found in an abundance of foods, many people can easily meet this goal. However, not all protein “packages” are created equal. Because foods contain a lot more than protein, it’s important to pay attention to what else is coming with it.

Animal-based foods (meat, poultry, fish, eggs, and dairy foods) tend to be good sources of complete protein, while plant-based foods (fruits, vegetables, grains, nuts, and seeds) often lack one or more essential amino acid.

Whey protein is a mixture of proteins isolated from whey, the liquid material created as a by-product of cheese production. The proteins consist of α-lactalbumin, β-lactoglobulin, serum albumin and immunoglobulins. Glycomacropeptide also makes up the third largest component but is not a protein. Whey protein is commonly marketed as a protein supplement, and various health claims have been attributed to it.

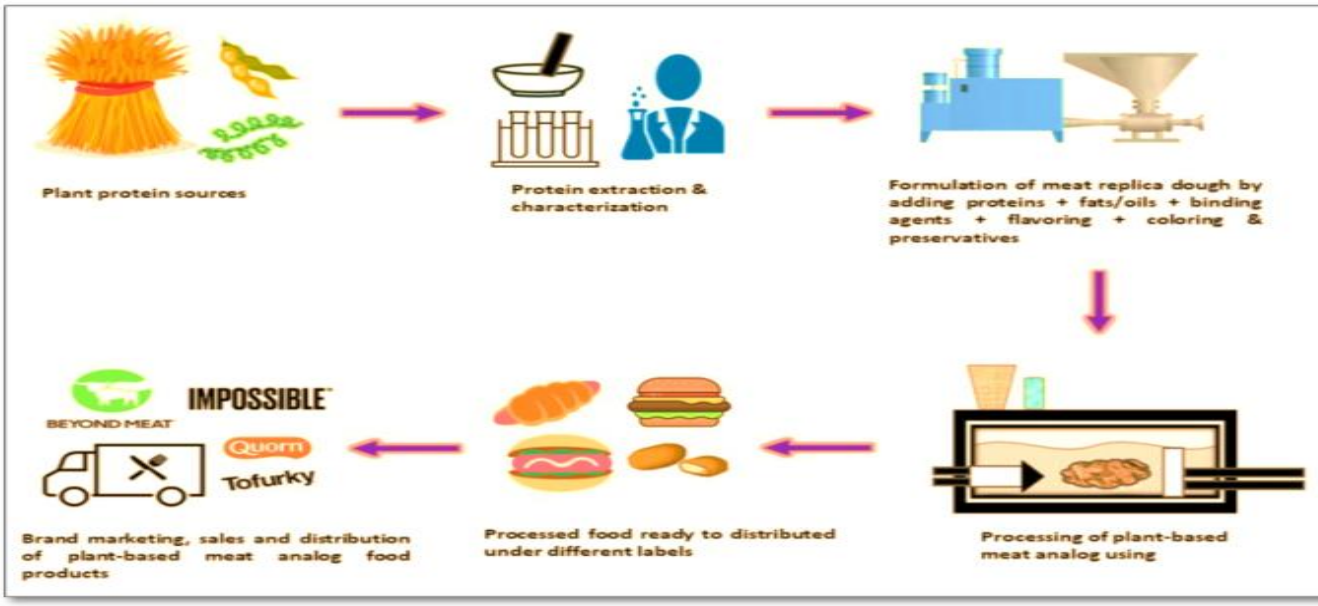
Whey is left over when milk is coagulated during the process of cheese production, and contains everything that is soluble from milk after the pH is dropped to 4.6 during the coagulation process. It is a 5% solution of lactose in water and contains the water soluble proteins of milk as well as some lipid content. Processing can be done by simple drying, or the relative protein content can be increased by removing the lactose, lipids and other non-protein materials.

The primary usage of whey protein supplements is for muscle growth and development. Eating whey protein supplements before exercise will not assist athletic performance, but it will enhance the body's protein recovery and synthesis after exercise because it increases the free amino acids in the body's free amino acid pool.



Meat analogues find raising interest of many consumers who are looking for indulgent, healthy, low environmental impact, ethical, cost-effective, and/or new food products. High moisture extrusion cooking enables the production of fresh, premium meat analogues that are texturally like muscle meat from plant or animal proteins. The appearance and eating sensation are similar to cooked meat while high protein content offers a similar nutritional value. This article focuses on plant-based meat analogues and covers process and product-related aspects including ingredients and structure formation, flavor, taste and nutritional value, postextrusion processing, packaging and shelf life, consumer benefits, and product-related environmental impacts.
Meat analogues, can be defined as products that mimic meat in its functionality, bearing similar appearance, texture, and sensory attributes to meat. Production of meat analogues has been on the increase, targeted at satisfying consumers' desire for indulgent, healthy, low environmental impact, and ethical meat substitutes.

The factors that lead to this shift is due to low fat and calorie foods intake, flexitarians, animal disease, natural resources depletion, and to reduce greenhouse gas emission. Currently, available marketed meat analog products are plant-based meat in which the quality (i.e., texture and taste) are similar to the conventional meat. The ingredients used are mainly soy proteins with novel ingredients added, such as mycoprotein and soy leghemoglobin.



COURTESY: ***MEENAKSHI SINGH***

PLANT BASED PROTEINS:

Plant protein is simply a meaningful food source of protein which is from plants. This group can include pulses, tofu, soya, tempeh, seitan, nuts, seeds, certain grains and even peas. Pulses are a large group of plants, which include chickpeas, lentils, beans (such as black, kidney and adzuki beans) and split peas.

Plant proteins are highly nutritious – not only as good sources of protein, but also because they provide other nutrients such as fibre, vitamins and minerals. Our intake of fibre tends to be too low, however by incorporating certain plant proteins into your diet, such as pulses, peas and nuts, you can easily boost your fibre intake.
Consumer demand for plant protein-based products is high and expected to grow considerably in the next decade. Factors contributing to the rise in popularity of plant proteins include: (1)potential health benefits associated with increased intake of plant-based diets; (2) consumer concerns regarding adverse health effects of consuming diets high in animal protein (e.g., increased saturated fat); (3) increased consumer recognition of the need to improve the environmental sustainability of food production; (4) ethical issues regarding the treatment of animals; and (5) general consumer view of protein as a “positive” nutrient (more is better). While there are health

and physical function benefits of diets higher in plant-based protein, the nutritional quality of plant proteins may be inferior in some respects relative to animal proteins.

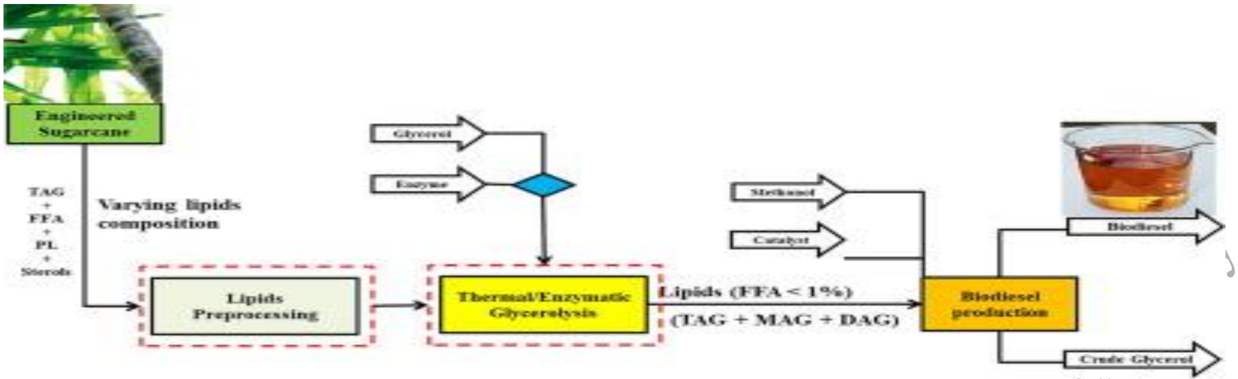
LIPIDS:

Discussing about another important biomolecule, lipids, are a broad group of naturally occurring molecules which includes fats, waxes, sterols, fat-soluble vitamins (such as vitamins A, D, E and K), monoglycerides, diglycerides, phospholipids, and others. The functions of lipids include storing energy, signaling, and acting as structural components of cell membranes. Lipids have applications in the cosmetic and food industries, and in nanotechnology.

Lipids may be broadly defined as hydrophobic or amphiphilic small molecules; the amphiphilic nature of some lipids allows them to form structures such as vesicles, multilamellar/unilamellar liposomes, or membranes in an aqueous environment. Biological lipids originate entirely or in part from two distinct types of biochemical subunits or "building-blocks": ketoacyl and isoprene groups.Using this approach, lipids may be divided into eight categories: fatty acyls, glycerolipids, glycerophospholipids, sphingolipids, saccharolipids, and polyketides (derived from condensation of ketoacyl subunits); and sterol lipids and prenol lipids (derived from condensation of isoprene subunits).

A biological membrane is a form of lamellar phase lipid bilayer. The formation of lipid bilayers is an energetically preferred process when the glycerophospholipids described above are in an aqueous environment.This is known as the hydrophobic effect. In an aqueous system, the polar heads of lipids align towards the polar, aqueous environment, while the hydrophobic tails minimize their contact with water and tend to cluster together, forming a vesicle; depending on the concentration of the lipid, this biophysical interaction may result in the formation of micelles, liposomes, or lipid bilayers. Other aggregations are also observed and form part of the polymorphism of amphiphile (lipid) behavior.
Some of the applications are: Within the body, lipids function as an energy reserve, regulate hormones, transmit nerve impulses, cushion vital organs, and transport fat-soluble nutrients. Fat in food serves as an energy source with high caloric density, adds texture and taste, and contributes to satiety.

Lipid obtained from food waste was used as a potential feedstock for biodiesel production using both a chemical catalyst and a biocatalyst. Base (KOH) catalyzed transesterification of the lipid allowed a 100% conversion of biodiesel in 2 h; whereas, Novozyme-435 yielded 90% **biodiesel** in 24 h. So lipids are having a main application in bidiesel production.
Biodiesel demonstrates an animal fat-based or vegetable oil diesel fuel, including long-chain alkyl (methyl, ethyl, or propyl) esters. Biodiesel is generally made by **esterifying lipids** (e.g., soybean oil, vegetable oil, and animal fat (tallow)) with an alcohol generating fatty acid esters. Biodiesel is suggested to be utilized in standard diesel engines and is thus well defined from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used singly or blended with gasoline in any proportions. Biodiesel blends can also be utilized as heating oil.



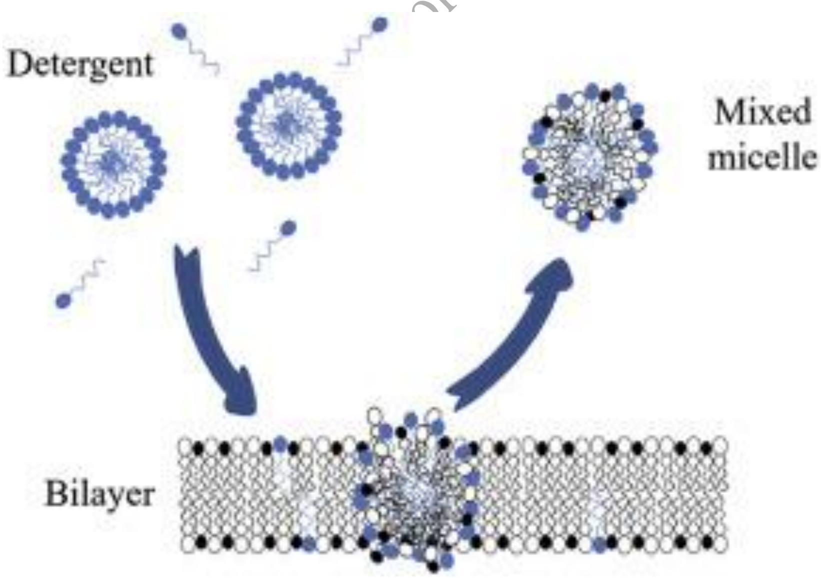
Biodiesel production

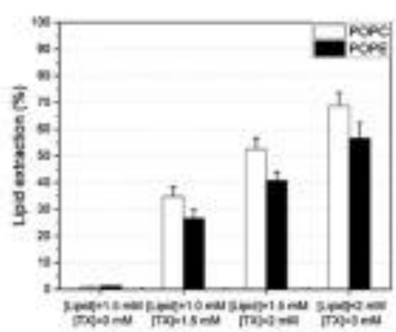
COURTESY*: <u>WEI JIN</u>*

Lipids also has an interesting application in **cleaning agents**. Considering the case of

<u>DETERGENTS:</u>

The hydrophobic end of the phospholipid bilayer stays away from the water. This avoids the dissolution of cell membrane in water. But the detergent can bind to the hydrophobic end of the cell membrane and form a solution with water, thus breaking the cell membrane barrier.
Detergent monomers solubilize membrane proteins by partitioning into the membrane bilayer. With increasing amounts of detergents, membranes undergo various stages of solubilization. The initial stage is lysis or rupture of the membrane.
While lipids also have the same general structure as detergents—a polar hydrophilic head group and a nonpolar hydrophobic tail— lipids differ from detergents in the shape of the monomers, in the type of aggregates formed in solution, and in the concentration range required for aggregation.





COURTESY: *<u>FAZAL SHAIK</u>*

ENZYMES:

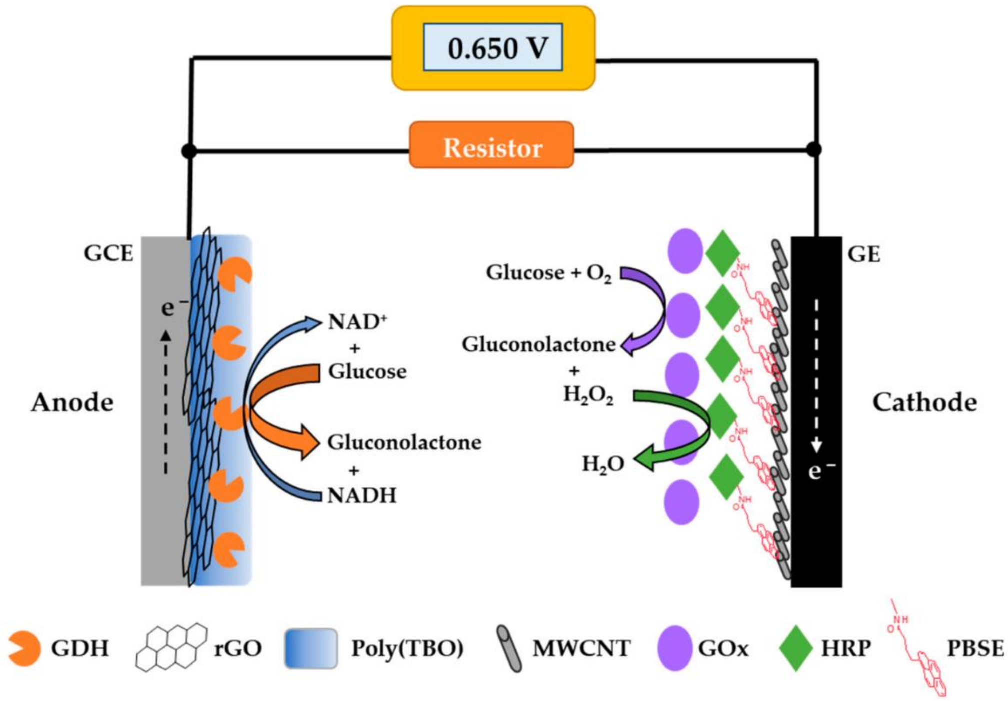
Are another important biomolecule, which are proteins that help speed up metabolism, or the chemical reactions in our bodies. They build some substances and break others down. All living things have enzymes. Our bodies naturally produce enzymes.
The six kinds of enzymes are **hydrolases, oxidoreductases, lyases, transferases, ligases and isomerases**.

Enzymes perform the critical task of lowering a reaction's activation energy—that is, the amount of energy that must be put in for the reaction to begin. Enzymes work by binding to reactant molecules and holding them in such a way that the chemical bond-breaking and bond-forming processes take place more readily.
Due to their high specificity, simplicity, and scalability, enzyme-based biosensors represent a fast, precise, and continuous monitoring of analytes. Additionally, the high specificity of enzymes enhances the ability to detect lower analyte concentration limits. So enzymes are used in biosensors.

Biosensors are employed in applications such as disease monitoring, drug discovery, and detection of pollutants, disease-causing micro-organisms and markers that are indicators of a disease in bodily fluids (blood, urine, saliva, sweat).
Various types of biosensors being used are enzyme-based, tissue-based, immunosensors, DNA biosensors, and thermal and piezoelectric biosensors. There are wide variety of enzymes used in biosensors. One such enzyme is glucose oxidase, mainly in amperometric glucose biosensor.

GLUCOSE OXIDASE IN BIOSENSORS:

Glucose oxidase (GOx) is widely used enzyme in glucose biosensor due to its better stability and relatively inexpensive. GOx catalyses the redox reaction and transfer electrons from enzyme active sites to electrode for glucose level analysis in blood samples. Amperometric glucose biosensor was fabricated by immobilizing glucose oxidase (GOx). Glucose oxidase (GOx), the most popular enzyme used for glucose detection, is able to reduce oxygen to hydrogen peroxide while at the same time transforming glucose to d-glucono-1,5-lactone. Quantification of glucose can be achieved based on either the detection of the hydrogen peroxide produced or the oxygen consumed.

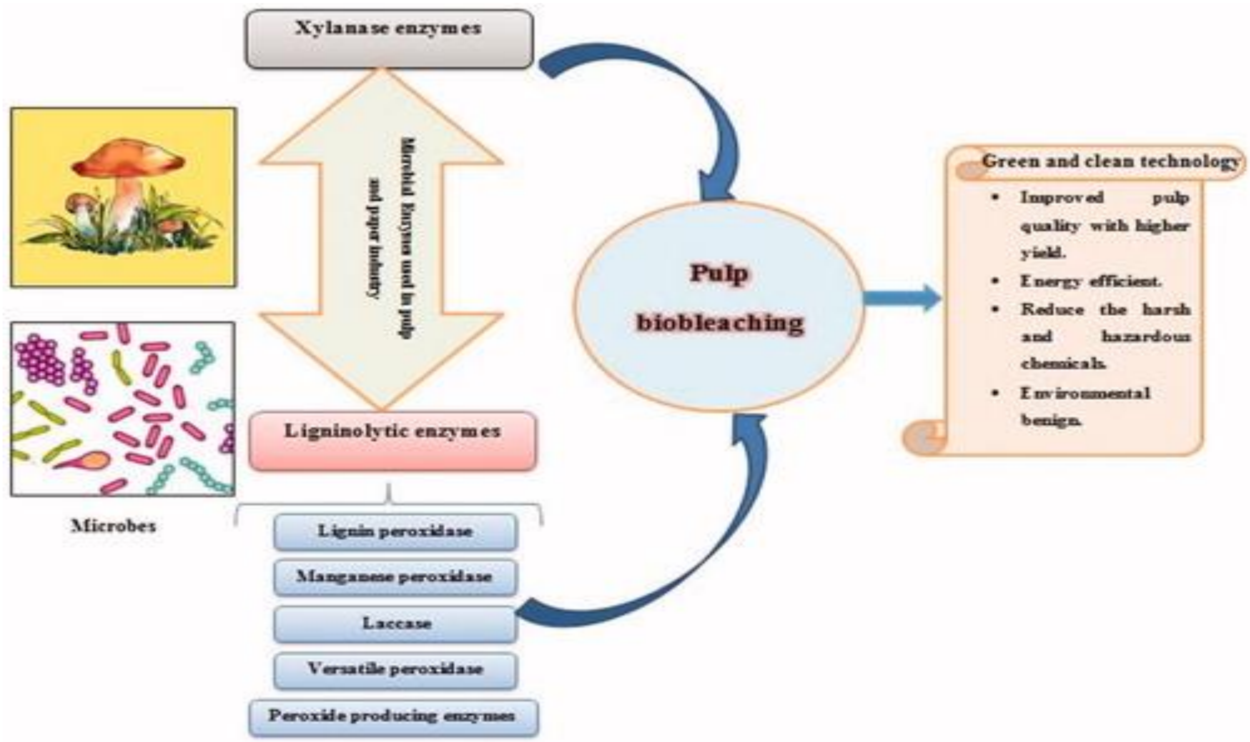


COURTESY*: RESEARCH GATE*

LIGNOLYTIC ENZYME IN BIO BLEACHING:

Ligninolytic enzymes play a key role in degradation and detoxification of lignocellulosic waste in environment. The major ligninolytic enzymes are laccase, lignin peroxidase, manganese peroxidase, and versatile peroxidase.
Ligninolytic fungi and enzymes (i.e., laccase, manganese peroxidase, and lignin peroxidase) have been applied recently in the production of second-generation biofuels.

White-rot fungi are the main producers of lignin-oxidizing enzymes. These fungi secrete a number of oxidative enzymes and some hitherto unknown substances (mediators) into their environment together effecting a slow but continuous degradation. The most important lignin-oxidizing enzymes are lignin peroxidases, manganese peroxidases and laccases. Lignin peroxidase and manganese peroxidase appear to constitute a major component of the ligninolytic system.



COURTESY:*SHARDESH KUMAR CHAURASIA*

MODULE 2

Module - 2

HUMAN ORGAN SYSTEMS AND BIO DESIGNS - 1 (QUALITATIVE):

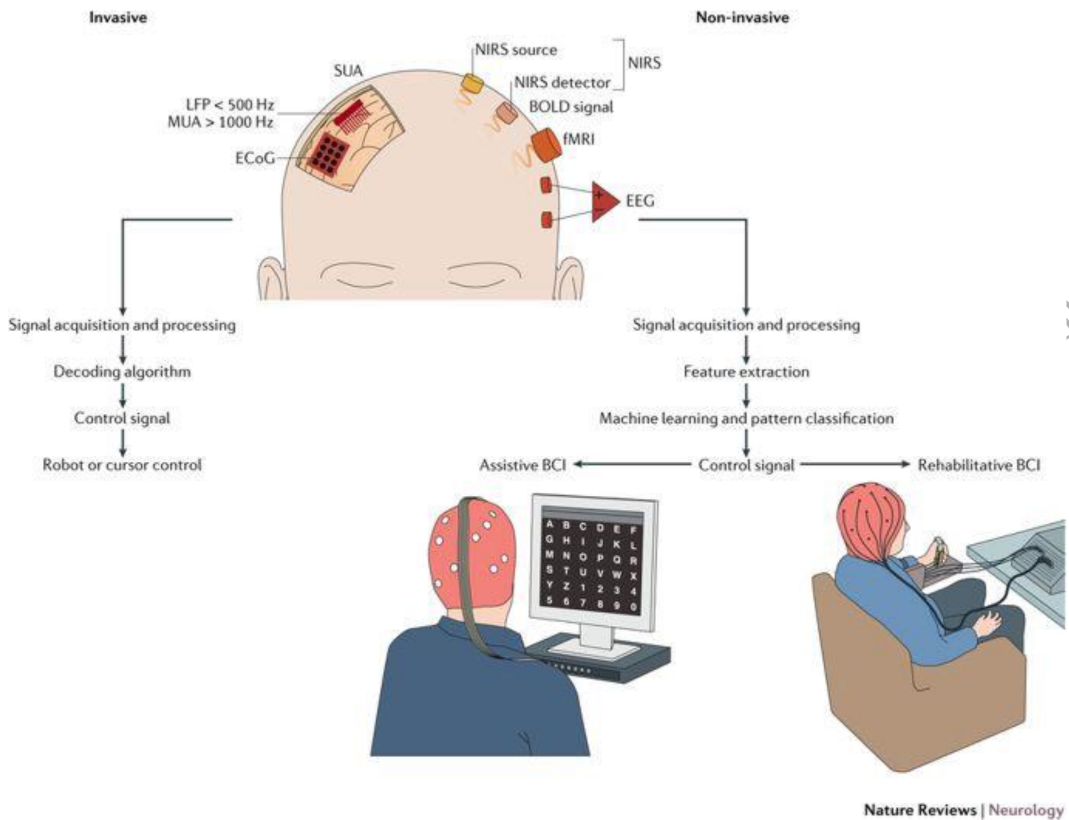
Brain as a CPU system (architecture, CNS and Peripheral Nervous System, signal transmission, EEG, Robotic arms for prosthetics. Engineering solutions for Parkinson's disease).Eye as a Camera system (architecture of rod and cone cells, optical corrections, cataract, lens materials, bionic eye).Heart as a pump system (architecture, electrical signalling - ECG monitoring and heart related issues, reasons for blockages of blood vessels, design of stents, pace makers, defibrillators).

HUMAN ORGAN SYSTEMS AND BIO DESIGNS:

The human body is a biological machine made of body systems; groups of organs that work together to produce and sustain life. Organ systems are:
Skeletal system, Muscular system, Cardiovascular system, Respiratory system, Nervous system, Digestive system, Urinary system, Endocrine system, Lymphatic system, Reproductive system, Integumentary system.

Biodesign is the use of living organisms in design. Its processes can be used in the creation of fashion, textiles, furniture and architecture. Nonprofits, design companies and universities around the world, including UC Davis, increasingly implement biodesign practices into research and product development.

Bio-design (actual or conceptual) embodies an emerging design movement which incorporates the use of living materials, or 'moist media,' such as fungi, algae, yeast, bacteria, and cultured tissue. This can be as part of standard crafting methods or the more complex fields of biomimicry and synthetic biology. The idea is to create a product whose properties are enhanced as a result of the use of these living materials. Some examples are explained below.



BRAIN AS A CPU SYSTEM:

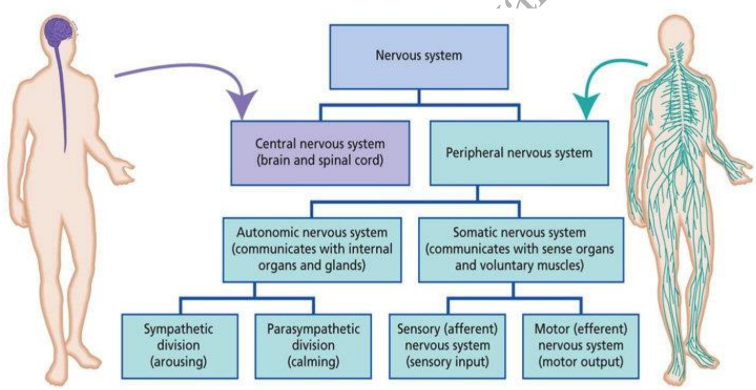
Both CPU and brain use electrical signals to send messages. The brain uses chemicals to transmit information; the computer uses electricity. Even though electrical signals travel at high speeds in the nervous system, they travel even faster through the wires in a computer. Both transmit information.

A BCI system is a computer-based system that takes brain signals, analyses them and translates them into commands that are relayed to a device to trigger a desired action. A BCI system does not use peripheral nerves and head muscles. The CNS (Central Nervous System), for example, is used to measure signals produced by the central nervous system. Thus, for example, a sensor that is activated by the voice or the movement of a muscle is not a BCI system. Also an EEG is not BCI itself, because it only records brain signals but it does not produce an output that acts on the user's environment. It is also wrong to think that BCI is a mind-reader. They do not export information from unsuspecting users or users unwillingly using the system. They allow users to act in their environment when they want it by reading their brain signals rather than muscles. The user and the BCI work together. The user, after a training session, produces brain signals encoded by the BCI system. The BCI then translates these commands and transmits them into an output device. Brain computer interfaces have contributed to various areas of research. Applications that are about medicine, neuro-technology and smart environment, neuro-marketing and advertising, education and self-regulation, games and entertainment, as well as security and identification.

The nervous system has two main parts: The **central nervous system** is made up of the brain and spinal cord. **The peripheral nervous system** is made up of nerves that branch off from the spinal cord and extend to all parts of the body.

1) CNS:
CNS includes the brain and spinal cord. The brain is the body's "control center." The CNS has various centers located within it that carry out the sensory, motor and integration of data. These centers can be subdivided to Lower Centers (including the spinal cord and brain stem) and higher centers communicating with the brain via effectors.

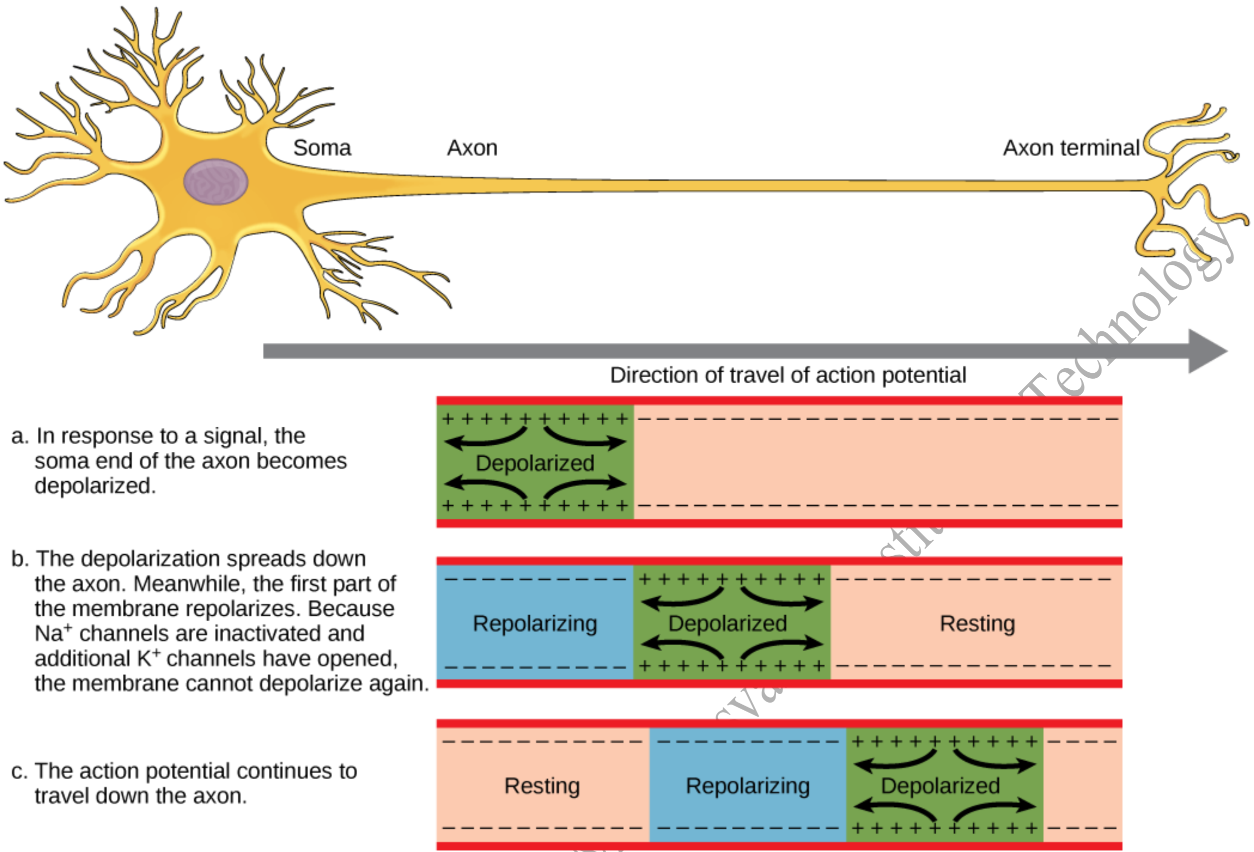
2) PNS:
PNS is a vast network of spinal and cranial nerves that are linked to the brain and the spinal cord. It contains sensory receptors which help in processing changes in the internal and external environment. This information is sent to the CNS via afferent sensory nerves. The PNS is then subdivided into the autonomic nervous system and the somatic nervous system. The autonomic has involuntary control of internal organs, blood vessels, smooth and cardiac muscles. The somatic has voluntary control of skin, bones, joints, and skeletal muscle. The two systems function together, by way of nerves from the PNS entering and becoming part of the CNS, and vice versa.



COURTESY: *MARC SEYMOUR*

SIGNAL TRANSMISSION:

A neuron sending a signal (i.e., a presynaptic neuron) releases a chemical called a neurotransmitter, which binds to a receptor on the surface of the receiving (i.e., postsynaptic) neuron. Neurotransmitters are released from presynaptic terminals, which may branch to communicate with several postsynaptic neurons.
Axon terminals are where neurotransmission begins. Hence, it is at axon terminals where the neuron sends its OUTPUT to other neurons. At electrical synapses, the OUTPUT will be the electrical signal itself. At chemical synapses, the OUTPUT will be neurotransmitter.
The correct outline for the sequence of transmission of an electrical impulse through a neuron is dendrites, cell body, axon, axon terminal.



COURTESY: *OPENSTAX COLLEGE,BIOLOGY*

ELECTRO ENCEPHALO GRAM [EEG]:

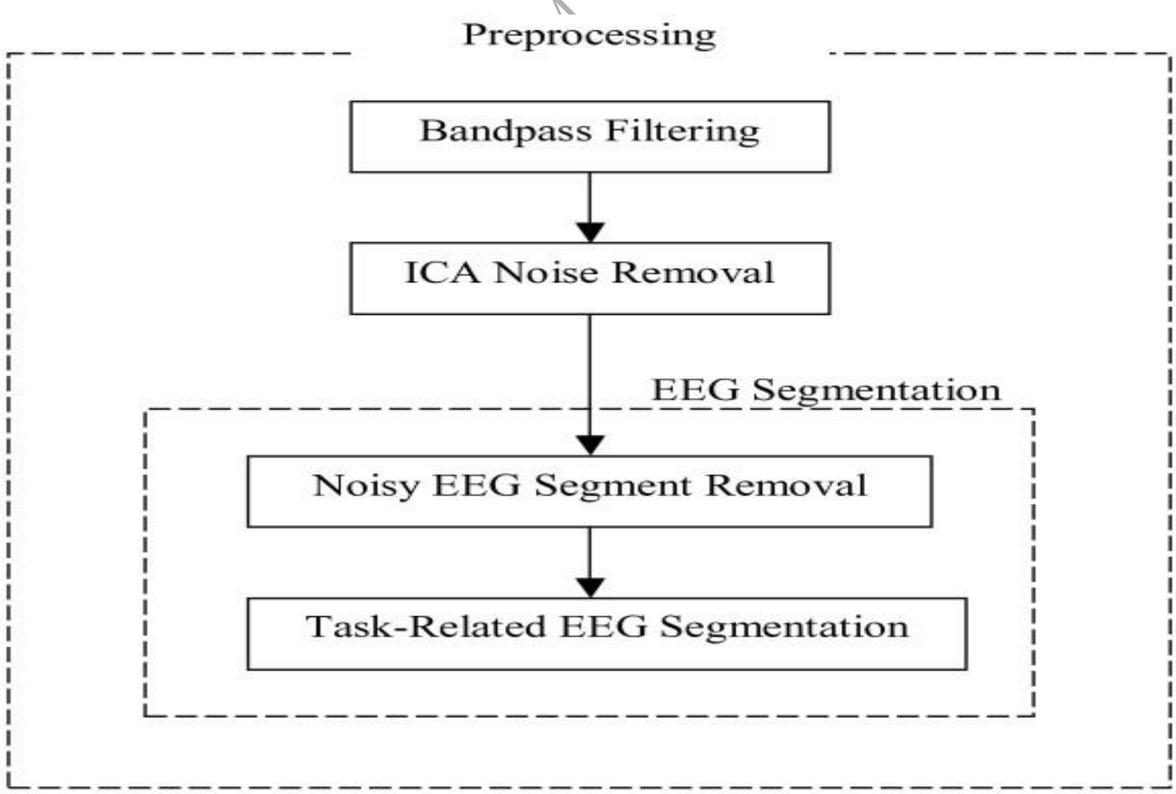
An electroencephalogram (EEG) is a test that measures electrical activity in the brain using small, metal discs (electrodes) attached to the scalp. Brain cells communicate via electrical impulses and are active all the time, even during asleep. This activity shows up as wavy lines on an EEG recording.
An EEG is one of the main diagnostic tests for epilepsy. An EEG can also play a role in diagnosing other brain disorders.
An EEG can find changes in brain activity that might be useful in diagnosing brain disorders, especially epilepsy or another seizure disorder. An EEG might also be helpful for diagnosing or treating:

- Brain tumors
- Brain damage from head injury
- Brain dysfunction that can have a variety of causes (encephalopathy)
- Sleep disorders
- Inflammation of the brain (herpes encephalitis)
- Stroke
- Sleep disorders

- Creutzfeldt-Jakob disease

An EEG might also be used to confirm brain death in someone in a persistent coma. A continuous EEG is used to help find the right level of anesthesia for someone in a medically induced coma. Voltage fluctuations measured by the EEG bioamplifier and electrodes allow the evaluation of normal brain activity including the posterior dominant rhythm (PDR), first described by Hans Berger. EEG can detect abnormal electrical discharges such as sharp waves, spikes or spike-and-wave complexes that are seen in people with epilepsy, thus it is often used to inform the medical diagnosis. EEG can detect the onset and spatio-temporal evolution of seizures and the presence of status epilepticus. It is also used to help diagnose sleep disorders, depth of anesthesia, coma, encephalopathies, cerebral hypoxia after cardiac arrest, and brain death. EEG used to be a first-line method of diagnosis for tumors, stroke and other focal brain disorders, but this use has decreased with the advent of high-resolution anatomical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT). Despite limited spatial resolution, EEG continues to be a valuable tool for research and diagnosis. It is one of the few mobile techniques available and offers millisecond-range temporal resolution which is not possible with CT, PET or MRI.

Derivatives of the EEG technique include evoked potentials (EP), which involves averaging the EEG activity time-locked to the presentation of a stimulus of some sort (visual, somatosensory, or auditory). Event-related potentials (ERPs) refer to averaged EEG responses that are time-locked to more complex processing of stimuli; this technique is used in cognitive science, cognitive psychology, and psychophysiological research.



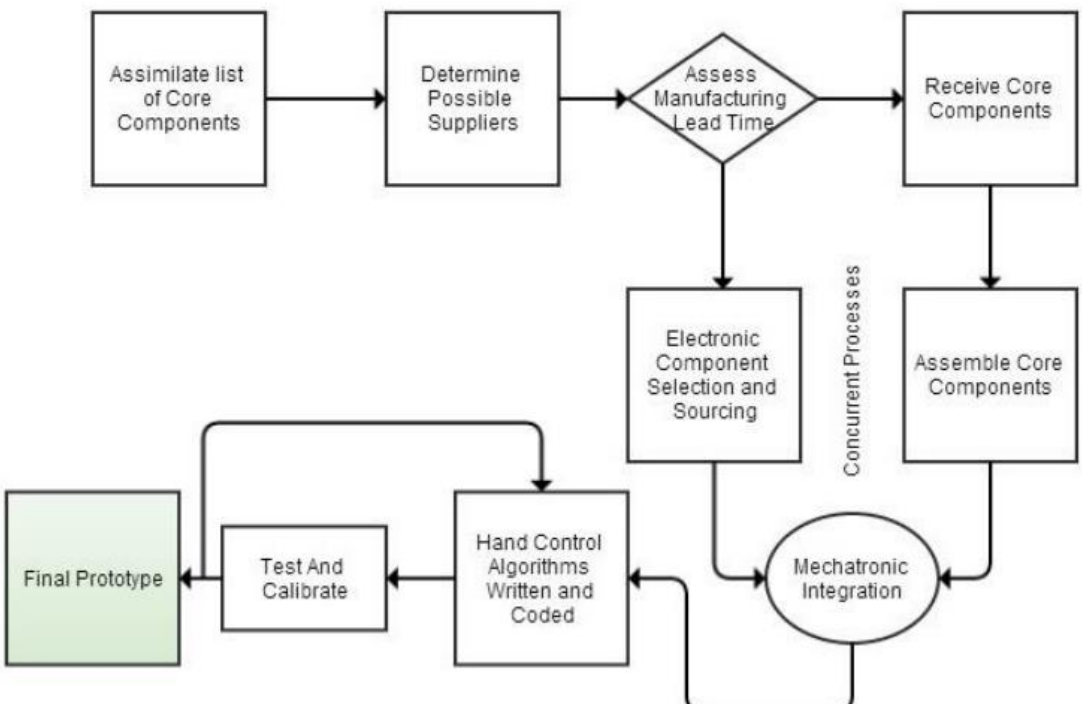
Department Of Biotechnology,

Sir M Visvesvaraya Institute of Technology

COURTESY: ***Z. JANE WANG***

ROBOTIC ARMS FOR PROSTHETICS:

Robotic prosthetic limb is a well-established research area that integrates advanced mechatronics, intelligent sensing, and control for achieving higher order lost sensorimotor functions while maintaining the physical appearance of amputated limb. Robotic prosthetic limbs are expected to replace the missing limbs of an amputee restoring the lost functions and providing aesthetic appearance. The main aspects are enhanced social interaction, comfortable amputee's life, and productive amputee to the society. With the advancement of sensor technology, in the last few decades significant contributions have been made in this area.
Most current robotic prostheses work by recording—from the surface of the skin—electrical signals from muscles left intact after an amputation. Some amputees can guide their artificial hand by contracting muscles remaining in the forearm that would have controlled their fingers.
If you are missing an arm or leg, an artificial limb can sometimes replace it. The device, which is called a prosthesis, can help you to perform daily activities such as walking, eating, or dressing.
Robotic arms can be used to automate the process of placing goods or products onto pallets. By automating the process, palletizing becomes more accurate, cost-effective, and predictable. The use of robotic arms also frees human workers from performing tasks that present a risk of bodily injury.



COURTESY: *RESEARCH GATE*

ENGINEERING SOLUTIONS FOR PARKINSON'S DISEASE:

Parkinson's disease is a progressive disorder that affects the nervous system and the parts of the body controlled by the nerves. Symptoms start slowly. The first symptom may be a barely noticeable tremor in just one hand. Tremors are common, but the disorder may also cause stiffness or slowing of movement.

In Parkinson's disease, certain nerve cells (neurons) in the brain gradually break down or die. Many of the symptoms are due to a loss of neurons that produce a chemical messenger in your brain called dopamine. When dopamine levels decrease, it causes atypical brain activity, leading to impaired movement and other symptoms of Parkinson's disease.

Parkinson's disease can't be cured, but medications can help control the symptoms, often dramatically. In some more advanced cases, surgery may be advised. Your health care provider may also recommend lifestyle changes, especially ongoing aerobic exercise.

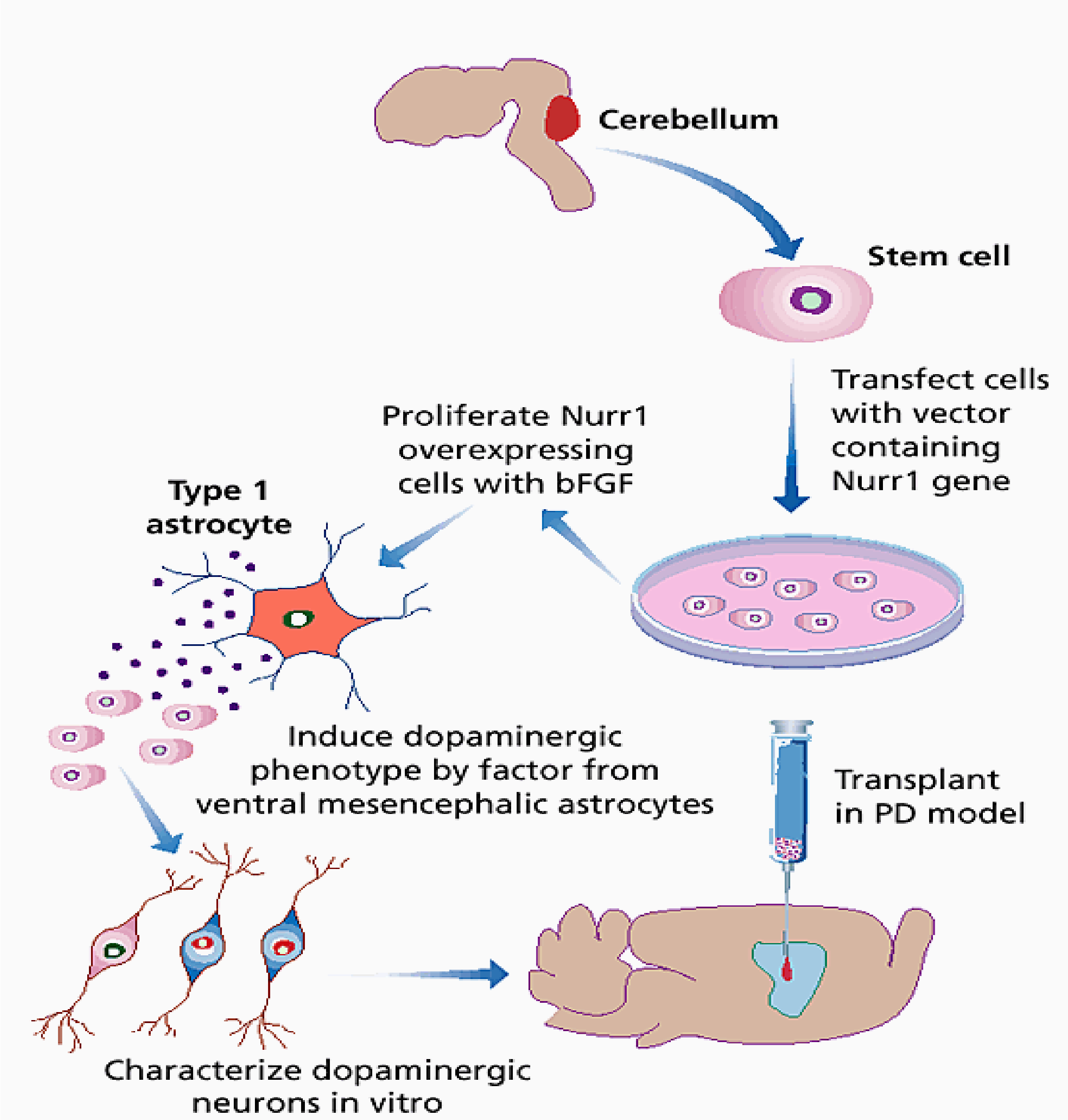
ENGINEERING SOLUTIONS TO THIS DISEASE ARE:

Deep Brain Stimulation – Deep Brain Stimulation (DBS) involves surgically implanting a neurotransmitter that sends electrical impulses to specific areas of your brain. This procedure has helped many people with Parkinson's reduce symptoms such as tremor, rigidity, and bradykinesia. There are six main types of medications available to treat symptoms of Parkinson disease: levodopa, dopamine agonists, and inhibitors of enzymes that inactivate dopamine (monoamine oxidase type B [MAO B] inhibitors and catechol-O-methyl transferase [COMT] inhibitors, anticholinergic drugs, and amantadine.

ENGINEERING NEURONS are another treatment method for this.

Transplantation of embryonic neurons can restore functional dopaminergic neurons in the brains of patients with Parkinson's disease. But while promising, cell transplantation therapy is still out of reach to most patients, in part because of the inaccessibility of human embryonic tissue.

First obtained neuronal stem cells from mouse cells transfected with a transcription factor that encourages cells to adopt a neuronal fate. They then co-cultured the cells with astrocytes, which release a factor that induces development into dopaminergic neurons. The engineered cells released dopamine, and some maintained the characteristics of dopaminergic neurons for up to two weeks after implantation into mouse brains.

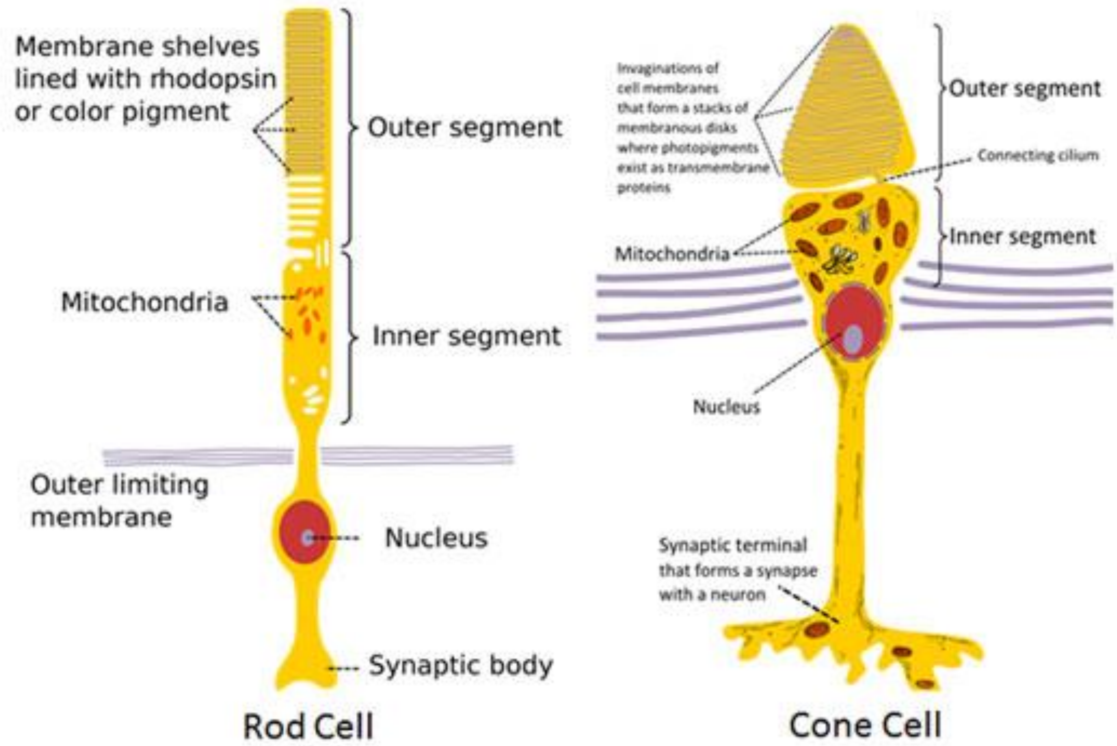

Cerebellum
Stem cell
Transfect cells with vector containing Nurr1 gene
Proliferate Nurr1 overexpressing cells with bFGF
Type 1 astrocyte
Induce dopaminergic phenotype by factor from ventral mesencephalic astrocytes
Transplant in PD model
Characterize dopaminergic neurons in vitro

EYE AS A CAMERA SYSTEM:

The human eye is a wonderful instrument, relying on refraction and lenses to form images. There are many similarities between the human eye and a camera, including:
A diaphragm to control the amount of light that gets through to the lens. This is the shutter in a camera, and the pupil, at the center of the iris, in the human eye. A lens to focus the light and create an image. The image is real and inverted. A method of sensing the image. In a camera, film is used to record the image; in the eye, the image is focused on the retina, and a system of rods and cones is the front end of an image-processing system that converts the image to electrical impulses and sends the information along the optic nerve to the brain.
There are two photoreceptors: **RODS AND CONES**

These photoreceptors are localized around an area near the centre of the retina called the macula, which is the functional center of the retina. The fovea is located in the centre of the macula. The macula is responsible for high-resolution, color vision, provided by different types of photoreceptors.

Photoreceptors in the retina are classified into two groups, named after their physical morphologies. Rod cells are highly sensitive to light and function in night vision, whereas cone cells are capable of detecting a wide spectrum of light photons and are responsible for colour vision. Rods and cones are structurally compartmentalized. They consist of five principal regions: Outer segment, connecting cilium, Inner segment, nuclear region, Synaptic region, Rods are responsible for vision at low light levels (scotopic vision). They do not mediate color vision and have a low spatial acuity.
Cones are active at higher light levels (photopic vision), are capable of color vision and are responsible for high spatial acuity. The central fovea is populated exclusively by cones. There are 3 types of cones which we will refer to as the short-wavelength sensitive cones, the middle-wavelength sensitive cones and the long-wavelength sensitive cones or S-cone, M-cones, and L-cones for short.



COURTESY: *EASY BIOLOGY CLASS*

OPTICAL CORRECTIONS:

A slight modification of geometrically correct lines (as of a building) for the purpose of making them appear correct to the eye.
The ability to see images or objects with clear, sharp vision results from light entering the eye. Light rays bend or refract when they hit the retina, sending nerve signals to the optic nerve, which then sends these signals to the brain. The brain processes them into images, allowing you to understand what you see. When these light rays bend incorrectly, it results in a refractive error and typically causes blurry or cloudy vision.
Since the primary cause of vision problems is caused by light bending incorrectly as it enters the eye, virtually any method of treatment that changes this can be categorized as a form of vision correction.
Eyeglasses and contact lenses – the most common types of corrective measures – are almost always recommended as the first course of treatment for vision problems. While they are considered a very basic method of vision correction, they are unable to control the refractive error from progressing. Patients whose vision worsens over time need new glasses or contacts. In these cases, longer-term solutions are needed.

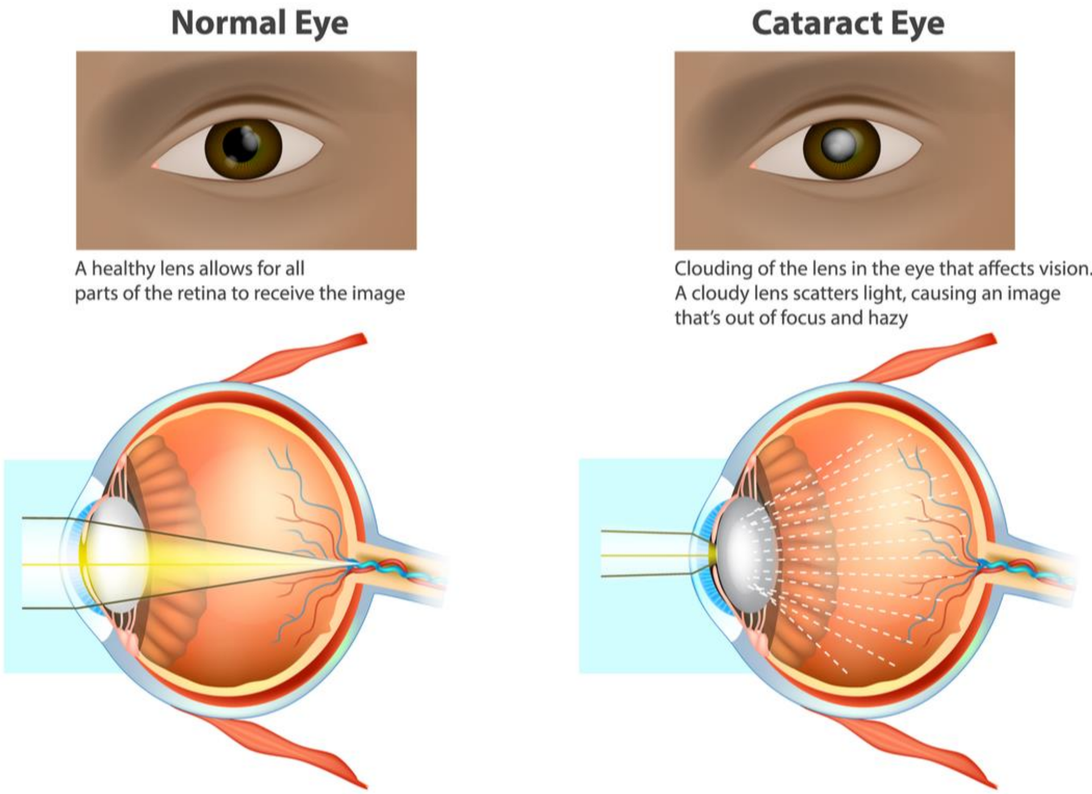
CATARACT:

A cataract is a clouding of the normally clear lens of the eye. At first, the cloudiness in your vision caused by a cataract may affect only a small part of the eye's lens and you may be unaware of any vision loss. As the cataract grows larger, it clouds more of your lens and distorts the light passing through the lens. This may lead to more-noticeable symptoms. A cataract is a cloudy lens. The lens is positioned behind the colored part of your eye (iris). The lens focuses light that passes into your eye, producing clear, sharp images on the retina — the light-sensitive membrane in the eye that functions like the film in a camera.
As you age, the lenses in your eyes become less flexible, less transparent and thicker. Age-related and other medical conditions cause proteins and fibers within the lenses to break down and clump together, clouding the lenses.

As the cataract continues to develop, the clouding becomes denser. A cataract scatters and blocks the light as it passes through the lens, preventing a sharply defined image from reaching your retina. As a result, your vision becomes blurred. Cataracts generally develop in both eyes, but not always at the same rate. The cataract in one eye may be more advanced than the other, causing a difference in vision between eyes. Cataracts may be partial or complete, stationary or progressive, hard or soft. Histologically, the main types of age-related cataracts are nuclear sclerosis, cortical, and posterior subcapsular.

Nuclear sclerosis is the most common type of cataract, and involves the central or 'nuclear' part of the lens. This eventually becomes hard, or 'sclerotic', due to condensation on the lens nucleus and the deposition of brown pigment within the lens. In its advanced stages, it is called a brunescent cataract. In early stages, an increase in sclerosis may cause an increase in refractive index of the lens. This causes a myopic shift (lenticular shift) that decreases hyperopia and enables presbyopic patients to see at near without reading glasses. This is only temporary and is called second sight.
Cortical cataracts are due to the lens cortex (outer layer) becoming opaque. They occur when changes in the fluid contained in the periphery of the lens causes fissuring. When these cataracts are viewed through an ophthalmoscope, or other magnification system, the appearance is similar to white spokes of a wheel. Symptoms often include problems with glare and light scatter at night.
Posterior subcapsular cataracts are cloudy at the back of the lens adjacent to the capsule (or bag) in which the lens sits. Because light becomes more focused toward the back of the lens, they can cause disproportionate symptoms for their size.

An immature cataract has some transparent protein, but with a mature cataract, all the lens protein is opaque. In a hypermature or Morgagnian cataract, the lens proteins have become liquid. Congenital cataract, which may be detected in adulthood, has a different classification and includes lamellar, polar, and sutural cataracts.



COURTESY*: THE EYE HEALTH CENTRE*

LENS MATERIALS:

Corrective spherocylindrical lenses are commonly used to treat refractive errors such as myopia, hyperopia, presbyopia, and astigmatism. Both lenses and prisms are also frequently used to improve eye alignment and treat diplopia in strabismus. Eyeglasses also serve an important role in protecting the eyes from physical trauma and harmful radiation. Lenses can be produced using a variety of materials and designed with several optical profiles to optimize use in specific applications. Critical lens properties include refractive index, Abbe number (chromatic dispersion), specific gravity, and ultraviolet absorption.

The most common lens material is, of course, optical glass, but crystals and plastics are frequently used, while mirrors can be made of essentially anything that is capable of being polished.

There are 5 main types of lens materials for eyeglasses and sunglasses. Each type of lens material can help correct refractive errors such as nearsightedness, farsightedness, astigmatism, or presbyopia.

Types of lens materials:

1. CR-39: The most used plastic lens material for years was CR-39. It was first developed as a replacement for glass lenses during World War II. It still has 55% of world market at age 60. The patent was awarded to Muskat and Strain of Pittsburgh Plate Glass Company (now named PPG) in 1946. CR-39 is available in all lens styles and from multiple manufacturers. The basic monomer comes from PPG, and then each company adds their own materials to create their lenses. Advantages include light weight, good optical properties, and tinting well. Disadvantages of CR-39 are that it is the thickest material and scratches easily.

2. Crown Glass is the most commonly used clear glass for ophthalmic lenses. In general, glass is the most durable material used for lenses. Crown glass is used mainly for single vision lenses and the distance carrier for most glass bifocals and trifocals. It has an index of refraction of 1.523, and an Abbe value of 59. It is approximately 4% thinner than CR-39 resin lenses and is 40% heavier than polycarbonate lenses and is slightly lighter than high index glass. It blocks out about 10% of UV light.

3. Flint Glass uses lead oxides in its chemical make up to increase its index of refraction to approximately 1.58 to 1.69. Its Abbe value ranges from 30 to 40. This material is relatively soft, displays a brilliant luster and has chromatic aberration. Although it was used in the past as a single vision alternative for higher Rx lenses, its use today is often limited to segments for some fused bifocals.
The advantages of glass lenses include optical clarity, resistance to scratches, and it is the least susceptible to chemicals. The disadvantages include that it is the heaviest material and it is less impact resistant than other materials.

4. Polycarbonate Lenses: Polycarbonate lenses were first developed by a company named Gentex. Polycarbonate is a thermoplastic which means it is moldable under sufficient heat. In the 1950's it was marketed under the name Lexan and due to its extraordinary resistance to impact was originally manufactured for safety devices.

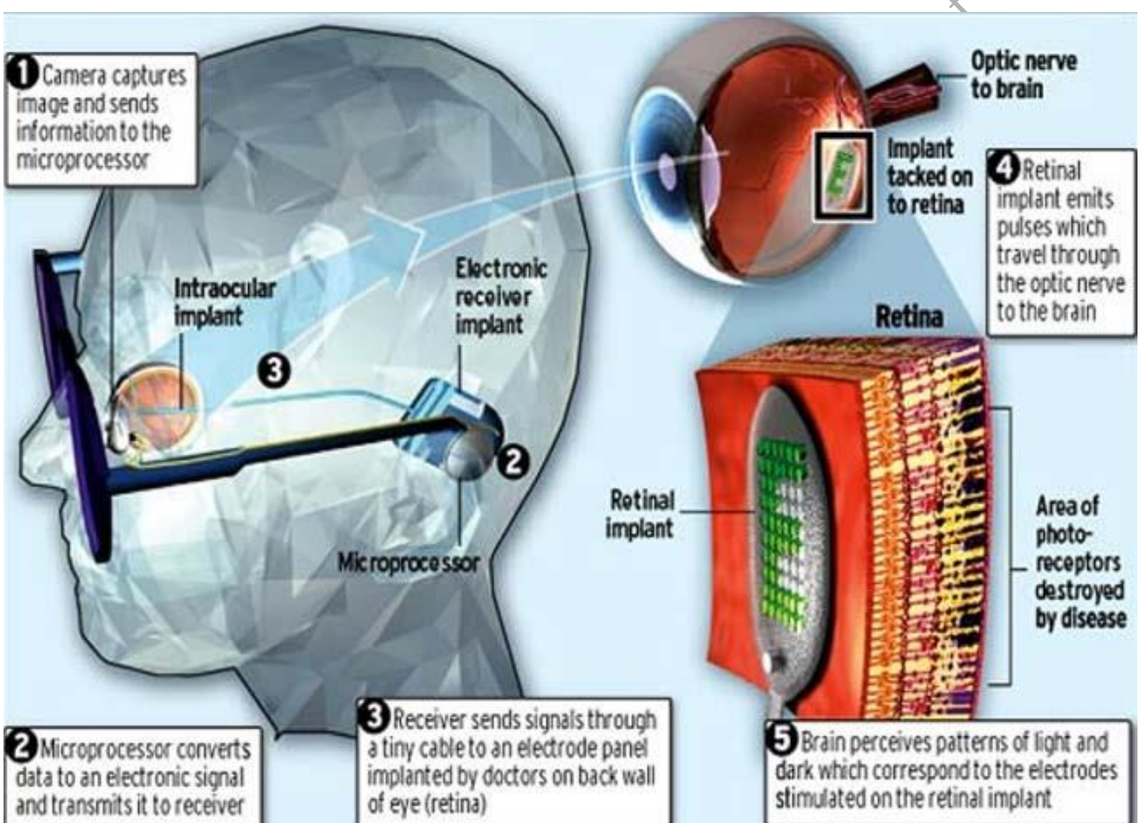
BIONIC EYES:

bionic eye, electrical prosthesis surgically implanted into a human eye in order to allow for the transduction of light (the change of light from the environment into impulses the brain can process) in people who have sustained severe damage to the retina.
The bionic eye comprises an external camera and transmitter and an internal microchip. The camera is mounted on a pair of eyeglasses, where it serves to organize the visual stimuli of the environment before emitting high-frequency radio waves. The stimulator microchip consists of an electrode array that is surgically implanted into the retina. That functions as an electrical relay in place of degenerated retinal cells. The radio waves that are emitted by the external camera and transmitter are received by the stimulator, which then fires electrical impulses. The impulses are relayed by the few remaining retinal cells and are transduced as normal to the optic nerve pathway, resulting in vision.

The bionic vision system consists of a camera, attached to a pair of glasses, which transmits high-frequency radio signals to a microchip implanted in the retina. Electrodes on the implanted chip convert these signals into electrical impulses to stimulate cells in the retina that connect to the optic nerve.

It is an expensive treatment and not everyone can afford it. b. Since research is still going on results are yet not 100% successful.

It's an artificial eye which provide visual sensations to the brain. It consist of electronic systems having image sensors, microprocessors, receivers, radio transmitters and retinal chips. Technology provided by this help the blind people to get vision again.
It consist of a computer chip which is kept in the back of effected person eye and linked with a mini video camera built into glasses that they wear. Then an image captured by the camera are focused to the chip which converts it into electronic signal that brain can interpret. The images produced by Bionic eye were not be too much perfect but they could be clear enough to recognize. The implant bypasses the diseased cells in the retina and go through the remaining possible cells.



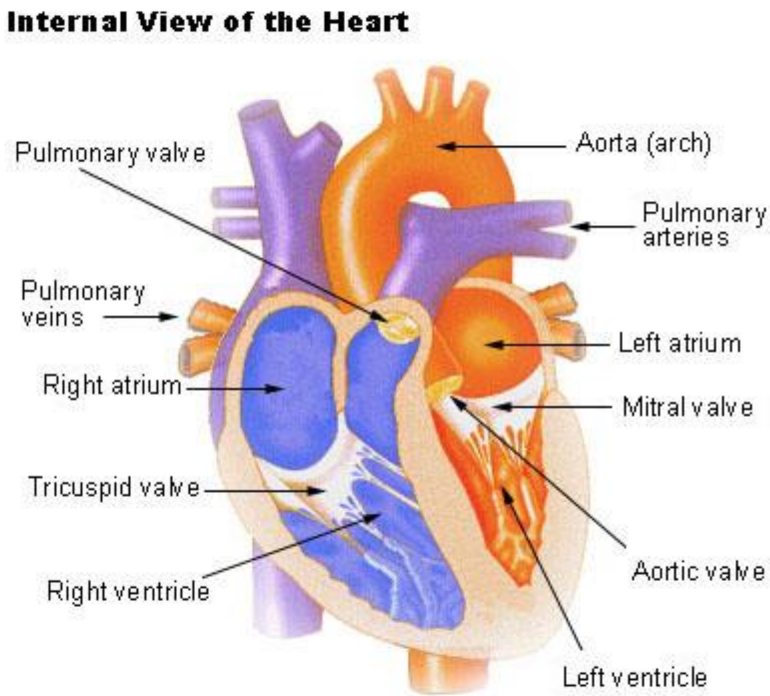
COURTESY*: CIRCUITDIGEST*

The device consists of 3,500 micro photodiodes which are set at the back part of the retina. The electrical signal which is sent to brain is obtained from these miniature solar cells array as they convert the normal light to electrical signal.

HEART AS A PUMP SYSTEM:

Heart is sort of like a pump, or two pumps in one. The right side of your heart receives blood from the body and pumps it to the lungs. The left side of the heart does the exact opposite: It receives blood from the lungs and pumps it out to the body. While an LVAD consists of thick tubes and a pump connected externally to the heart muscle and aorta, percutaneous heart pumps place a much smaller tube inside the heart's chambers. These tiny heart pumps are placed in the heart via a thin tube called a catheter that is threaded through a puncture site in the skin. The human heart is very strong and is capable of pumping blood up to 30 feet distance. An average heart beats maximum of 70-80 beats per minute and is considered healthy. The efficiency of the heart can be maintained and improved by performing physical activity. The heart is called a double pump because each side pumps blood to a different circulation. Deoxygenated blood from the body drains to the right side of the heart. This is the first pump that sends blood to the lungs, called the pulmonary circulation, where it becomes oxygenated and releases carbon dioxide.

Here is what happens as blood flows through the heart and lungs:
The blood first enters the right atrium. The blood then flows through the tricuspid valve into the right ventricle. When the heart beats, the ventricle pushes blood through the pulmonic valve into the pulmonary artery. The pulmonary artery carries blood to the lungs where it "picks up" oxygen. It then leaves the lungs to return to the heart through the pulmonary vein. The blood enters the left atrium. It drops through the mitral valve into the left ventricle. The left ventricle then pumps blood through the aortic valve and into the aorta. The aorta is the artery that feeds the rest of the body through a system of blood vessels. Blood returns to the heart from the body via two large blood vessels called the superior vena cava and the inferior vena cava. This blood carries little oxygen, as it is returning from the body where oxygen was used. The vena cava pump blood into the right atrium and the cycle begins all over again.



COURTESY: *SEER TRAINING MODULES*

The human heart is a four-chambered muscular organ, shaped and sized roughly like a man's closed fist with two-thirds of the mass to the left of midline. The heart is enclosed in a pericardial sac that is lined with the parietal layers of a serous membrane. The visceral layer of the serous membrane forms the epicardium.

The myocardium of the heart wall is a working muscle that needs a continuous supply of oxygen and nutrients to function efficiently. For this reason, cardiac muscle has an extensive network of blood vessels to bring oxygen to the contracting cells and to remove waste products.

ELECTRICAL SIGNALING:

The sinus node generates an electrical stimulus regularly, 60 to 100 times per minute under normal conditions. The atria are then activated. The electrical stimulus travels down through the conduction pathways and causes the heart's ventricles to contract and pump out blood.

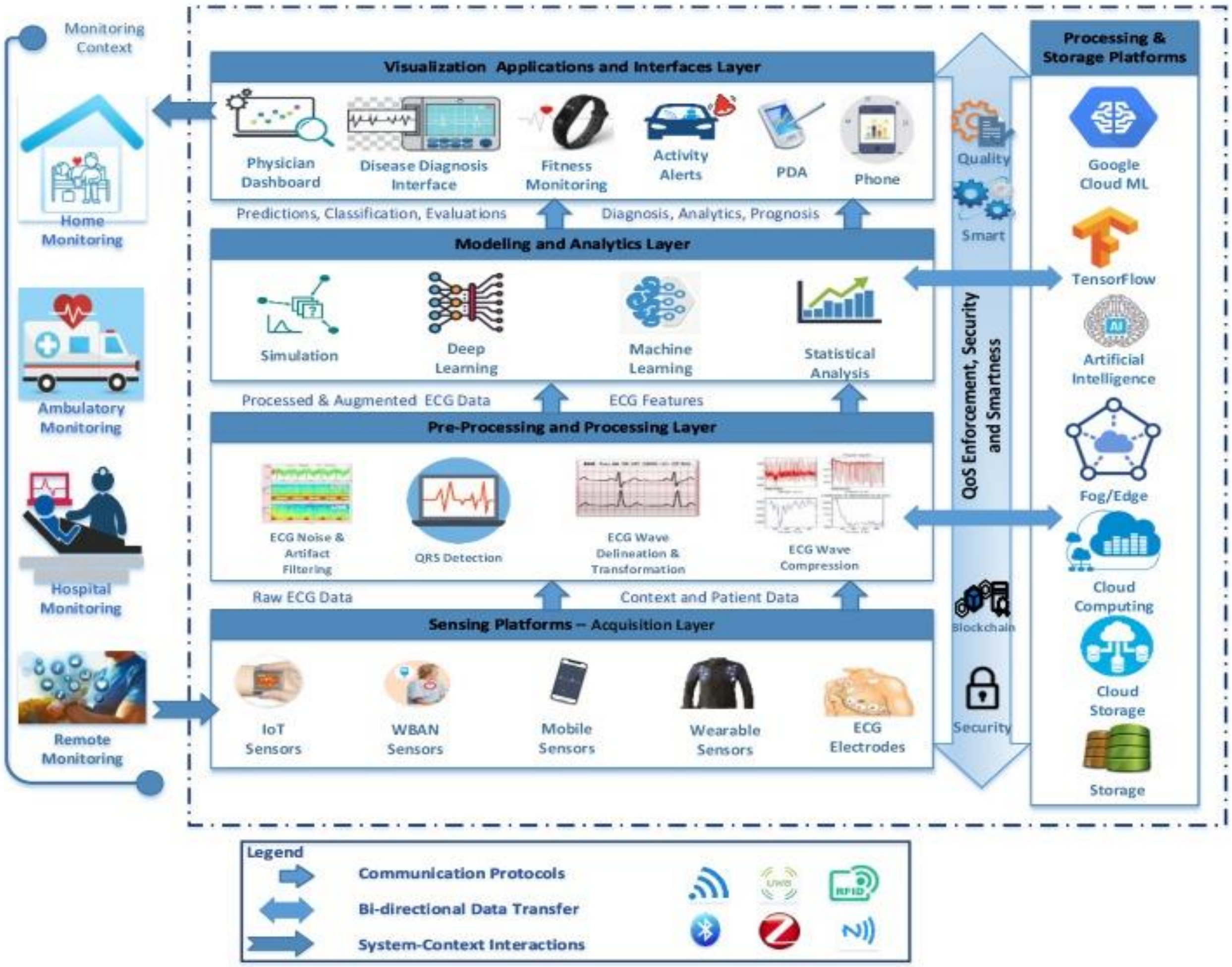
ECG MONITORING:

ECG monitoring systems have been developed and widely used in the healthcare sector for the past few decades and have significantly evolved over time due to the emergence of smart enabling technologies.

Nowadays, ECG monitoring systems are used in hospitals, homes, outpatient ambulatory settings, and in remote contexts. They also employ a wide range of technologies such as IoT, edge computing, and mobile computing. In addition, they implement various computational settings in terms of processing frequencies, as well as monitoring schemes. They have also evolved to serve purposes and targets other than disease diagnosis and control, including daily activities, sports, and even mode-related purposes.

This massive diversity in ECG monitoring systems' contexts, technologies, computational schemes, and purposes makes it hard for researchers and professionals to design, classify, and analyze ECG monitoring systems. Some efforts attempted to provide a common understanding of ECG monitoring systems' processes, guiding the design of efficient monitoring systems. However, these studies lack comprehensiveness and completeness.
They work for specific contexts, serve specific targets, or are suitable for specific technologies. This makes the available ECG monitoring system processes and architectures hard to generalize and reuse. On the other hand, some studies attempted to analyze ECG monitoring systems' attributes and provide classification taxonomies, supporting better analysis and understanding of the ECG systems reported in the literature. However, exiting reviews related to ECG monitoring in the literature can be intuitive and incomprehensive.

They do not consider the latest technological trends, and they target very narrow research niches, such as wearable sensors, mobile sensors, disease diagnosis, heartbeat detection, emotion recognition, or ECG compression methods. Hence, there is a need to provide a comprehensive, expert-verified taxonomy of ECG monitoring systems, a common architecture, and a complete set of processes to guide the classification, analysis, and design of these systems.

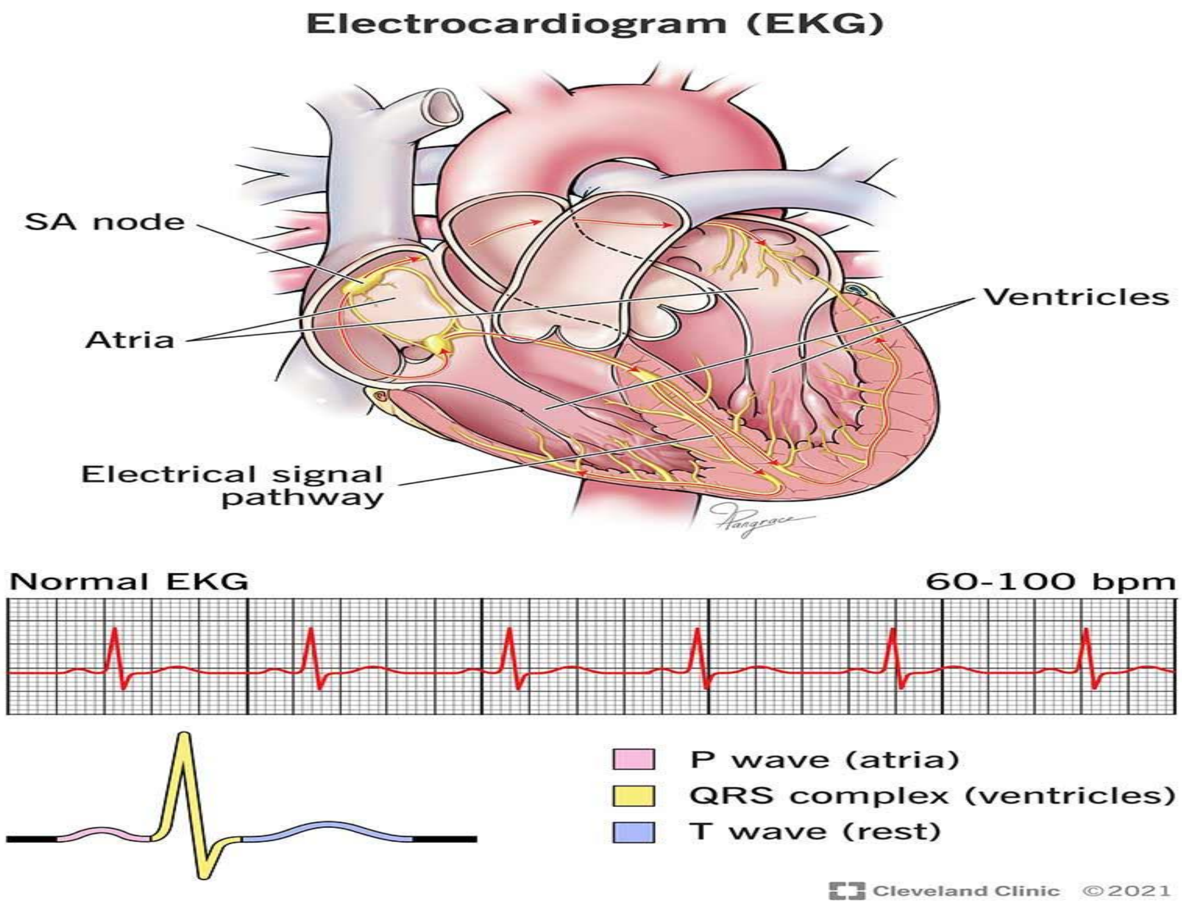


COURTESY: <u>*MDPI*</u>

The existing ECG classification algorithms usually include signal preprocessing, such as wavelet transform and manual feature extraction, but the amount of computation will increase the delay of the real-time classification system. In recent years, deep learning algorithm with their advantages of automatic learning features is increasingly used in the field of health care, such as medical image recognition and segmentation, time series data monitoring, and analysis. At present, the outstanding algorithm can establish an end-to-end DNN network to learn the characteristics of ECG records by using the extensive digital characteristics of ECG data, which saves a lot of signal preprocessing steps. Because the performance of DNN increases with the amount of training data, this method can make good use of the extensive digitization of ECG data.

Arrhythmias are any abnormal activation sequence of the myoscardium. Some of these include myocardial infarction, which is caused by the sudden loss of blood supply to the heart. One of the most difficult and essential health problems in the real world is the prediction of heart disease. This condition affects the function of blood vessels and can weaken the body of the patient. According to the WHO, around 18 million people die yearly due to heart disease globally.

Due to the increasing prevalence of cardiac diseases, people are prone to prevent devastating event from happening. They are used to diagnose a patient's cardiac condition.



Electrocardiography (ECG) is a quick and easily accessible method for diagnosis and screening of **cardiovascular diseases** including **heart failure (HF**). Artificial intelligence (AI) can be used for semi-automated ECG analysis. The aim of this evaluation was to provide an overview of AI use in HF detection from ECG signals and to perform a meta-analysis of available studies.

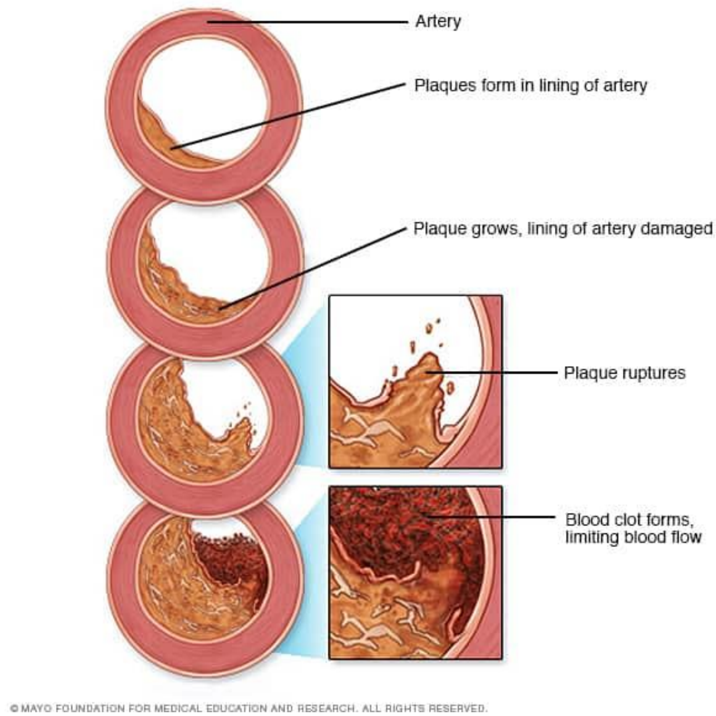
Evaluation of symptoms suggestive of HF currently demands physicians to valuate various parameters including imaging and laboratory data and the electrocardiogram (ECG). Besides a standard examination that includes an ECG, imaging information, such as echocardiography or magnetic resonance imaging, is seen as gold standard in diagnosis of HF. Nevertheless, an adequate use of such imaging data is associated with relevant technical infrastructure and medical expertise. The ECG is a well-established, quick, and easily accessible method for diagnosis and screening of various cardiovascular diseases. It provides specific features that indicate presence of HF or prognosis in HF patients especially to rule out HF in case of a normal ECG. However, use of an ECG as primary diagnostic instrument often only yields insufficient diagnostic specificity. Further, general practitioner–based ECG reporting has varying results, introducing further diagnostic uncertainty.

Devices providing medically relevant information generated directly by individuals outside the healthcare system such as smartphones with health applications or wearables including smartwatches are an emerging trend. This development promises that a growing number of, e.g., ECG data generated at home will be available for a diagnostic screening. Such data have already shown potential in computer-aided decision support systems to warn patients of rhythmic abnormalities. Management of this quantity of data, however, might be a challenge for the individual healthcare professional, as well as for the healthcare system itself. The potentially beneficial use of artificial intelligence (AI) in cardiology in general has been discussed already, e.g., as a tool for clinicians that could facilitate precision in daily practice and even might improve patient outcomes. AI might also be able to help in interpretation of ECG signals and could therefore be used to analyze ECG data in specific cases and on a large scale for early identification of cardiovascular diseases such as HF.

REASONS FOR BLOCKAGES OF BLOOD VESSELS:

Coronary artery disease is a common heart condition. The major blood vessels that supply the heart (coronary arteries) struggle to send enough blood, oxygen and nutrients to the heart muscle. Cholesterol deposits (plaques) in the heart arteries and inflammation are usually the cause of coronary artery disease.

Signs and symptoms of coronary artery disease occur when the heart doesn't get enough oxygen-rich blood. If you have coronary artery disease, reduced blood flow to the heart can cause chest pain (angina) and shortness of breath. A complete blockage of blood flow can cause a heart attack. Coronary artery disease starts when fats, cholesterols and other substances collect on the inner walls of the heart arteries. This condition is called atherosclerosis. The buildup is called plaque. Plaque can cause the arteries to narrow, blocking blood flow. The plaque can also burst, leading to a blood clot.



Besides high cholesterol, damage to the coronary arteries may be caused by:
Diabetes or insulin resistance, High blood pressure, Not getting enough exercise (sedentary lifestyle), Smoking or tobacco use.

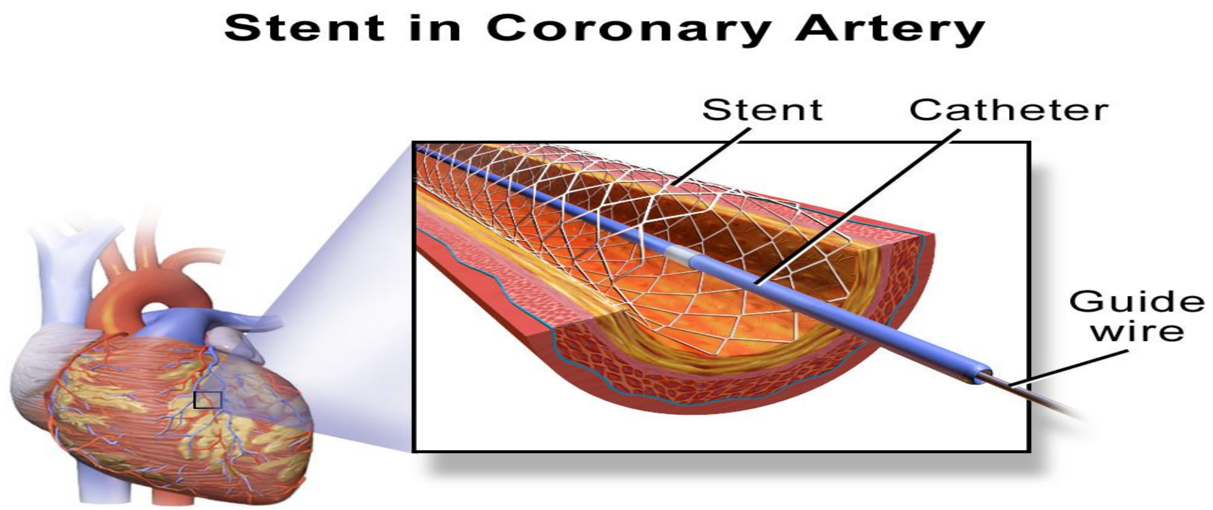
DESIGN OF STENTS:

A stent is a tiny tube that can play a big role in treating your heart disease. It helps keep your arteries -- the blood vessels that carry blood from your heart to other parts of your body, including the heart muscle itself -- open.
Most stents are made out of wire mesh and are permanent. Some are made out of fabric. These are called stent grafts and are often used for larger arteries.
Others are made of a material that dissolves and that your body absorbs over time. They're coated in medicine that slowly releases into your artery to prevent it from being blocked again.

Why Would You Need a Stent?

If a fatty substance called plaque builds up inside an artery, it can reduce blood flow to your heart. This is called coronary heart disease and it can cause chest pain.
The plaque can also cause a blood clot that blocks blood flowing to your heart, which may lead to a heart attack.
By keeping an artery open, stents lower your risk of chest pain. They can also treat a heart attack that's in progress.

Doctor usually inserts a stent using a minimally invasive procedure. They will make a small incision and use a catheter to guide specialized tools through your blood vessels to reach the area that needs a stent. This incision is usually in the groin or arm. One of those tools may have a camera on the end to help your doctor guide the stent. During the procedure, doctor may also use an imaging technique called an angiogram to help guide the stent through the vessel.
Using the necessary tools, doctor will locate the broken or blocked vessel and install the stent. Then they will remove the instruments from your body and close the incision.



DESIGN:

Most of these stents are constructed from a nickel titanium alloy. Balloon expandable stents are susceptible to permanent deformation when they are compressed extrinsically, which is not an issue in the coronary tree. Self-expanding stents do not have this limitation. Furthermore, self-expanding stents have less axial stiffness and are thus more flexible and will conform to the shape of the vessel rather than the vessel conforming to the shape of the stent. Balloon expandable stents, by virtue of their design, resist expansion by the balloon, but they have less acute recoil when they are placed in a poorly compliant lesion. However, after the initial deployment, the stent is at its maximal diameter and cannot get larger, whereas a self-expanding stent that is appropriately oversized for the vessel will exhibit a chronic outward force on the lesion and may lead to a larger lumen over time. For the reasons above, there are some coronary lesions where balloon expandable stents are not ideal, such as aneurysmal, ectatic vessels, thrombus laden vessels, and vessels that are tapering with a large size mismatch between distal reference and proximal reference vessels.

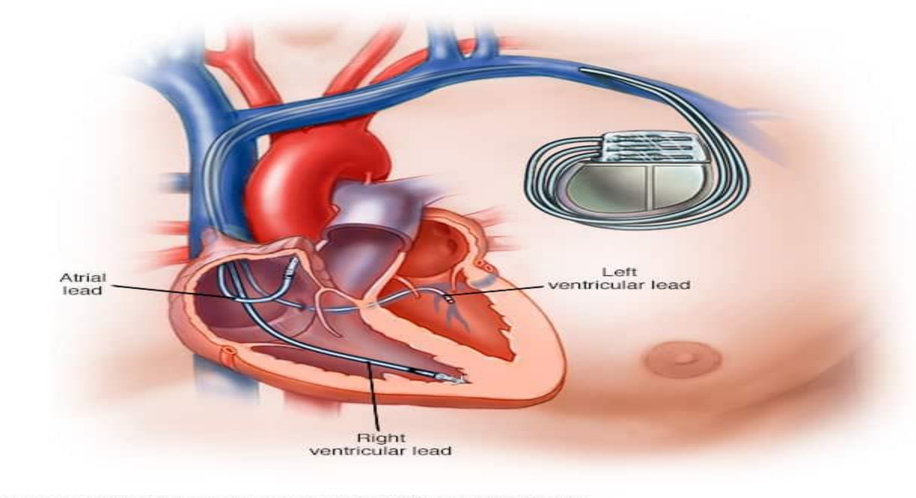
PACE MAKERS:

A pacemaker is a small device that's placed (implanted) in the chest to help control the heartbeat. It's used to prevent the heart from beating too slowly. Implanting a pacemaker in the chest requires a surgical procedure.

A pacemaker is also called a cardiac pacing device.

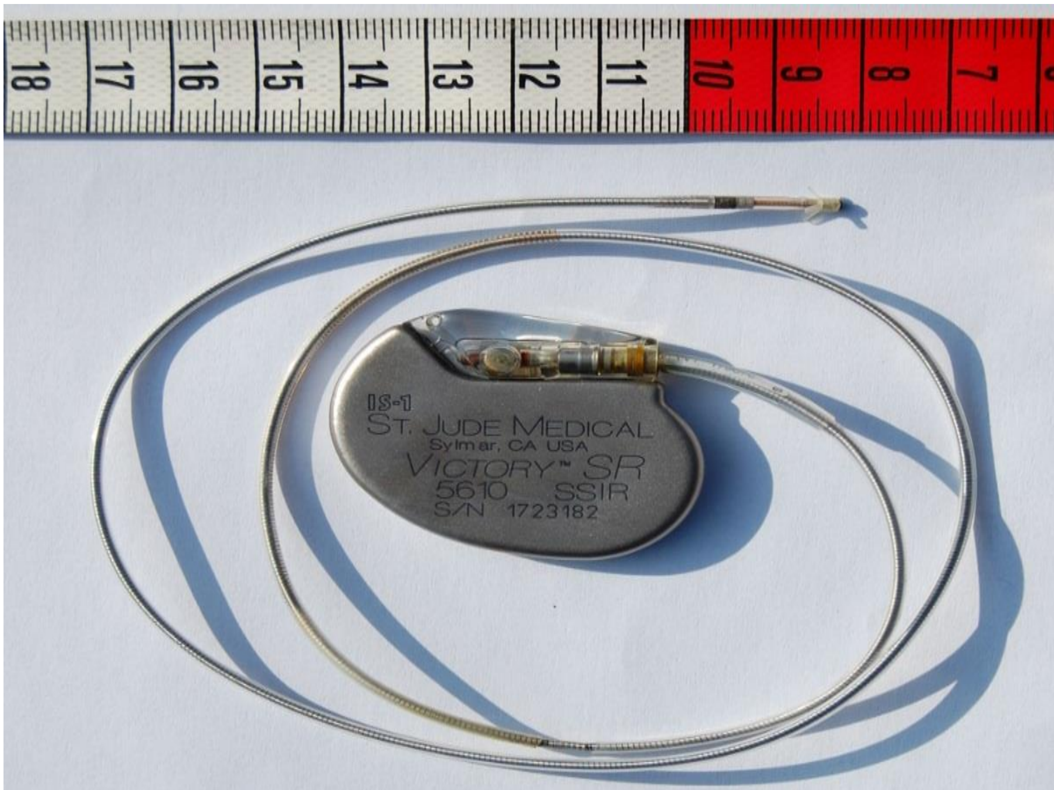
Types:
Single chamber pacemaker. This type usually carries electrical impulses to the right ventricle of your heart.
Dual chamber pacemaker. This type carries electrical impulses to the right ventricle and the right atrium of your heart to help control the timing of contractions between the two chambers.
Biventricular pacemaker. Biventricular pacing, also called cardiac resynchronization therapy, is for people who have heart failure and heartbeat problems. This type of pacemaker stimulates both of the lower heart chambers (the right and left ventricles) to make the heart beat more efficiently.
A **pacemaker** is implanted to help control your heartbeat. Your doctor may recommend a temporary pacemaker when you have a slow heartbeat (bradycardia) after a heart attack, surgery or medication overdose but your heartbeat is otherwise expected to recover. A pacemaker may be implanted permanently to correct a chronic slow or irregular heartbeat or to help treat heart failure. Pacemakers work only when needed. If your heartbeat is too slow (bradycardia), the pacemaker sends electrical signals to your heart to correct the beat.

Some newer pacemakers also have sensors that detect body motion or breathing rate and signal the devices to increase heart rate during exercise, as needed.



COURTESY: *WIKIMEDIA COMMONS*

A pacemaker has two parts:
1) Pulse generator. This small metal container houses a battery and the electrical circuitry that controls the rate of electrical pulses sent to the heart.
2) Leads (electrodes). One to three flexible, insulated wires are each placed in one or more chambers of the heart and deliver the electrical pulses to adjust the heart rate. However, some newer pacemakers don't require leads. These devices, called leadless pacemakers, are implanted directly into the heart muscle.



DEFIBRILLATORS:

Defibrillators are devices that send an electric pulse or shock to the heart to restore a normal heartbeat. They are used to prevent or correct an arrhythmia, an uneven heartbeat that is too slow or too fast. If the heart suddenly stops, defibrillators can also help it beat again. Different types of defibrillators work in different ways. Automated external defibrillators (AEDs), which are now found in many public spaces, are used to save the lives of people experiencing cardiac arrest. Even untrained bystanders can use these devices in an emergency.

Other defibrillators can prevent sudden death among people who have a high risk of a life-threatening arrhythmia. They include implantable cardioverter defibrillators (ICDs), which are surgically placed inside your body, and wearable cardioverter defibrillators (WCDs), which rest on the body. It can take time and effort to get used to living with a defibrillator, and it is important to be aware of possible complications.

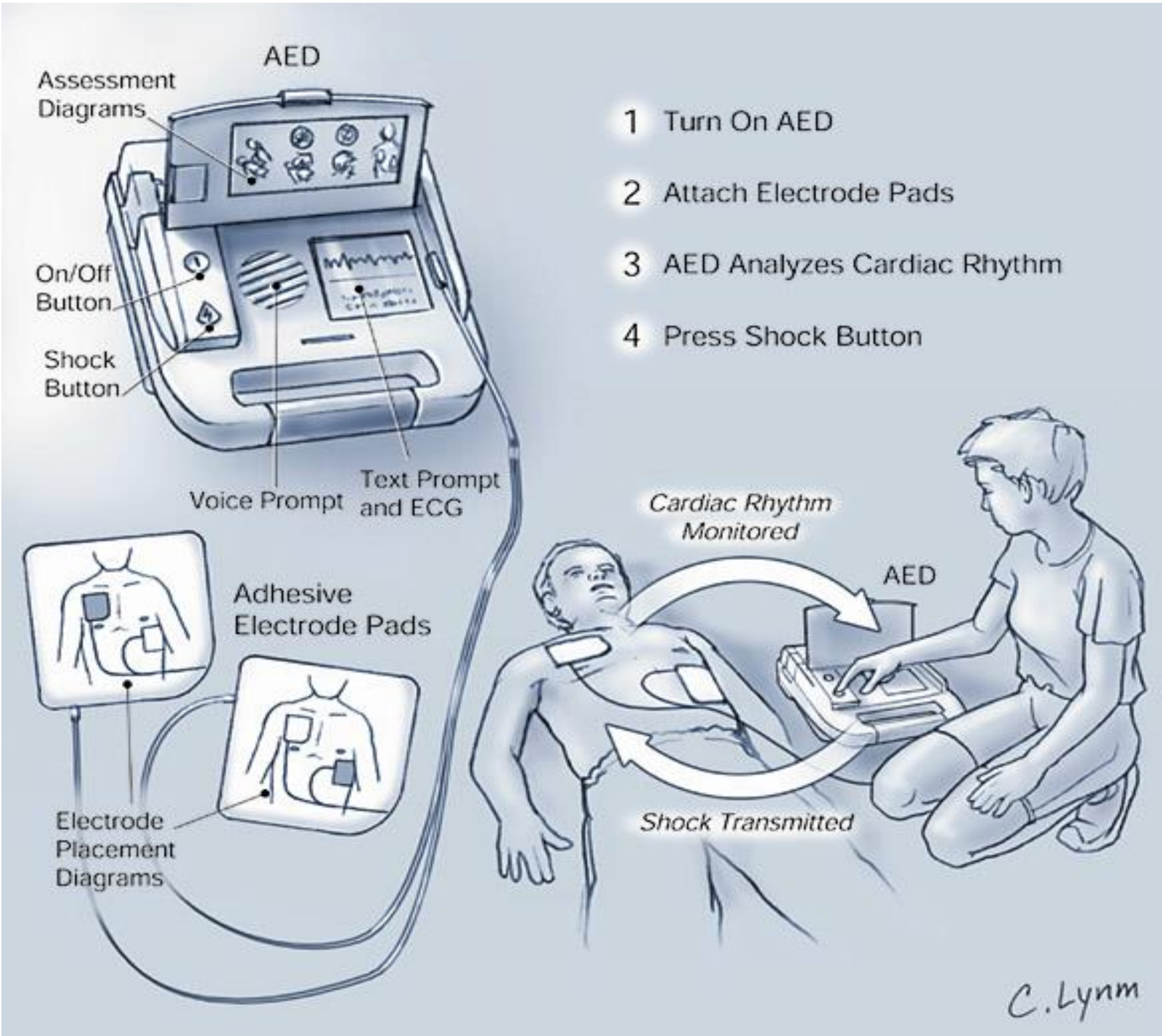
There are three types of defibrillators: AEDs, ICDs, and WCDs.

An AED is a lightweight, battery-operated, portable device that checks the heart's rhythm and sends a shock to the heart to restore normal rhythm. The device is used to help people having cardiac arrest.

Sticky pads with sensors, called electrodes, are attached to the chest of someone who is having cardiac arrest. The electrodes send information about the person's heart rhythm to a computer in the AED. The computer analyzes the heart rhythm to find out whether an electric shock is needed. If it is needed, the electrodes deliver the shock.

ICDs are placed through surgery in the chest or stomach area, where the device can check for arrhythmias. Arrhythmias can interrupt the flow of blood from your heart to the rest of your body or cause your heart to stop. The ICD sends a shock to restore a normal heart rhythm.
An ICD can give off a low-energy shock that speeds up or slows down an abnormal heart rate, or a high-energy shock to correct a fast or irregular heartbeat. If low-energy shocks do not restore your normal heart rhythm, the device may switch to high-energy shocks for defibrillation.
ICDs are similar to pacemakers, but pacemakers deliver only low-energy electrical shocks. ICDs have a generator connected to wires that detect your heart's beats and deliver a shock when needed. Some ICDs have wires that rest inside one or two chambers of the heart. Others do not have wires going into the heart chambers but instead rest on the heart to monitor its rhythm.
The ICD can also record the heart's electrical activity and heart rhythms. The recordings can help your healthcare provider fine-tune the programming of the device so it works better to correct irregular heartbeats. The device is programmed to respond to the type of arrhythmia you are most likely to have.

WCDs have sensors that attach to the skin. They are connected by wires to a unit that checks your heart's rhythm and delivers shocks when needed. Like an ICD, the WCD can deliver low- and high-energy shocks. The device has a belt attached to a vest that is worn under your clothes. Your provider fits the device to your size. It is programmed to detect a specific heart rhythm.


AED
Assessment Diagrams
On/Off Button
Shock Button
Voice Prompt
Text Prompt and ECG
Adhesive Electrode Pads
Electrode Placement Diagrams
1 Turn On AED
2 Attach Electrode Pads
3 AED Analyzes Cardiac Rhythm
4 Press Shock Button
Cardiac Rhythm Monitored
AED
Shock Transmitted
C. Lynm

MODULE 3

Module - 3

HUMAN ORGAN SYSTEMS AND BIO-DESIGNS - 2 (QUALITATIVE):

Lungs as purification system (architecture, gas exchange mechanisms, spirometry, abnormal lung physiology - COPD, Ventilators, Heart-lung machine). Kidney as a filtration system (architecture, mechanism of filtration, CKD, dialysis systems). Muscular and Skeletal Systems as scaffolds (architecture, mechanisms, bioengineering solutions for muscular dystrophy and osteoporosis).

HUMAN ORGAN SYSTEMS AND BIO ORGANS – I:

LUNGS AS A PURIFICATION SYSTEM:

Introduction:
Every cell in your body needs oxygen to live. The air we breathe contains oxygen and other gases. The respiratory system's main job is to move fresh air into your body while removing waste gases. Once in the lungs, oxygen is moved into the bloodstream and carried through your body. At each cell in your body, oxygen is exchanged for a waste gas called carbon dioxide. Your bloodstream then carries this waste gas back to the lungs where it is removed from the bloodstream and then exhaled. Your lungs and the respiratory system automatically perform this vital process, called gas exchange.
In addition to gas exchange, your respiratory system performs other roles important to breathing. These include:

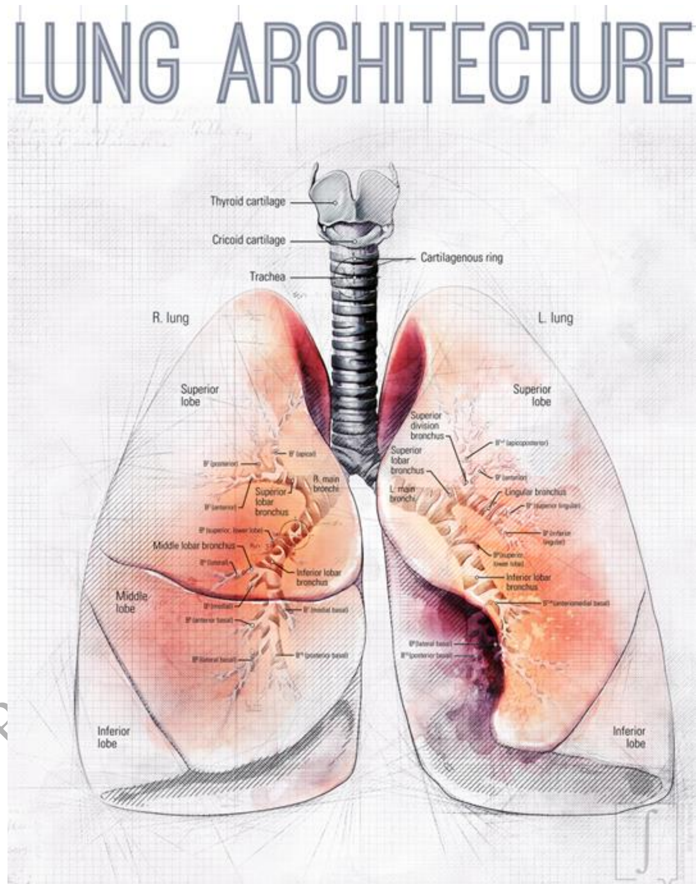
- Bringing air to the proper body temperature and moisturizing it to the right humidity level.
- Protecting your body from harmful substances. This is done by coughing, sneezing, filtering, or swallowing them.
- Supporting your sense of smell.

Lungs help in the purification of blood. Arteries carry pure oxygenated blood from the heart to other parts of the body. Veins carry impure venous blood back from other parts of the body to the right side of the heart. This impure blood goes to the lungs for purification.
When the breath is inhaled, oxygen from the air comes in contact with the impure blood and the blood takes up oxygen. The waste matter in the blood releases carbonic acid and the blood is purified. The purified blood is carried to the heart by the veins.

Architecture:
The lung parenchyma is mainly comprised of numerous air-containing passages and intervening fine structures, corresponding to alveolar ductal lumens and alveoli, as well as alveolar septa and small pulmonary vessels occupying 10% of total parenchymal volume.
The primary function of the lungs is gas exchange. However, the lungs perform several important

non-respiratory functions that are vital for normal physiology.
The lung, with its unique ability to distend and recruit pulmonary vasculature, acts as a reservoir of blood, fine-tuning preload to the left heart to optimize cardiac output.

- The lung acts as a filter against endogenous and exogenous emboli, preventing them from accessing systemic circulation.
- Pulmonary epithelium forms the first line of defense against inhaled particles.
- Pulmonary endothelial cells are responsible for the uptake, metabolism, and biotransformation of several exogenous and endogenous substances.
- Pulmonary metabolic capacity is easily saturated, but pulmonary endothelial binding of some drugs alters their pharmacokinetics.
-

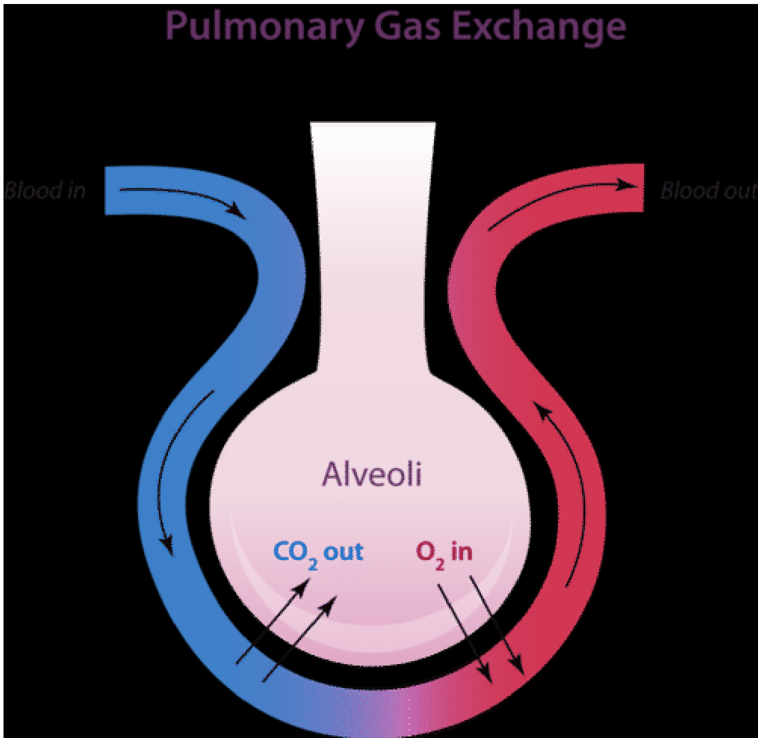


COURTESY: *EDWARD RUDOLF WEIBEL*

GAS EXCHANGE MECHANISMS:

Air enters the body through the mouth or nose and quickly moves to the pharynx or throat. From there, it passes through the larynx, or voice box, and enters the trachea.
The trachea is a strong tube that contains rings of cartilage that prevent it from collapsing. Within the lungs, the trachea branches into a left and right bronchus. These further divide into smaller and

smaller branches called bronchioles. The smallest bronchioles end in tiny air sacs. These are called alveoli.
They inflate when a person inhales and deflate when a person exhales. During gas exchange oxygen moves from the lungs to the bloodstream. At the same time, carbon dioxide passes from the blood to the lungs. This happens in the lungs between the alveoli and a network of tiny blood vessels called capillaries, which are located in the walls of the alveoli.



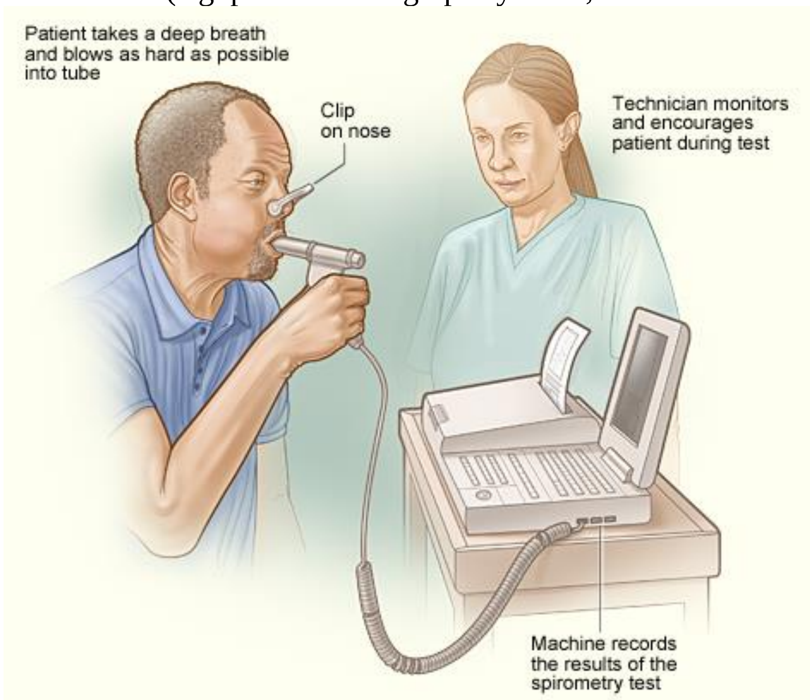
ILLUSTRATED BY *D.M. GOMEZ*

The walls of the alveoli share a membrane with the capillaries. That's how close they are. This lets oxygen and carbon dioxide diffuse, or move freely, between the respiratory system and the bloodstream.
Oxygen molecules attach to red blood cells, which travel back to the heart. At the same time, the carbon dioxide molecules in the alveoli are blown out of the body the next time a person exhales. The gas exchange allows the body to replenish the oxygen and eliminate carbon dioxide. Doing both is necessary for survival.

SPIROMETRY:

Spirometry (spy-ROM-uh-tree) is a common office test used to assess how well your lungs work by measuring how much air you inhale, how much you exhale, and how quickly you exhale. Spirometry is used to diagnose asthma, chronic obstructive pulmonary disease (COPD), and other conditions that affect breathing.
175 years have elapsed since John Hutchinson introduced the world to his version of an apparatus that had been in development for nearly two centuries, the spirometer.

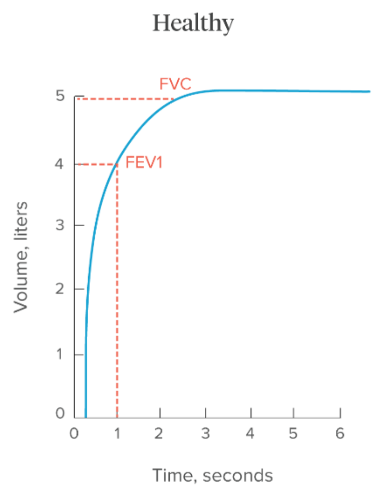
Spirometers can be divided into two basic groups:
• Volume-measurement devices (e.g. wet and dry spirometers).
• Flow-measurement devices (e.g. pneumotachograph systems, mass flow meters).



Requirements of an acceptable spirometer are:
• Spirometers must be able to accumulate volume for ≥15 s.
• The measuring volume should be ≥8 L (body temperature and pressure, saturated).
• The accuracy of reading should be at least ±3% (or ±0.05 L) with flows from 0–14 L per s.
• The total resistance to airflow at 14 L per s should be <1.5 cmH2O per L per s (<0.15 kPa per L per s).

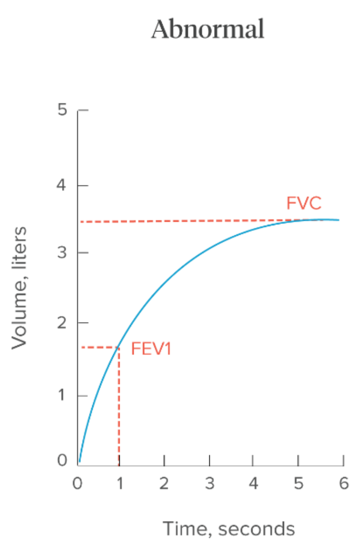
HOW TO CALCULATE THE NORMAL RATE OF RESPIRATION IN A SPIROMETER:

The FEV1/FVC Ratio (FEV1%) parameter is calculated by dividing the measured FEV1 value by the measured FVC value. The Measured column shows the absolute (numerical) ratio, and the Predicted column shows the ratio expressed as a percentage. In healthy adults of the same gender, height, and age, the normal Predicted percentage should be between 70% and 85%.



ABNORMAL LUNG PHYSIOLOGY:

Percentages lower than 70% are considered abnormal. This is an important measurement because obstructive diseases such as COPD, chronic bronchitis, and emphysema cause increased airway resistance to expiratory airflow, and may result in percentages of 45% to 60%. Restrictive diseases such as pulmonary fibrosis tend to reduce both FEV1 and FVC values, so the percentage can remain within the normal range, or even increase.



COPD:

Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory lung disease that causes obstructed airflow from the lungs. Symptoms include breathing difficulty, cough, mucus (sputum) production, and wheezing. It's typically caused by long-term exposure to irritating gases or particulate matter, most often from cigarette smoke. People with COPD are at increased risk of developing heart disease, lung cancer, and a variety of other conditions.
Emphysema and chronic bronchitis are the two most common conditions that contribute to COPD. These two conditions usually occur together and can vary in severity among individuals with COPD.

Symptoms:
COPD symptoms often don't appear until significant lung damage has occurred, and they usually worsen over time, particularly if smoking exposure continues.

Signs and symptoms of COPD may include:

- Shortness of breath, especially during physical activities
- Wheezing
- Chest tightness
- A chronic cough that may produce mucus (sputum) that may be clear, white, yellow, or greenish
- Frequent respiratory infections
- Lack of energy
- Unintended weight loss (in later stages)
- Swelling in ankles, feet, or legs

Tests may include:

- Lung (pulmonary) function tests.
- Chest X-ray.
- CT scan.
- Arterial blood gas analysis.
- Laboratory tests.

Medications:
Several kinds of medications are used to treat the symptoms and complications of COPD. You may take some medications regularly and others as needed.

- Bronchodilators
- Inhaled steroids
- Combination inhalers
- Oral steroids
- Phosphodiesterase-4 inhibitors
- Theophylline
- Antibiotics

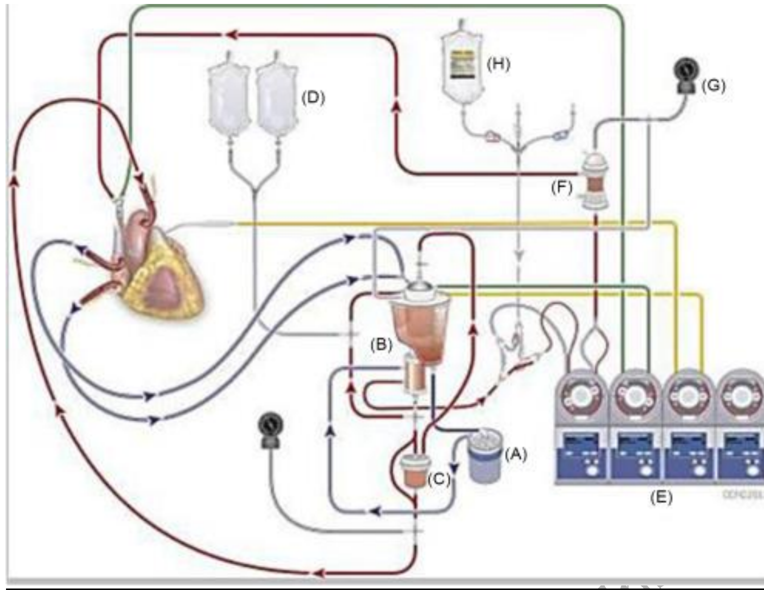
Mechanical ventilation is a lifesaving therapy in patients who have acute respiratory failure due to chronic obstructive pulmonary disease (COPD). Mechanical ventilation either invasive or non-invasive has an important role in the management of acute exacerbation of COPD (AECOPD).

VENTILATOR:

Mechanical ventilators are machines that act as bellows to move air in and out of your lungs. Your respiratory therapist and doctor set the ventilator to control how often it pushes air into your lungs and how much air you get. You may be fitted with a mask to get air from the ventilator into your lungs or you may need a breathing tube if your breathing problem is more serious. When you're ready to be taken off the ventilator, your healthcare team will "wean" you or decrease the ventilator support until you can start breathing on your own.

HEART LUNG MACHINE:

A heart-lung machine is an apparatus that does the work both of the heart (i.e., pumps blood) and the lungs (i.e., oxygenates the blood) during, for example, open-heart surgery The basic function of the machine is to oxygenate the body's venous supply of blood and then to pump it back into the arterial system.
Blood returning to the heart is diverted through the machine before returning to the arterial circulation. Some of the more important components of these machines include pumps, oxygenators, temperature regulators, and filters. The heart-lung machine also provides intracardiac suction, filtration, and temperature control.



Blood drains by gravity or with the use of gentle suction into the oxygenator venous reservoir labeled (B). (A) represents the arterial pump that pumps the blood from the venous reservoir (B) and delivers blood to the membrane oxygenator which is attached to the lower part of the venous reservoir. Once oxygen, carbon dioxide, and heat exchange have occurred the blood is directed thru an arterial blood filter (C). A purge line to the uppermost part of the filter serves for the removal of any microemboli that may have been introduced into the blood during its passage through the circuit. The oxygenated blood is introduced back into the patient's circulatory system through cannulae (a large tube connected to the circuit) placed in the ascending aorta. The line attached to intravenous bags labeled (D) provides a method for priming the CPB circuit with electrolyte fluid or a port for adding blood during bypass. Four roller pumps labeled (E) in the diagram are auxiliary. The one on the far left is used to pump a cardioplegia solution with a mixture of blood and additives, labeled (H), and used to arrest the heart. This solution is cooled with a separate heat exchanger labeled (F).

KIDNEY AS FILTRATION SYSTEM:

Introduction:

Kidneys remove wastes and extra fluid from the body. Kidneys also remove acid that is produced by the cells of the body and maintain a healthy balance of water, salts, and minerals—such as sodium, calcium, phosphorus, and potassium—in the blood. Without this balance, nerves, muscles, and other tissues in the body may not work normally.

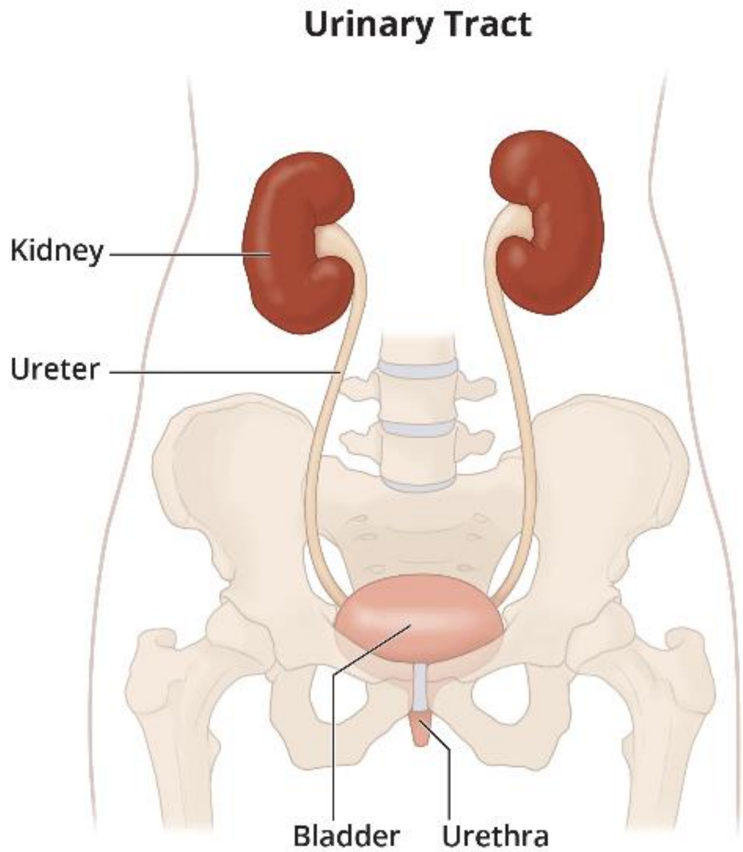
Kidneys also make hormones that help

- Control blood pressure.
- Make red blood cells NIH external link.

•Keeps bones strong and healthy.

Architecture:

The kidneys are two bean-shaped organs, each about the size of a fist. They are located just below the rib cage, one on each side of the spine. Healthy kidneys filter about a half cup of blood every minute, removing wastes and extra water to make urine. The urine flows from the kidneys to the bladder through two thin tubes of muscle called ureters, one on each side of the bladder. Your bladder stores urine. Kidneys, ureters, and bladder are part of your urinary tract.

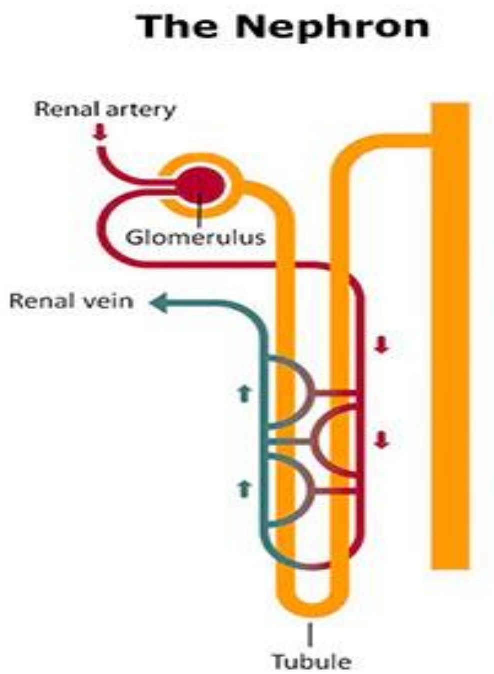


COURTESY: *HANS BACHOFEN*

MECHANISM OF FILTRATION:

Each kidney is made up of about a million filtering units called nephrons. Each nephron includes a filter, called the glomerulus, and a tubule. The nephrons work through a two-step process: the glomerulus filters blood, and the tubule returns needed substances to your blood and removes wastes.

Each nephron has a glomerulus to filter your blood and a tubule that returns needed substances to your blood and pulls out additional wastes. Wastes and extra water become urine.
The glomerulus filters your blood. As blood flows into each nephron, it enters a cluster of tiny blood vessels—the glomerulus. The thin walls of the glomerulus allow smaller molecules, wastes, and fluid—mostly water—to pass into the tubule. Larger molecules, such as proteins and blood cells, stay in the blood vessel. The tubule returns needed substances to your blood and removes wastes.



COURTESY: *SAMUEAL SCHRUCHB*

A blood vessel runs alongside the tubule. As the filtered fluid moves along the tubule, the blood vessel reabsorbs almost all of the water, along with minerals and nutrients your body needs. The tubule helps remove excess acid from the blood. The remaining fluid and wastes in the tubule become urine.

How does blood flow through my kidneys?

Blood flows into the kidney through the renal artery. This large blood vessel branches into smaller and smaller blood vessels until the blood reaches the nephrons. In the nephron, blood is filtered by the tiny blood vessels of the glomeruli and then flows out of the kidney through the renal vein.

Blood circulates through your kidneys many times a day. In a single day, kidneys filter about 150 quarts of blood. Most of the water and other substances that filter through your glomeruli are returned to the blood by the tubules. Only 1 to 2 quarts become urine.

When the kidney doesn't function properly, chronic kidney disease occurs when a disease or condition impairs kidney function, causing kidney damage to worsen over several months or years.

CKD:

Chronic kidney disease includes conditions that damage your kidneys and decrease their ability to keep you healthy by filtering wastes from your blood. If kidney disease worsens, wastes can build to high levels in your blood and make you feel sick. You may develop complications like

- high blood pressure
- anemia (low blood count)
- weak bones

- poor nutritional health
- nerve damage

Symptoms:
People with CKD may not feel ill or notice any symptoms. The only way to find out for sure if you have CKD is through specific blood and urine tests. These tests include the measurement of both the creatinine level in the blood and the protein in the urine.

Treatment:
Depending on the cause, some types of kidney disease can be treated. Often, though, chronic kidney disease has no cure. Treatment usually consists of measures to help control signs and symptoms, reduce complications, and slow the progression of the disease. If your kidneys become severely damaged, you might need treatment for end-stage kidney disease.

DIALYSIS:

Dialysis is a procedure to remove waste products and excess fluid from the blood when the kidneys stop working properly. It often involves diverting blood to a machine to be cleaned.
There are 2 main types of dialysis:

- Haemodialysis involves diverting blood into an external machine, where it's filtered before being returned to the body
- Peritoneal dialysis involves pumping dialysis fluid into the space inside your abdomen (tummy) to draw out waste products from the blood passing through vessels lining the inside of the abdomen

MUSCULAR AND SKELETAL SYSTEM AS SCAFFOLDS:

Skeletal muscle architecture is one of the most important properties that determine a muscle’s force and excursion capability. In the current review, basic architectural terms first are reviewed, and then specific examples relevant to upper extremity anatomy are presented. Specific examples of anatomic considerations required for surgical reconstruction after radial nerve palsy also are detailed. Together, these data show not only the wide variety of architectural designs in human muscles but the importance of considering architectural design when making surgical decisions.
The relationship between structure and function in skeletal muscle has been described and probed for more than a century. A classic study has elucidated the microscopic and ultrastructural properties of skeletal muscle fibers, yielding great insights into their function. However, less attention has been given to excellent and insightful studies of the macroscopic properties of skeletal muscle tissues dating back to the 1600s. This macroscopic arrangement of muscle fibers is known as a muscle’s architecture.

Architecture:
The musculoskeletal system (locomotor system) is a human body system that provides our body with movement, stability, shape, and support. It is subdivided into two broad systems:
Muscular system, which includes all types of muscles in the body. Skeletal muscles, in particular, are the ones that act on the body joints to produce movements. Besides muscles, the muscular

system contains the tendons which attach the muscles to the bones.
Skeletal system, whose main component is the bone. Bones articulate with each other and form the joints, providing our bodies with a hard-core, yet mobile, skeleton. The integrity and function of the bones and joints are supported by the accessory structures of the skeletal system; articular cartilage, ligaments, and bursae.

Besides its main function to provide the body with stability and mobility, the musculoskeletal system has many other functions; the skeletal part plays an important role in other homeostatic functions such as storage of minerals (e.g., calcium) and hematopoiesis, while the muscular system stores most of the body's carbohydrates in the form of glycogen.

Mechanism:
The nervous system (your body's command center) controls your voluntary muscle movements. Voluntary muscles are ones you control intentionally. Some involve large muscle groups to do activities like jumping. Others use smaller movements, like pushing a button.
Movements happen when:
Our nervous system (brain and nerves) sends a message to activate your skeletal (voluntary) muscles. Our muscle fibers contract (tense up) in response to the message. When the muscle activates or bunches up, it pulls on the tendon. Tendons attach muscles to bones. The tendon pulls the bone, making it move. To relax the muscle, your nervous system sends another message. It triggers the muscles to relax or deactivate. The relaxed muscle releases tension, moving the bone to a resting position.
Hundreds of conditions can cause problems with the musculoskeletal system. They can affect the way you move, speak and interact with the world. Some of the most common causes of musculoskeletal pain and movement problems are:

- Aging

- Arthritis
- Back problems
- Cancer
- Congenital abnormalities
- Injuries
- Osteoporosis
- Muscular dystrophy

Everyone has pain in their muscles and joints from time to time. One of the most common musculoskeletal conditions is Osteoporosis. More than 60% of people in the United States have Osteoporosis at some point in their lives. Arthritis is also very common. More than 54 million adults in the U.S. have Muscular dystrophy. Most people recover from these disorders without long-term health problems.

BIO-ENGINEERING SOLUTIONS FOR MUSCULAR DYSTROPHY AND OSTEOPOROSIS :

Awareness is increasing that bone morbidity due to osteoporosis is a major complication of Duchenne muscular dystrophy (DMD) and its treatment and that it requires monitoring for early diagnosis and intervention to prevent clinically important sequelae.
The traditional method of fabricating 3D muscle constructs first developed more than 25 years ago involves casting myogenic cells within a cylindrically shaped collagen-I gel that is anchored at the ends to porous felts. In this system, cell-mediated gel compaction and remodeling result in the generation of uniaxial passive stress within the gel, which, in turn, promotes the fusion of myoblasts into myotubes and also myotube alignment. Alternatively, myoblasts, or mixtures of myogenic precursors and fibroblasts, can be cultured on laminin- or hydrogel-coated dishes until spontaneous contractions of formed myotubes detach the entire cell layer, allowing it to self-assemble into a cylindrical tissue construct attached at the ends to premade suture anchors.

Although cell alignment within 3D constructs is not required for the formation of contractile myotubes, it increases fusion efficiency while passive stress promotes both cell survival and myogenesis. In addition to collagen I, different natural hydrogels and their chemically modified derivatives can support the 3D growth and fusion of myogenic cells; the most functional results have been achieved using fibrin-based gels. Carefully optimizing the composition of the fibrin gel to enhance cell-matrix interactions as well as optimizing the starting cell population to improve myogenic fusion and SC maintenance and providing dynamic culture conditions to improve cell survival and maturation have enabled rodent skeletal muscle tissues to be engineered with contractile properties comparable to those of native muscle (e.g., twitch and tetanus-force amplitudes).

Rapid-prototyping techniques for hydrogel molding can be further used to vary local myofiber alignment and to design complex muscle structures, and advanced biomaterials can deliver angiogenic, myogenic, and pro-survival factors to cells in a spatiotemporally controlled fashion. In addition to using biomaterial scaffolds, scaffold-free muscle tissue constructs have been generated using magnetic fields that allow the controlled assembly of magnetically labeled cells, as well as thermo-responsive polymers that allow controlled cell detachment from culture surfaces.

Although hydrogels have been the dominant muscle-engineering scaffold in vitro, in vivo studies of muscle repair have mainly utilized acellular natural scaffolds, porous matrices made of degradable polymeric materials, or scaffold-free myoblast sheets.

Module 4

Module - 4

NATURE-BIOINSPIRED MATERIALS AND MECHANISMS (QUALITATIVE)

Echolocation (ultrasonography, sonars), Photosynthesis (photovoltaic cells, bionic leaf). Bird flying (GPS and aircrafts), Lotus leaf effect (Super hydrophobic and self-cleaning surfaces), Plant burrs (Velcro), Shark skin (Friction reducing swim suits), Kingfisher beak (Bullet train). Human Blood substitutes - hemoglobin-based oxygen carriers (HBOCs) and Perflourocarbons (PFCs).

ECHOLOCATION:

In nature's sonar system, echolocation occurs when an animal emits a sound wave that bounces off an object, returning an echo that provides information about the object's distance and size. Over a thousand species echolocate, including most bats, all-toothed whales, and small mammals. Human echolocation is the ability of humans to detect objects in their environment by sensing echoes from those objects, and by actively creating sounds: for example, by tapping their canes, lightly stomping their feet, snapping their fingers, or making clicking noises with their mouths. People trained to orient by echolocation can interpret the sound waves reflected by nearby objects, accurately identifying their location and size.

Many blind individuals passively use natural environmental echoes to sense details about their environment; however, others actively produce mouth clicks and can gauge information about their environment using the echoes from those clicks. Both passive and active echolocation help blind individuals sense their environments.

Those who can see their environments often do not readily perceive echoes from nearby objects, due to an echo suppression phenomenon brought on by the precedence effect. However, with training, sighted individuals with normal hearing can learn to avoid obstacles using only sound, showing that echolocation is a general human ability.

Mechanics:

Vision and hearing are akin in that each interprets detections of reflected waves of energy. Vision processes light waves that travel from their source, bounce off surfaces throughout the environment and enter the eyes. Similarly, the auditory system processes sound waves as they travel from their source, bounce off surfaces, and enter the ears. Both neural systems can extract a great deal of information about the environment by interpreting the complex patterns of reflected energy that their sense organs receive. In the case of sound, these waves of reflected energy are referred to as echoes.

ULTRASONOGRAPHY:

Ultrasound:

Ultrasound refers to sound above the human audible limit of 20 kHz. Ultrasound of frequencies up to 10 MHz and beyond is used in medical diagnosis, therapy, and surgery. In investigative

applications, an ultrasound source (transmitter) directs pulses into the body.
When the pulse encounters a boundary between organs or between two tissue regions of different densities, reflections of sound occur. By scanning the body with Ultrasound and detecting echoes generated by various organs, a sonogram of the internal structure(s) can be generated. The method is called diagnostic imaging by echolocation.

SONOGRAPHY OF KIDNEY

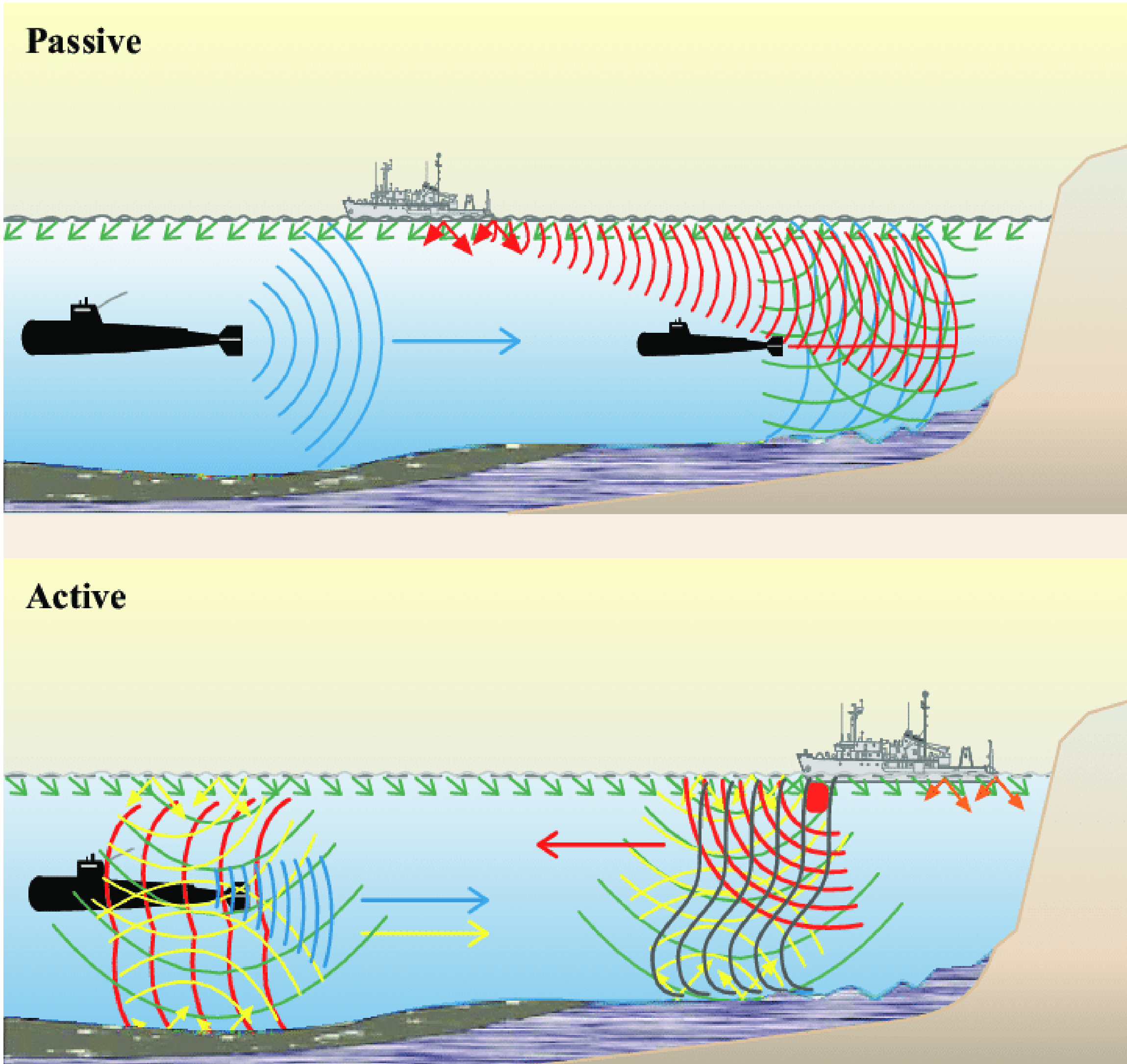
COURTESY: *ALANA BIGGERS*

Diagnostic ultrasound, also called sonography or diagnostic medical sonography, is an imaging method that uses sound waves to produce images of structures within your body. The images can provide valuable information for diagnosing and directing treatment for a variety of diseases and conditions.

SONARS:

Sonar (sound navigation and ranging or sonic navigation and ranging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, measure distances (ranging), communicate with or detect objects on or under the surface of the water, such as other vessels.
"Sonar" can refer to one of two types of technology:

- passive sonar means listening for the sound made by vessels;
- active sonar means emitting pulses of sounds and listening for echoes.

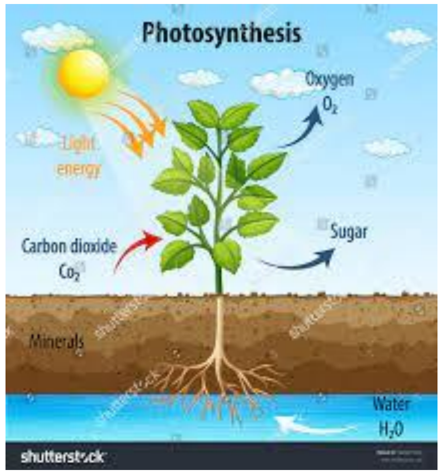


COURTESY: *PHILIPPE ROUX*

Sonar may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water. Acoustic location in the air was used before the introduction of radar. Sonar may also be used for robot navigation, and SODAR (an upward-looking in-air sonar) is used for atmospheric investigations. The term sonar is also used for the equipment used to generate and receive the sound. The acoustic frequencies used in sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). The study of underwater sound is known as underwater acoustics or hydroacoustics.

PHOTOSYNTHESIS:

Most life on Earth depends on photosynthesis. The process is carried out by plants, algae, and some types of bacteria, which capture energy from sunlight to produce oxygen (O2) and chemical energy stored in glucose (a sugar). Herbivores then obtain this energy by eating plants, and carnivores obtain it by eating herbivores.



The Process:
During photosynthesis, plants take in carbon dioxide (CO2) and water (H2O) from the air and soil. Within the plant cell, the water is oxidized, meaning it loses electrons, while the carbon dioxide is reduced, meaning it gains electrons. This transforms the water into oxygen and the carbon dioxide into glucose. The plant then releases the oxygen back into the air, and stores energy within the glucose molecules.

Chlorophyll:
Inside the plant cell are small organelles called chloroplasts, which store the energy of sunlight. Within the thylakoid membranes of the chloroplast is a light-absorbing pigment called chlorophyll, which is responsible for giving the plant its green color. During photosynthesis, chlorophyll absorbs energy from blue- and red-light waves and reflects green-light waves, making the plant appear green.

PHOTOVOLTAIC CELLS:

WHAT IS PHOTOVOLTAIC?
The sun’s copious energy is captured by two engineering systems: photosynthetic plant cells and photovoltaic cells (PV). Photosynthesis converts solar energy into chemical energy, delivering different types of products such as building blocks, biofuels, and biomass; photovoltaics turn it into electricity which can be stored and used to perform work.

Understanding better the way by which natural photosynthetic complexes perform these processes may lead to insight into the design of artificial photosynthetic systems and the development of new technologies for solar energy conversion. A broad variety of bio-inspired concepts and applications are emerging, ranging from light-induced water splitting, Plant Microbial Fuel Cells to hybrid systems. These latter combine photosynthesis and photovoltaics and have great potential in agriphotovoltaic concepts such as the side-by-side arrangement of solar cells and plants, and systems consisting of transparent solar cells which are placed in front or above the plant. One of the applications that can contribute to bringing together the worlds of photosynthesis and photovoltaics is the photovoltaic cell.

solar cell

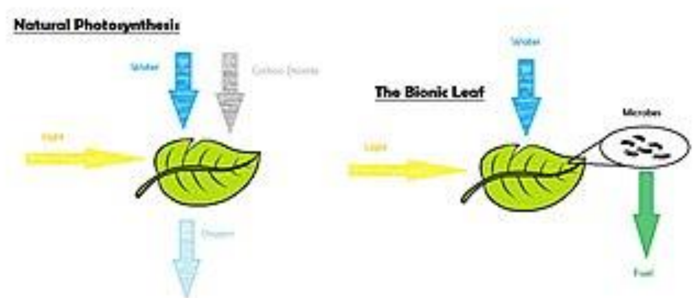
A solar cell, or photovoltaic cell, is an electronic device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices are often the electrical building blocks of photovoltaic modules, known colloquially as solar panels. The common single-junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 volts to 0.6 volts.

Application:

- Remote Locations
- Stand-Alone Power.
- Power in Space.
- Building-Related Needs.
- Military Uses.
- Transportation.

<u>BIONIC LEAF:</u>

The Bionic Leaf is a biomimetic system that gathers solar energy via photovoltaic cells that can be stored or used in several different functions. Bionic leaves can be composed of both synthetic (metals, ceramics, polymers, etc.) and organic materials (bacteria), or solely made of synthetic materials. The Bionic Leaf has the potential to be implemented in communities, such as urbanized areas to provide clean air as well as providing needed clean energy.



COURTESY: *NOCERA, DANIEL G*

Mechanics:

Natural Photosynthesis vs. The Bionic Leaf at its simplest form.

In natural photosynthesis, photosynthetic organisms produce energy-rich organic molecules from water and carbon dioxide by using solar radiation. Therefore, the process of photosynthesis removes carbon dioxide, a greenhouse gas, from the air. Artificial photosynthesis, as performed by the Bionic Leaf, is approximately 10 times more efficient than natural photosynthesis. Using a catalyst, the Bionic Leaf can remove excess carbon dioxide in the air and convert that to use alcohol fuels, like isopropanol and isobutanol.

The efficiency of the Bionic Leaf's artificial photosynthesis is the result of bypassing obstacles in natural photosynthesis through its artificiality. In natural systems, numerous energy conversion bottlenecks limit the overall efficiency of photosynthesis. As a result, most plants do not exceed 1% efficiency and even microalgae grown in bioreactors do not exceed 3%. Existing artificial photosynthetic solar-to-fuels cycles may exceed natural efficiencies but cannot complete the cycle via carbon fixation. When the catalysts of the Bionic Leaf are coupled with the bacterium Ralstonia eutropha, this results in a hybrid system capable of carbon dioxide fixation. This system can store more than half of its input energy as products of carbon dioxide fixation. Overall, the hybrid design allows for artificial photosynthesis with efficiencies rivaling that of natural photosynthesis.

Applications:

- Agriculture
- Atmosphere
- Bionic Facades

<u>BIRD FLYING:</u>

Bird flight is the primary mode of locomotion used by most bird species in which birds take off and fly. Flight assists birds with feeding, breeding, avoiding predators, and migrating.

Bird flight is one of the most complex forms of locomotion in the animal kingdom. Each facet of this type of motion, including hovering, taking off, and landing, involves many complex movements. As different bird species adapted over millions of years through evolution for specific environments, prey, predators, and other needs, they developed specializations in their wings and acquired different forms of flight.

GPS:

GPS is a system. It's made up of three parts: satellites, ground stations, and receivers. Satellites act like stars in constellations—we know where they are supposed to be at any given time. The ground stations use radar to make sure they are actually where we think they are. A receiver, as you might find in your phone or your car, is constantly listening for a signal from these satellites. The receiver figures out how far away they are from some of them.
Once the receiver calculates its distance from four or more satellites, it knows exactly where you are. Presto! From miles up in space your location on the ground can be determined with incredible precision! They can usually determine where you are within a few yards of your actual location. More high-tech receivers, though, can figure out where you are within a few inches!

GPS AND BIRD FLIGHT:

Scientists have long known that birds navigate using the earth's magnetic field. Now, a new study has found subtle mechanics in the brain of pigeons that allow them to find their way.
A team at Baylor College of Medicine in the U.S. identified a group of 53 cells in a pigeon's brain that record detailed information on the Earth's magnetic field, a kind of internal global positioning system (GPS).

Experiment:
Prof. Dickman and his colleague Le-Qing Wu set up an experiment in which pigeons were held in a dark room and used a 3D coil system to cancel out the planet's natural geomagnetic field and generate a tunable, artificial magnetic field inside the room. While they adjusted the elevation angles and magnitude of their artificial magnetic field, they simultaneously recorded the activity of the 53 neurons in the pigeons' brains which had already been identified as candidates for such sensors.
So, they measured the electrical signals from each one as the field was changed and found that every neuron had its characteristic response to the magnetic field, each giving a sort of 3-D compass reading along the familiar north-south directions as well as pointing directly upward or downward. In life, this could help the bird determine not only it's heading just as a compass does, but would also reveal its approximate position, the researchers said.
Each cell also showed a sensitivity to field strength, with the maximum sensitivity corresponding to the strength of the Earth's natural field, they added. And like a compass, the neurons had opposite responses to different field "polarity", the magnetic north and south of a field, which surprised the researchers most of all. Several hypotheses hold that birds' magnetic navigation arises in cells that contain tiny chunks of metal in their noses or beaks, or possibly in an inner ear organ.
However, the most widely held among them was thrown into question when researchers found that purported compass cells in pigeon beaks were a type of white blood cell.

AIRCRAFT:

MECHANISM:

Lift, Drag, and Thrust:

The fundamentals of bird flight are similar to those of aircraft, in which the aerodynamic forces sustain flight lift, drag, and thrust. Lift force is produced by the action of airflow on the wing, which is an airfoil. The airfoil is shaped such that the air provides a net upward force on the wing, while the movement of air is directed downward. The additional net lift may come from airflow around the bird's body in some species, especially during intermittent flight while the wings are folded or semi-folded (cf. lifting body).

Aerodynamic drag is the force opposite to the direction of motion, and hence the source of energy loss in flight. The drag force can be separated into two portions, lift-induced drag, which is the inherent cost of the wing producing lift (this energy ends up primarily in the wingtip vortices), and parasitic drag, including skin friction drag from the friction of air and body surfaces and form drag from the bird's frontal area. The streamlining of the bird's body and wings reduces these forces. Unlike aircraft, which have engines to produce thrust, birds flap their wings with a given flapping amplitude and frequency to generate thrust.

LOTUS LEAF EFFECT:

The lotus leaf is well-known for having a highly water-repellent, or superhydrophobic, surface, thus giving the name to the lotus effect. Water repellency has received much attention in the development of self-cleaning materials, and it has been studied in both natural and artificial systems.

SUPERHYDROPHOBIC AND SELF-CLEANING SURFACES:

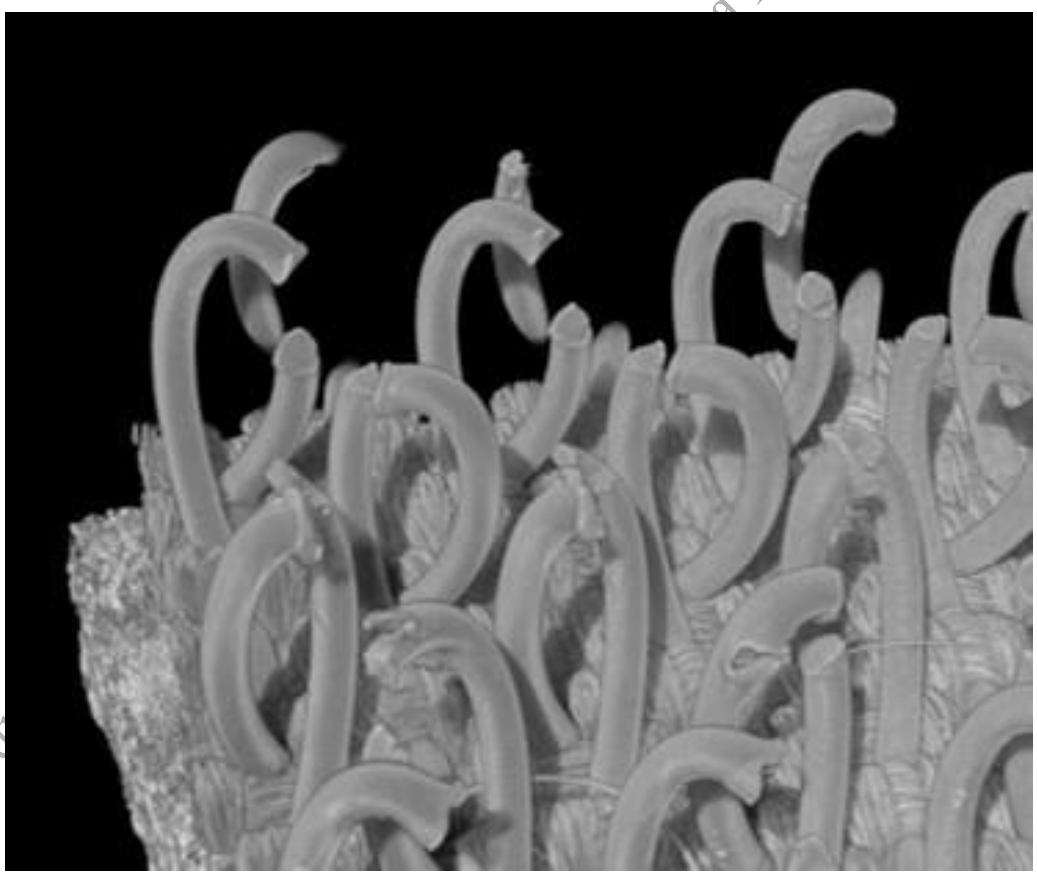
The self-cleaning function of superhydrophobic surfaces is conventionally attributed to the removal of contaminating particles by impacting or rolling water droplets, which implies the action of external forces such as gravity. Here, we demonstrate a unique self-cleaning mechanism whereby the contaminated superhydrophobic surface is exposed to condensing water vapor, and the contaminants are autonomously removed by the self-propelled jumping motion of the resulting liquid condensate, which partially covers or fully encloses the contaminating particles. The jumping motion of the superhydrophobic surface is powered by the surface energy released upon the coalescence of the condensed water phase around the contaminants. The jumping-condensate mechanism is shown to spontaneously clean superhydrophobic cicada wings, where the contaminating particles cannot be removed by gravity, wing vibration, or wind flow. Our findings offer insights into the development of self-cleaning materials.

Mechanism:

An autonomous mechanism to achieve self-cleaning on superhydrophobic surfaces, where the contaminants are removed by self-propelled jumping condensate powered by surface energy. When exposed to condensing water vapor, the contaminating particles are either fully enclosed or partially covered with the resulting liquid condensate. Building upon our previous publications showing self-propelled jumping upon drop coalescence (5, 6), we show particle removal by the merged condensate drop with a size comparable to or larger than that of the contaminating particle(s). Further, we report a distinct jumping mechanism upon particle aggregation, without a condensate drop of comparable size to that of the particles, where a group of particles exposed to water condensate clusters together by capillarity and self-propels away from the superhydrophobic surface.

PLANT BURRS:

A bur (also spelled burr) is a seed or dry fruit or infructescence that has hooks or teeth. The main function of the bur is to spread the seeds of the bur plant, often through epizoochory. The hooks of the bur are used to catch on to for example fur or fabric, so that the bur, which contains seeds, then can be transported along with the thing it attached itself to. Another use for the spines and hooks is physical protection against herbivores. Their ability to stick to animals and fabrics has shaped their reputation as bothersome.
Some other forms of diaspores, such as the stems of certain species of cactus also are covered with thorns and may function as burs. Bur-bearing plants such as Xanthium species are often single-stemmed when growing in dense groups, but branch and spread when growing singly. The number of burs per fruit along with the size and shape can vary largely between different bur plants.



MICROSCOPIC VIEW OF BURR
COURTESY: *ŠUKLJE, TOMAZ*

Relevance to humans:

Burs are best known as sources of irritation, injury to livestock, damage to clothing, punctures to tires, and clogging equipment such as agricultural harvesting machinery. Furthermore, because of their ability to compete with crops over moisture and nutrition, bur plants can be labeled as weeds and therefore also be subject to removal. Methods of controlling the spread of bur plants include the use of herbicides, slashing, and cultivation among others.

Some have however been used for such purposes as fabric fulling, for which the fuller's teasel is a traditional resource. The bur of burdock was the inspiration for the hook and loop fastener, also known as Velcro.

VELCRO:

Mr. de Mestral examined the burr under a microscope and realized the small hooks of the burr and loops of the fur/fabric allowed the burr to adhere exceedingly well. This sparked his idea to mimic the structure as a potential fastener.

Originally VELCRO is envisioned as a fastener for clothing, today, Velcro is used across a wide array of industries and applications; including healthcare, the military, land vehicles, aircraft, and even spacecraft.

SHARK SKIN:

The texture is rough since it has small scales similar to teeth, called Dermal Denticles. Each species has a uniquely shaped denticle. They have a covering of dentine, a central pulp canal containing blood vessels, and a single nerve.

The denticles play an important part in swimming efficiency. The water is channeled by the ‘skin teeth' and flows across the fins and around the body. The teeth also break up the interface between skin and water, reducing the friction between the two entities. The teeth and skin also help protect the shark from injuries and several elements in the water. It's like a suit of armor for sharks.

COURTESY: *CROSS, DANIEL T*

Relevance to humans:

It is typically made with acetate and rayon yarns, as well as with worsted wool and various synthetic blends. The combination of the color of the yarns and the twill weaving pattern in which the colored threads run diagonally to the white yarns results in the finish for which sharkskin fabric is known. It has a smooth but crisp texture and a two-tone lustrous appearance. Lightweight and wrinkle-free, sharkskin is ideal for curtains, tablecloths, and napkins. Sharkskin fabric is popular for both men's and women's worsted suits, light winter jackets, and coats. Sharkskin is commonly used as a liner in diving suits and wetsuits.

SHARK SKIN AND SWIMSUITS:

Scientists have been able to replicate the dermal denticles in swimsuits and also the bottom of ships or boats. When cargo ships can squeeze out even a single percent in efficiency, they burn less bunker oil and don't require cleaning chemicals for their hulls. Besides that, this sharkskin mechanism is also applied to create surfaces in hospitals that resist bacteria growth since the bacteria can't catch hold of the rough surface.

Sharkskin-inspired swimsuits received a lot of media attention during the 2008 Summer Olympics when the spotlight was shining on Michael Phelps. However, they are now banned in most of the major competitions.

KINGFISHER BEAK:

The kingfishers have long, dagger-like bills. The bill is usually longer and more compressed in species that hunt fish, and shorter and broader in species.

Relationship with humans:
Kingfishers are generally shy birds, but despite this, they feature heavily in human culture, generally due to the large head supporting its powerful mouth, their bright plumage, or some species' interesting behavior.
For the Dusun people of Borneo, the Oriental dwarf kingfisher is considered a bad omen, and warriors who see one on the way to battle should return home. Another Bornean tribe considers the banded kingfisher an omen bird, albeit generally a good omen. The sacred kingfisher, along with other Pacific kingfishers, was venerated by the Polynesians, who believed it had control over the seas and waves.

THE BEAK THAT INSPIRED A BULLET TRAIN:

The Strategy:
The secret is in the shape of the kingfisher’s beak. A long and narrow cone, the kingfisher’s beak parts and enters the water without creating a compression wave below the surface or a noisy splash above. The fine point of the conical beak presents little surface area or resistance to the water upon entry, and the evenly and gradually enlarging cross-section of the beak keeps fluid flowing smoothly around it as it penetrates further into the water column. This buys the bird crucial milliseconds to reach the fish before the fish knows to flee. The length of the beak is critical here: the longer it is, the more gradually the angle of the wedge expands. A shorter, fatter, or rounder beak would increase the wedge angle, resulting in a splash, a compression wave, and a fleeing fish.

The Potential:
Eiji Nakatsu, the chief engineer of the company operating Japan’s fastest trains, wondered if the kingfisher’s beak might serve as a model for how to redesign trains not to create such a thunderous noise when leaving tunnels and breaking through the barrier of tunnel air and outside-air. Sure enough, as his team tested different shapes for the front of the new train, the train became quieter and more efficient as the geometry of its nose became more like the shape of a kingfisher’s beak, requiring 15% less energy while traveling even faster than before.

HUMAN BLOOD SUBSTITUTES:

Shortages in blood supplies and concerns about the safety of donated blood have fueled the development of so-called blood substitutes. The two major types of blood substitutes are volume expanders, which include solutions such as saline that are used to replace lost plasma volume, and oxygen therapeutics, which are agents designed to replace oxygen normally carried by the hemoglobin in red blood cells. Of these two types of blood substitutes, the development of oxygen therapeutics has been the most challenging. One of the first groups of agents developed and tested were perfluorocarbons, which effectively transport and deliver oxygen to tissues but cause complex side effects, including flulike reactions, and are not metabolized by the body.

Other oxygen therapeutics include agents called hemoglobin-based oxygen carriers (HBOCs), which are made by genetically or chemically engineering hemoglobin isolated from the red blood cells of humans or bovines. HBOCs do not require refrigeration, are compatible with all blood types, and efficiently distribute oxygen to tissues. A primary concern associated with these agents is their potential to cause severe immune reactions.

Blood from the human umbilical cord has been studied for its potential as a substitute source of red blood cells for transfusion. Red blood cells can be extracted from cord blood via sedimentation as the blood is cooled. Donated cord blood can be screened for infectious organisms and other contaminants. Research concerning its potential use for transfusion is ongoing. Of particular concern for implementation are the establishment of safe, effective, and ethical procedures for cord blood collection as well as the development of criteria that help to ensure safe transfusion and the preservation of cord blood quality.

Hemoglobin-based oxygen carriers (HBOCs) AND Perfluorocarbons (PFC) :

Pharmaceutical companies attempted to develop HBOCs (also called oxygen therapeutics) and PFCs starting in the 1980s and at first, seemed to have some success. However, the results of most human clinical trials have been disappointing. A study published in 2008 in the Journal of the American Medical Association summarized the results of 16 clinical trials on five different blood substitutes administered to 3,500 patients.

Those receiving blood substitutes had a threefold increase in the risk of heart attacks compared with the control group given human donor blood. However, a closer analysis of the results showed that some of the negative statistics were misleading.

The artificial blood products reviewed in this study varied in their benefits and risks, and some blood substitutes had very few serious side effects. The findings suggest that some blood substitutes may be safer and more beneficial than scientists originally thought.

1) HBOCs:

Hemoglobin-based oxygen carriers (HBOCs) are “made of” natural hemoglobins that were originally developed as blood substitutes but have been extended to a variety of hypoxic clinical situations due to their ability to release oxygen. Compared with traditional preservation protocols, the addition of HBOCs to traditional preservation protocols provides more oxygen to organs to meet their energy metabolic needs, prolongs preservation time, reduces ischemia-reperfusion injury to grafts, improves graft quality, and even increases the number of transplantable donors. The focus of the present study was to review the potential applications of HBOCs in solid organ preservation and provide new approaches to understanding the mechanism of promising strategies for organ preservation.

2) PFCs:

PFCs remain in the bloodstream for about 48 hours. Because of their oxygen-dissolving ability, PFCs were the first group of artificial blood products studied by scientists. They are first-generation blood substitutes. Unlike the red-colored HBOCs, PFCs are usually white. However, since they do not mix with blood they must be emulsified before they can be given to patients. PFCs are such good oxygen carriers that researchers are now trying to find out if they can reduce swollen brain tissue in traumatic brain injury. PFC particles may cause flu-like symptoms in some patients when they exhale these compounds.

Module 5

Module – 5

TRENDS IN BIOENGINEERING (QUALITATIVE):

Bioprinting techniques and materials, 3D printing of ear, bone and skin. 3D printed foods. Electrical tongue and electrical nose in food science, DNA origami and Biocomputing, Bioimaging and Artificial Intelligence for disease diagnosis. Self-healing Bioconcrete (based on bacillus spores, calcium lactate nutrients and biomineralization processes) and Bioremediation and Biomining via microbial surface adsorption (removal of heavy metals like Lead, Cadmium, Mercury, Arsenic).

DNA ORIGAMI AND BIOCOMPUTING:

Biological materials are self-assembled with near-atomic precision in living cells, whereas synthetic 3D structures generally lack such precision and controllability. Recently, DNA nanotechnology, especially DNA origami technology, has been useful in the bottom-up fabrication of well-defined nanostructures ranging from tens of nanometers to sub-micrometers. In this Primer, we summarize the methodologies of DNA origami technology, including origami design, synthesis, functionalization and characterization. We highlight applications of origami structures in nanofabrication, nano photonics and nanoelectronics, catalysis, computation, molecular machines, bioimaging, drug delivery and biophysics. We identify challenges for the field, including size limits, stability issues and the scale of production, and discuss their possible solutions. We further provide an outlook on next-generation DNA origami techniques that will allow in vivo synthesis and multiscale manufacturing.

DNA origami is the nanoscale folding of DNA to create arbitrary two- and three-dimensional shapes at the nanoscale. The specificity of the interactions between complementary base pairs makes DNA a useful construction material, through design of its base sequences. DNA is a well-understood material that is suitable for creating scaffolds that hold other molecules in place or to create structures all on its own.

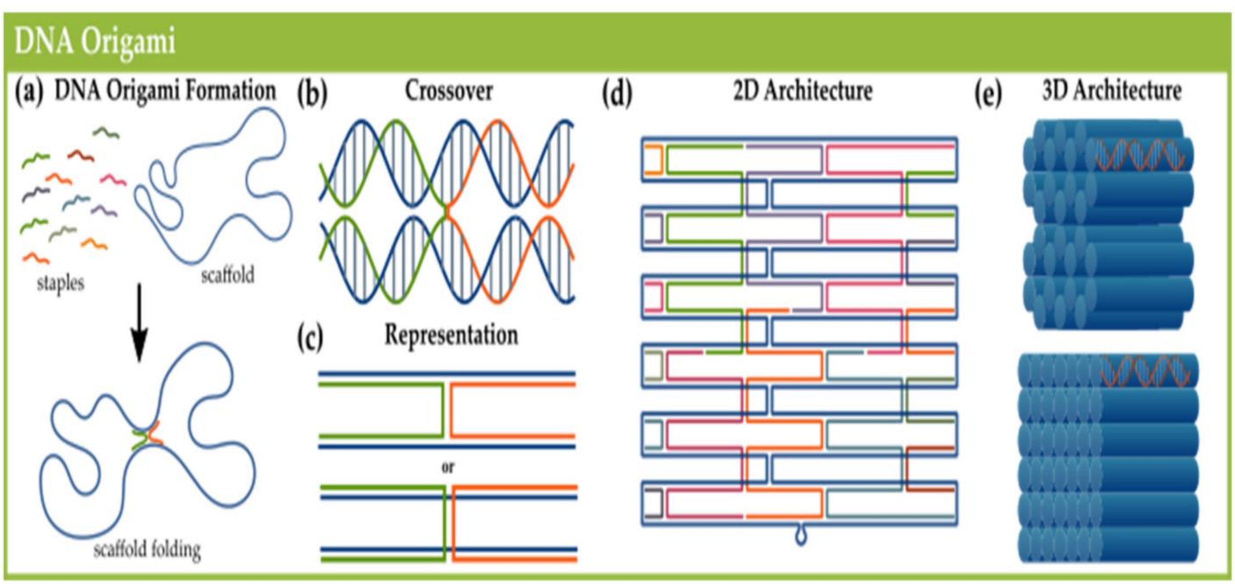
The current method of DNA origami was developed by Paul Rothemund at the California Institute of Technology. The process involves the folding of a long single strand of viral DNA (typically the 7,249 bp genomic DNA of M13 bacteriophage) aided by multiple smaller "staple" strands. These shorter strands bind the longer in various places, resulting in the formation of a pre-defined two- or three-dimensional shape. Examples include a smiley face and a coarse map of China and the Americas, along with many three-dimensional structures such as cubes.

To produce a desired shape, images are drawn with a raster fill of a single long DNA molecule. This design is then fed into a computer program that calculates the placement of individual staple strands. Each staple binds to a specific region of the DNA template, and thus due to Watson-Crick base pairing, the necessary sequences of all staple strands are known and displayed. The DNA is mixed, then heated and cooled. As the DNA cools, the various staples pull the long strand into the desired shape. Designs are directly observable via several methods, including electron microscopy, atomic force microscopy, or fluorescence microscopy when DNA is coupled to fluorescent materials.

Bottom-up self-assembly methods are considered promising alternatives that offer cheap, parallel synthesis of nanostructures under relatively mild conditions.
Since the creation of this method, software was developed to assist the process using CAD software. This allows researchers to use a computer to determine the way to create the correct staples needed to form a certain shape. One such software called caDNAno is an open source software for creating such structures from DNA. The use of software has not only increased the ease of the process but has also drastically reduced the errors made by manual calculations.

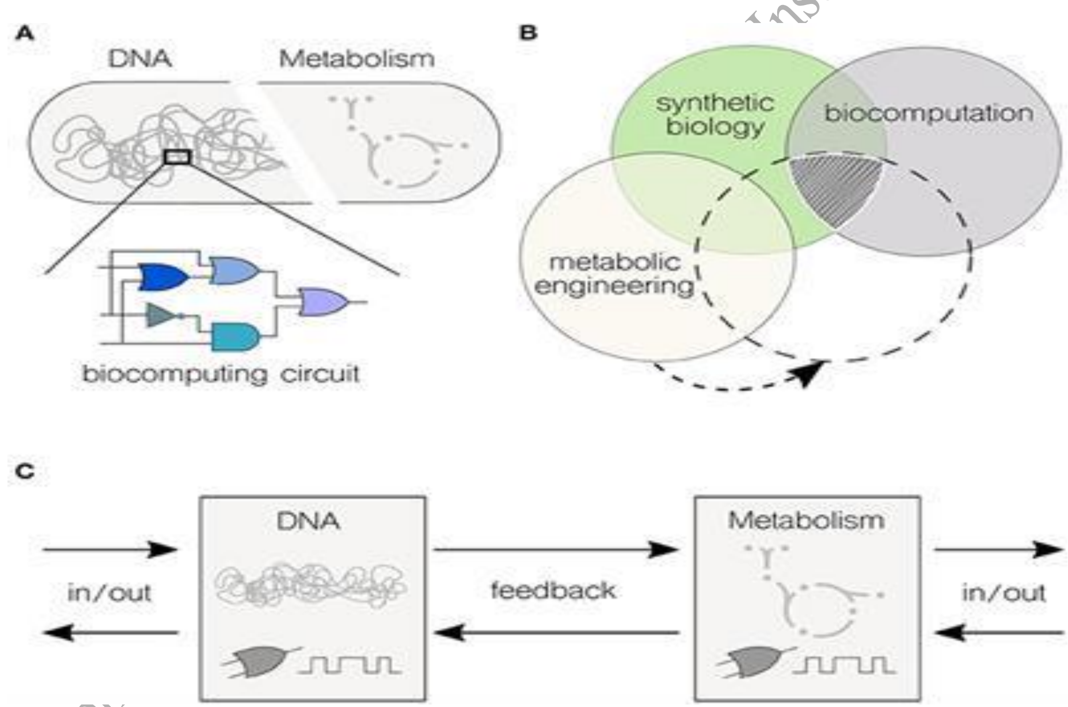
Applications:
Many potential applications have been suggested in literature, including enzyme immobilization, drug delivery systems, and nanotechnological self-assembly of materials. Though DNA is not the natural choice for building active structures for nanorobotic applications, due to its lack of structural and catalytic versatility, several papers have examined the possibility of molecular walkers on origami and switches for algorithmic computing. The following paragraphs list some of the reported applications conducted in the laboratories with clinical potential.

Long strands of DNA are folded into a complex scaffold of staple strands having 200–300 nucleotides. This leads to formation of a complex structure that has characteristic features because of their nanoscale dimensions. These DNA nanostrustures are known to still be in their preliminary developmental stages, since key domains, such as their biocompatibility and physiochemical characterizations are yet to be established. However, theoretically, DNA origami has the immense potential to contribute significantly in a wide range of fields, such as diagnosis and drug delivery. Cancer therapy and diagnosis is one such potential domain where DNA origami showed significant anticancer efficacy and may contribute immensely.

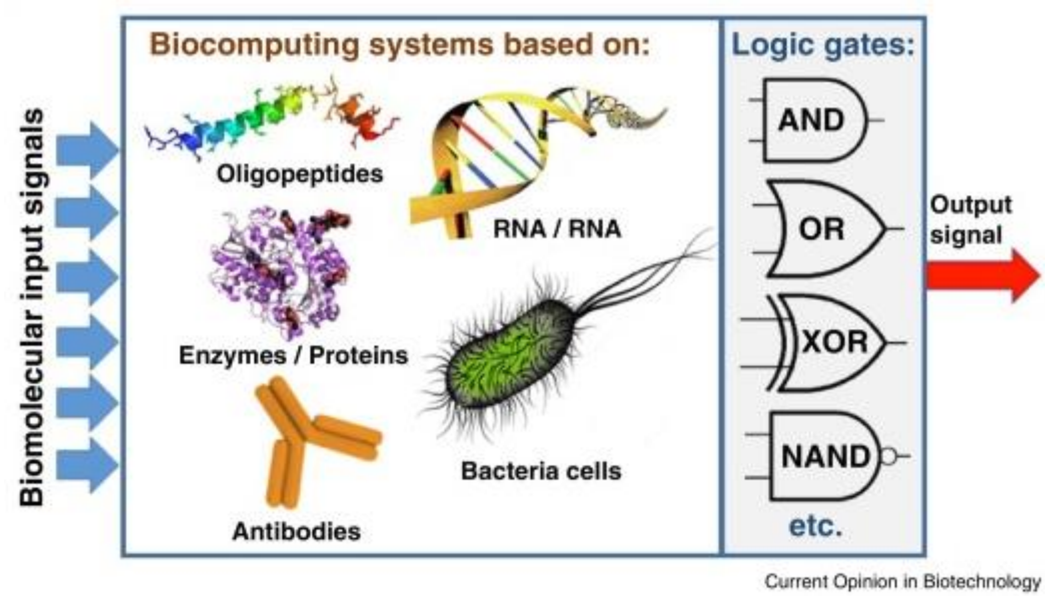


BIOCOMPUTING:

A computer that uses components of biological origin (such as molecules of DNA) instead of electrical components. The device is rudimentary—it can only perform basic high-school-level math problems.
In the quest to understand and model the healthy or sick human body, re searchers and medical doctors are utilizing more and more quantitative tools and techniques. This trend is pushing the envelope of a new field we call Biomedical Computing, as an exciting frontier among signal processing, pattern recognition, optimization, nonlinear dynamics, computer science and biology, chemistry and medicine.



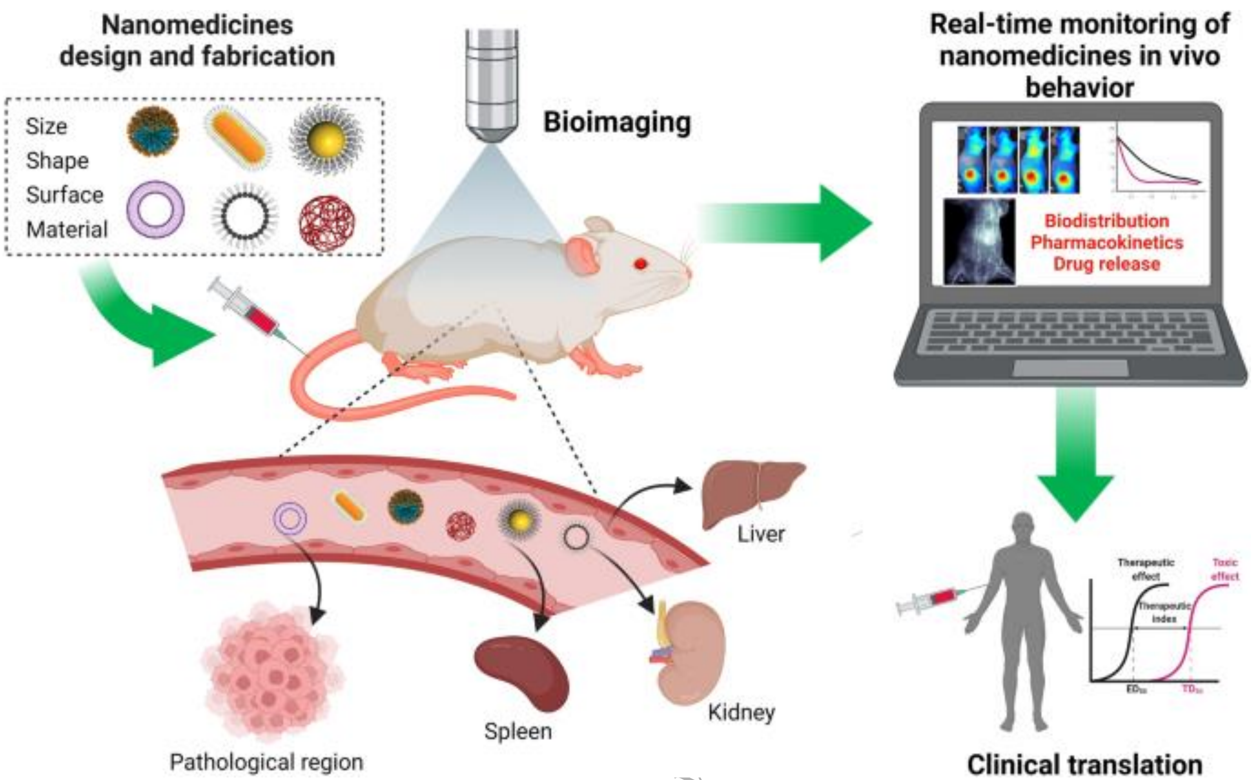
Computing process which use synthesized biological components to store and manipulate data analogous to processes in the human body. The result is small, faster computing processes that operates with great accuracy. Main component used is DNA. The main application is in disease prediction and disease diagnosis.

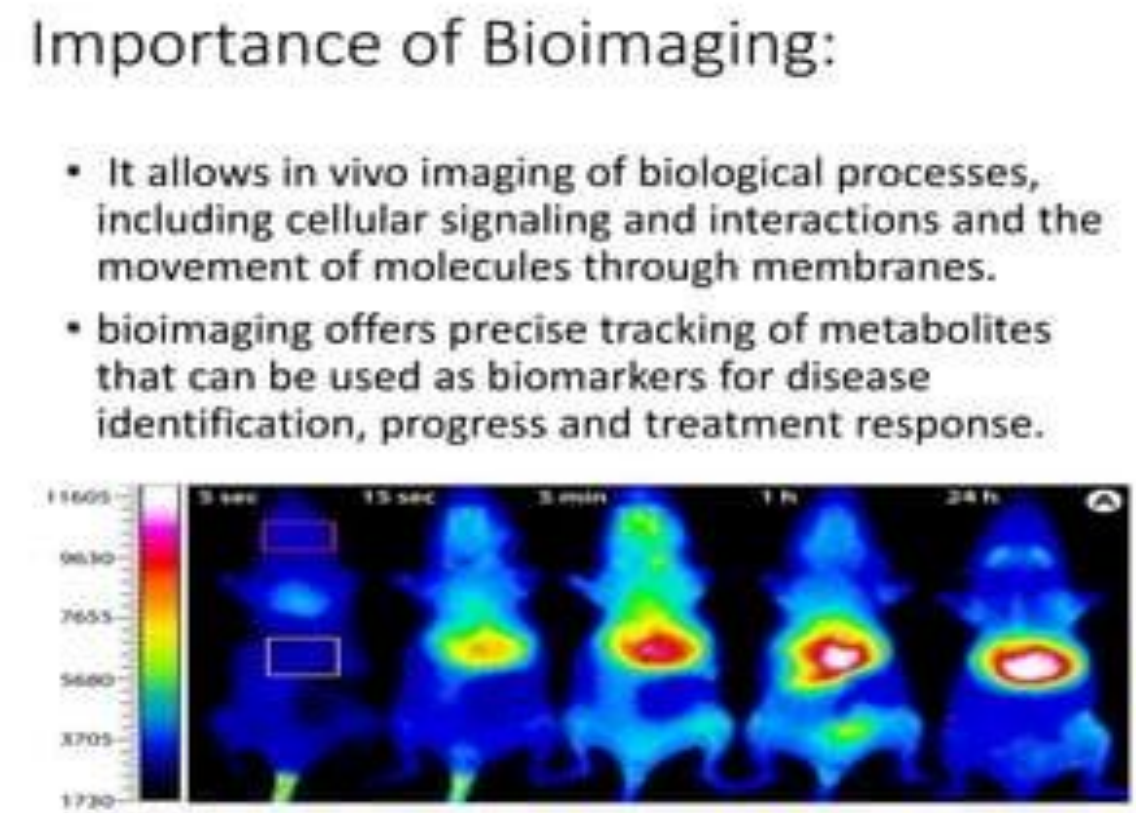


BIOIMAGING AND ARTIFICIAL INTELLIGENCE FOR DISEASE DIAGNOSIS:

1) BIOIMAGING:

Bioimaging is a noninvasive process of visualizing biological activity in a specific period. It does not inhibit the various life processes such as movement, respiration, etc., and it helps to report the 3D structure of specimens apart from inferencing physically. It is helpful in connecting the observation of subcellular structures and all the tissues in the multicellular organisms.
The imaging of biological samples, or bioimaging, plays a key role in current life science research, enabling scientists to analyze molecules, cells and tissues from a range of living systems.
Nanoparticle fluorescence imaging has been used in gene detection, protein analysis, enzyme activity evaluation, element tracing, cell tracking, early stage disease diagnosis, tumor related research, and monitoring real time therapeutic effects.
Bioimaging spans the observation of subcellular structures and entire cells over tissues up to entire multicellular organisms. Among others, it uses light, fluorescence, electrons, ultrasound, X-ray, magnetic resonance and positrons as sources for imaging.


Nanomedicines
design and fabrication
Size
Shape
Surface
Material
Bioimaging
Real-time monitoring of
nanomedicines in vivo
behavior
Biodistribution
Pharmacokinetics
Drug release
Liver
Spleen
Kidney
Pathological region
Therapeutic effect
Toxic effect
Therapeutic index
Clinical translation



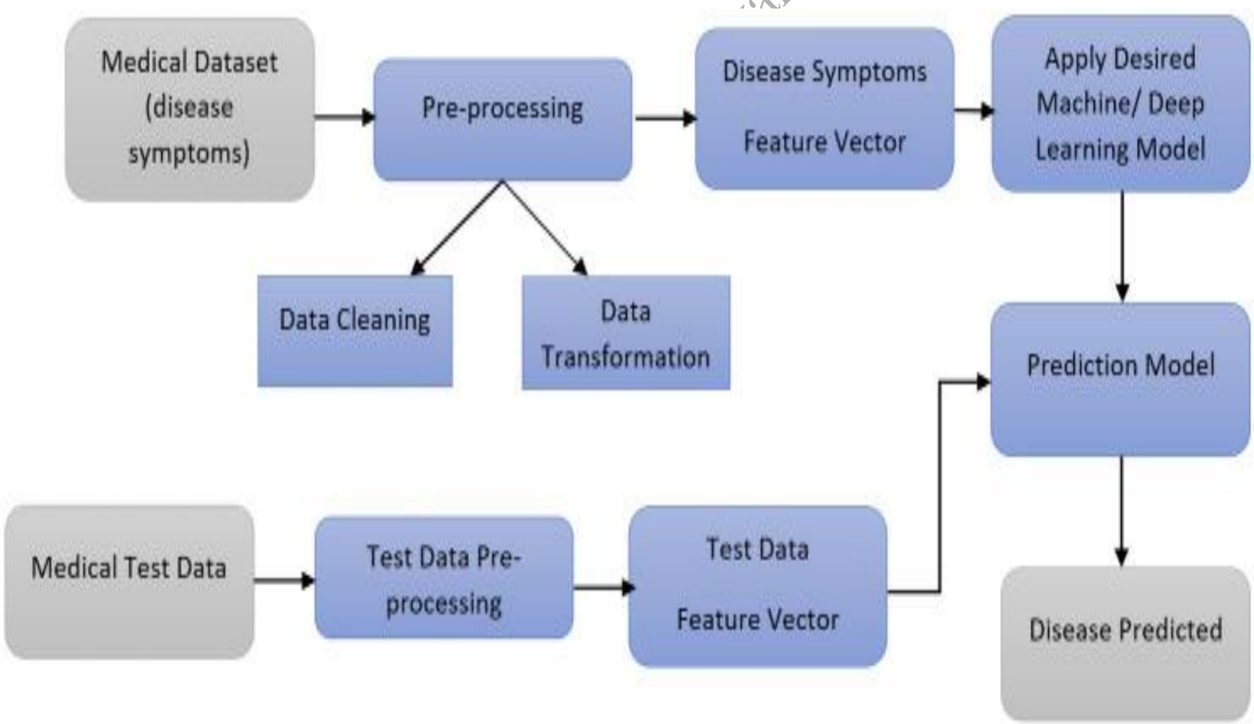
2) ARTIFICIAL INTELLIGENCE IN DISEASE DIAGNOSIS:

Artificial intelligence can assist providers in a variety of patient care and intelligent health systems. Artificial intelligence techniques ranging from machine learning to deep learning are prevalent in healthcare for disease diagnosis, drug discovery, and patient risk identification. Numerous medical data sources are required to perfectly diagnose diseases using artificial intelligence techniques, such as ultrasound, magnetic resonance imaging, mammography, genomics, computed tomography scan, etc. Furthermore, artificial intelligence primarily enhanced the infirmary experience and sped up preparing patients to continue their rehabilitation at home.

Detecting any irresistible ailment is nearly an afterward movement and forestalling its spread requires ongoing data and examination. Hence, acting rapidly with accurate data tosses a significant effect on the lives of individuals around the globe socially and financially (Minaee et al. 2020). The best thing about applying AI in health care is to improve from gathering and processing valuable data to programming surgeon robots.
AI describes the capability of a machine to study the way a human learns, e.g., through image identification and detecting pattern in a problematic situation. AI in health care alters how information gets composed, analysed, and developed for patient care.

System planning is the fundamental abstract design of the system. It includes the framework's views, the course of action of the framework, and how the framework carries on underneath clear conditions. A solid grip of the framework design can help the client realize the limits and boundaries of the said framework. In pre-preparing, real-world information requires upkeep and pre-preparing before being taken care of by the calculation. Because of the justifiable explanation, real-world data regularly contains mistakes regarding the utilized measures yet cannot practice such blunders. Accordingly, information pre-preparing takes this crude information, cycles it, eliminates errors, and spares it an extra examination. Information experiences a progression of steps during pre-handling: Information is purged by various strategies in information cleaning. These strategies involve gathering information, such as filling the information spaces that are left clear or decreasing information, such as the disposal of commas or other obscure characters. In information osmosis, the information is joined from a combination of sources.

The information is then amended for any blend of mistakes, and they are quickly taken care of. Information Alteration: Data in this progression is standardized, which depends upon the given calculation. Information standardization can be executed utilizing several ways. This progression is obligatory in most information mining calculations, as the information wants to be as perfect as possible. Information is then mutual and developed.



SELF HEALING BIOCONCRETE:

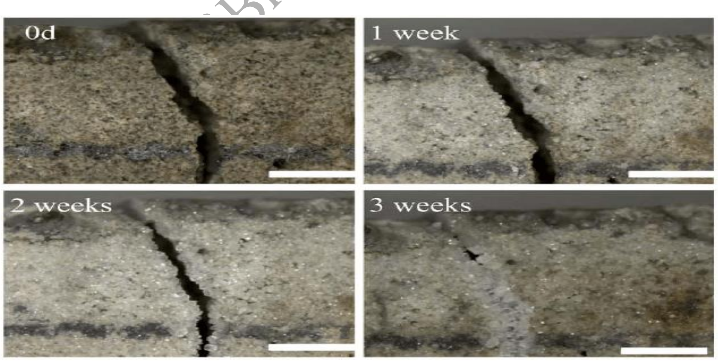
Bio-concrete is a self-healing form of concrete designed to repair its own cracks.
To heal cracks in the concrete, Jonkers chose bacteria (Bacillus pseudo?rmus and B. cohnii), that are able to produce limestone on a biological basis. The positive side-effect of this property: the

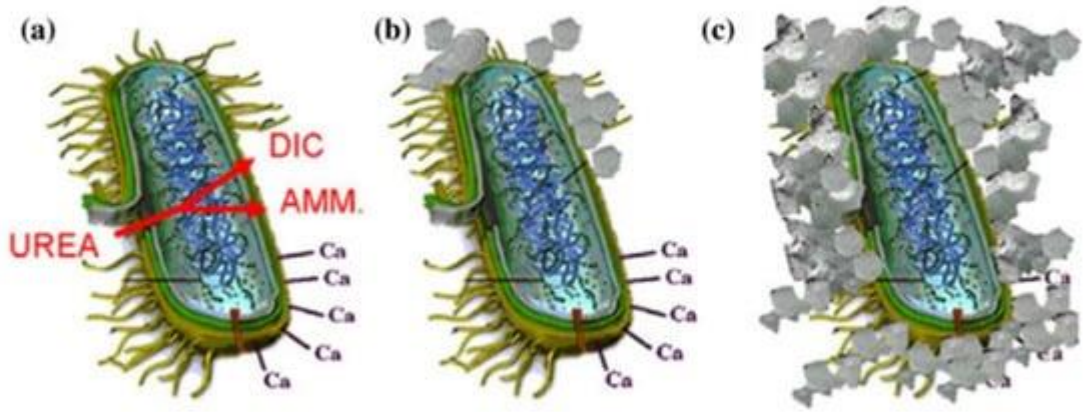
bacteria consume oxygen, which in turn prevents the internal corrosion of reinforced concrete. However, the bacteria do not pose a risk to human health, since they can only survive under the alkaline conditions inside the concrete. Based on these findings, Jonkers and his team of researchers developed three different bacterial concrete mixtures: self-healing concrete, repair mortar, and a liquid repair system.

In self-healing concrete, bacterial content is integrated during construction, while the repair mortar and liquid system only come into play when acute damage has occurred on concrete elements. Self-healing concrete is the most complex of the three variants. Bacterial spores are encapsulated within two-to four-millimeter wide clay pellets and added to the cement mix with separate nitrogen, phosphorous and a nutrient agent. This innovative approach ensures that bacteria can remain dormant in the concrete for up to 200 years. Contact with nutrients occurs only if water penetrates into a crack – and not while mixing cement. This variant is well-suited for structures that are exposed to weathering, as well as points that are difficult to access for repair workers. Thus, the need for expensive and complex manual repairs is eliminated.

Self-healing concrete is nothing but concrete which can retain itself to the original state when it is subjected to cracks." Bio-concrete is a material that will biologically produce minerals like limestone with the help of bacteria present in it, which will heal cracks that appear on the concrete surfaces.Bacterial self-healing is an innovative technology allowing repairing open micro-cracks in concrete by CaCO3 precipitation. This bio-technology improves the durability of the structure. In this paper, peptone, yeast extract and Bacillus Subtilis were added as microbial adjuvant in concrete mix design.
Rahbar predicts self-healing concrete could extend the life of a structure from 20 years, for example, to 80 years. Other research into creating self-healing concrete has focused on adding microbes and Bacillus megaterium, a spore-forming bacteria that produces an enzyme that is expelled into the concrete mix.

The healing agent consisting of B. cohnii spores, calcium lactate and yeast extract immobilized in light-weight aggregates was also combined with cement, fly ash, limestone powder,PVA fibers,water in a repair mortar.





BIOREMEDIATION AND BIO MINING VIA MICROBIAL SURFACE ADSORPTION:

1) BIOREMEDIATION:

Bioremediation is a biotechnical process, which abates or cleans up contamination. It is a type of waste management technique which involves the use of organisms to remove or utilize the pollutants from a polluted area**.**
Types of Bioremediation
Bioremediation is of three types –

1) Biostimulation:
As the name suggests, the bacteria is stimulated to initiate the process. The contaminated soil is first mixed with special nutrients substances including other vital components either in the form of liquid or gas. It stimulates the growth of microbes thus resulting in efficient and quick removal of contaminants by microbes and other bacterias.

2) Bioaugmentation:
At times, there are certain sites where microorganisms are required to extract the contaminants. For example – municipal wastewater. In these special cases, the process of bioaugmentation is used. There's only one major drawback in this process. It almost becomes impossible to control the growth of microorganisms in the process of removing the contaminant.

3) Intrinsic Bioremediation:
The process of intrinsic bioremediation is most effective in the soil and water because of these two biomes which always have a high probability of being full of contaminants and toxins. The process of intrinsic bioremediation is mostly used in underground places like underground petroleum tanks. In such place, it is difficult to detect a leakage and contaminants and toxins can find their way to enter through these leaks and contaminate the petrol. Thus, only microorganisms can remove the toxins and clean the tanks.

Bioremediation helps clean up water sources, create healthier soil, and improve air quality around the globe. But unlike excavation-based remediation processes, which can be disruptive, bioremediation is less intrusive and can facilitate remediation of environmental impacts without damaging delicate ecosystems.

Immobilization of microbial cells and enzymes by adsorption takes place through their physical interaction with the surface of water-insoluble carriers. This method, commonly used in bioremediation processes, is quick, simple, eco-friendly and cost-effective.
Microorganisms are utilized in bioremediation because of their ability to degrade environmental pollutants due to their metabolism via biochemical pathways related to the organism's activity and growth.

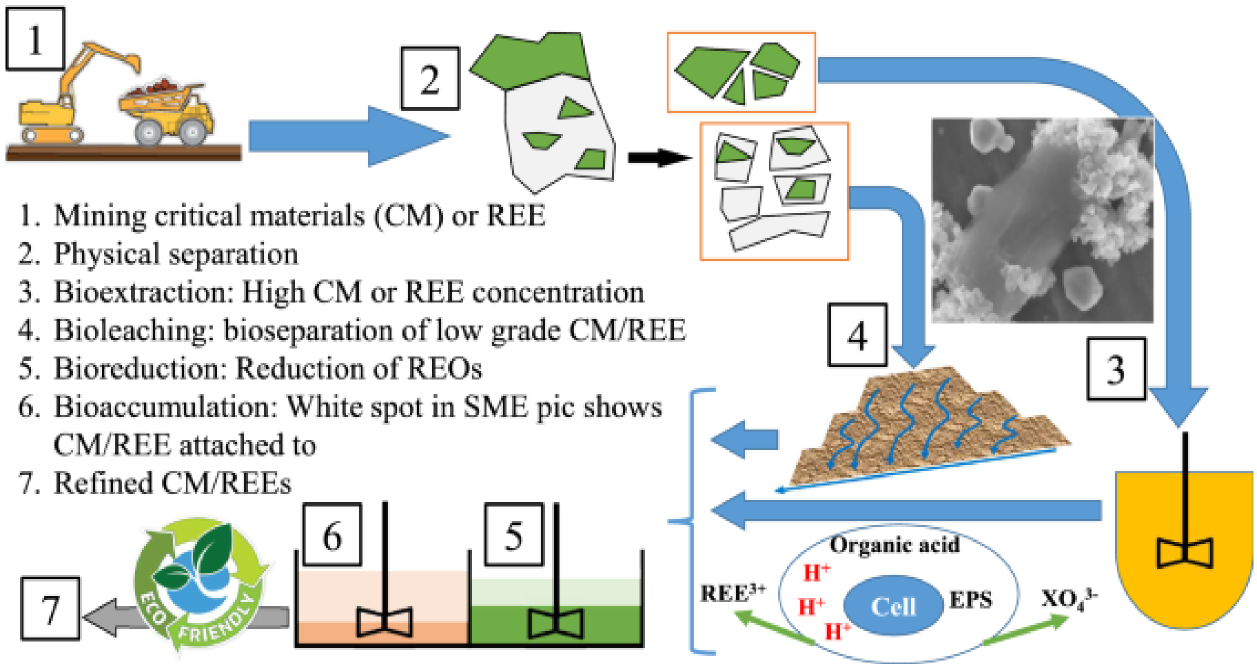
2) BIOMINING:

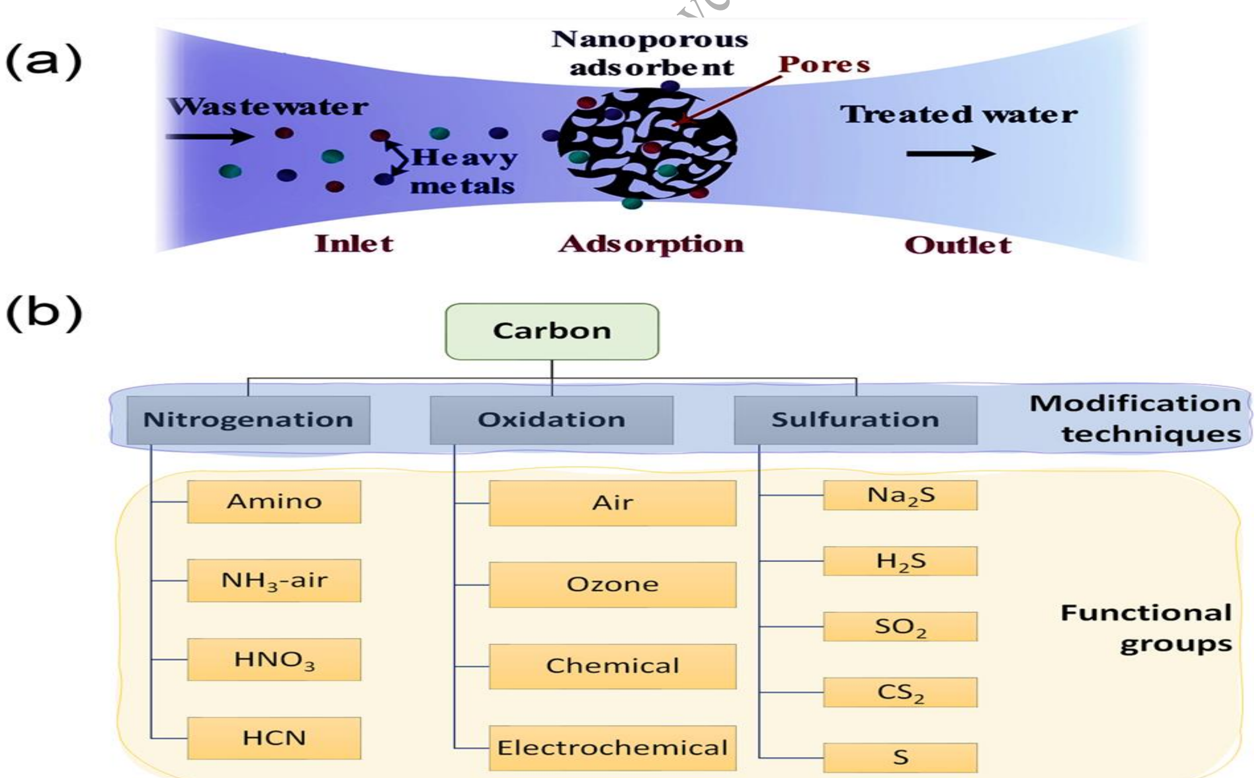
Biomining is the process of using microorganisms (microbes) to extract metals of economic interest from rock ores or mine waste. Biomining techniques may also be used to clean up sites that have been polluted with metals.

Valuable metals are commonly bound up in solid minerals. Some microbes can oxidize those metals, allowing them to dissolve in water. This is the basic process behind most biomining, which is used for metals that can be more easily recovered when dissolved than from the solid rocks. A different biomining technique, for metals which are not dissolved by the microbes, uses microbes to break down the surrounding minerals, making it easier to recover the metal of interest directly from the remaining rock.

Most current biomining operations target valuable metals like copper, uranium, nickel, and gold that are commonly found in sulfidic (sulfur-bearing) minerals. Microbes are especially good at oxidizing sulfidic minerals, converting metals like iron and copper into forms that can dissolve more easily. Other metals, like gold, are not directly dissolved by this microbial process, but are made more accessible to traditional mining techniques because the minerals surrounding these metals are dissolved and removed by microbial processes. When the metal of interest is directly dissolved, the biomining process is called "bioleaching," and when the metal of interest is made more accessible or "enriched" in the material left behind, it is called "biooxidation." Both processes involve microbial reactions that can happen anywhere the microbes, rocks, and necessary nutrients, like oxygen, occur together.

Bioleaching (or biomining) is a process in mining and biohydrometallurgy (natural processes of interactions between microbes and minerals) that extracts valuable metals from a low-grade ore with the help of microorganisms such as bacteria or archaea.
Instead of separating the metal from the pyrite with high temperatures or pressures, biomining uses microbes from the Acidthiobacillus and Leptospirillum genera to do the job.





A) Heavy metal ions adsorption process; the metal ions of wastewater adhere to the surface of nanoporous adsorbents, which has a high surface area due to its porosity. The adsorption process could be selective for one or more metals than others. The regeneration process could be achieved using a desorbing agent.

B) Various modification techniques (i.e., nitrogenation, oxidation, and sulfuration) are used to functionalize carbon with different functional groups. Functionalization enhances adsorption capacity and stability.