MODULE-4

NATURE-BIOINSPIRED MATERIALS AND MECHANISMS (QUALITATIVE):

Syllabus

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 perfluorocarbon's (PFCs).

Introduction

Nature has inspired many innovative materials and mechanisms that are being explored and developed for various applications here are few examples.

Spider silks

Spider silk is a wonder material that, weight for weight, is stronger than steel, tougher than Kevlar and can be more elastic than rubber. It's also flexible and antimicrobial. Scientists have used silk to make bulletproof armor, violin strings, medical bandages, optical fiber cables and even extravagant clothing

Gecko-Inspired adhesives

Geckos are known for their ability to climb walls and ceilings due to their unique adhesive properties. Scientists have been studying the structure and function of gecko feet to develop adhesives that can be develop various applications, such as robotics and aerospace.

Shark skin-inspired surfaces

The skin of sharks has a unique texture that helps reduce drag and increase speed in water. scientists have studied the structure of shark skin to develop surfaces for boats and airplanes that can reduce drag and increase efficiency.

Lotus leaf-inspired surfaces

The surface of a lotus leaf is covered in tiny, water-repellent that help keep the leaf clean. Scientists have studied the lotus leaf structure to develop self-cleaning surfaces for various applications, including textiles and medical devices.

Echolocation (ultrasonography, sonars),

Sonar

S.O.N.A.R, an acronym for "sound navigation and ranging," is a similar system to radar in terms of transmitting and receiving waves through pulses to determine distance and speed. However, it functions through the use of sound waves and is highly effective underwater.

- Sound waves are mechanical waves, which means they are oscillations, or back and forth movements at regular speeds, of matter.
- When a mechanical wave strikes an obstacle or comes to the end of the medium it travels in, some portion of the wave is reflected back into the original medium.
- Water turns out to be a fantastic medium – albeit a slow one – for carrying mechanical waves long distances, making Sonar the top choice for underwater object detection.

Echolocation

Echolocation is a natural sound wave transmission and detection method used by animals to accomplish the same goal of object detection.

- Though sometimes referred to as sonar in casual conversation, echolocation requires no human-made device to function and is used both above and below water. Animals use echolocation by sending out sound waves in the air or water before them.
- They can then determine information about objects in their path through the echoes produced when those sounds are reflected.
- However, echolocation is more generally associated with the use of ultrasound by non-human animals.
- Ultrasound is sound that has a mechanical wave frequency higher than the human ear can detect though they operate the same as audible sound waves.

Ultrasonography

- Ultrasonography uses high-frequency sound (ultrasound) waves to produce images of internal organs and other tissues.
- A device called a transducer converts electrical current into sound waves, which are sent into the body's tissues. Sound waves bounce off structures in the body and are reflected back to the transducer, which converts the waves into electrical signals.
- A computer converts the pattern of electrical signals into an image, which is displayed on a monitor and recorded as a digital computer image.
- No x-rays are used, so there is no radiation exposure during

Ultrasonography (procedure)

- If certain parts of the abdomen are being examined, people may be asked to refrain from eating and drinking for several hours before the test. For examination of female reproductive organs, women may be asked to drink a large amount of fluid to fill their bladder.
- Usually, the examiner places thick gel on the skin over the area to be examined to ensure good sound transmission. A handheld transducer is placed on the skin and moved over the area to be evaluated.
- To evaluate some body parts, the examiner inserts the transducer into the body
- The examiner sometimes attaches the transducer to a viewing tube called an endoscope and passes it into the body. This procedure is called endoscopic ultrasonography. The endoscope can be passed down the throat to view the heart (transesophageal echocardiography) or through the stomach to view the liver and other nearby organs.
- Heart: For example, to detect abnormalities in the way the heart beats, structural abnormalities such as defective heart valves, and abnormal enlargement of the heart's chambers or walls (ultrasonography of the heart is called echocardiography)
- Blood vessels: For example, to detect dilated and narrowed blood vessels
- Gallbladder and biliary tract: For example, to detect gallstones and blockages in the bile ducts
- Liver, spleen, and pancreas: For example, to detect tumors and other disorders

- Urinary tract: For example, to distinguish benign cysts from solid masses (which may be cancer) in the kidneys or to detect blockages such as stones or other structural abnormalities in the kidneys, ureters, or bladder
- Female reproductive organs: For example, to detect tumors and inflammation in the ovaries, fallopian tubes, or uterus
- Pregnancy: For example, to evaluate the growth and development of the fetus and to detect abnormalities of the placenta (such as a misplaced placenta, called placenta previa)
- Ultrasonography can also be used to guide doctors when they remove a sample of tissue for a biopsy. Ultrasonography can show the position of the biopsy instrument, as well as the area to be biopsied (such as a mass). Thus, doctors can see where to insert the instrument and can guide it directly to its target.

Photosynthesis:

Photosynthesis is the process that converts solar energy into chemical energy that is used by biological systems (that means us).

Photosynthesis has 3 major events:

1. Sunlight is converted into chemical energy
2. Water (H_2O) is split into oxygen (O_2)
3. Carbon dioxide (CO_2) is fixed into sugars ($C_6H_{12}O_6$

The photosynthesis reaction:

$$6CO_2 + 12\,H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6\,H_2O + 6\,O_2$$

The Photosynthesis Reaction is divided into two parts:

Light reactions or "light dependent reactions"

capture light energy to power photosynthesis. Light reactions occur during the day time.

They take place in the thylakoids.

Dark reactions or "light independent reactions" do not need light energy to power their reactions and can occur day or night.

Discovered by three scientists, the dark reactions are also called the Calvin-Bensen-Bassham cycle or just Calvin Cycle.

Photovoltaic cells

Photovoltaic cells also known as solar cells, are electronic devices that convert light energy into electrical energy. these cells are made of semiconductor materials such as silicon, and are typically thin, flat, and rectangular in shape. when light usually from the sun, falls on the photovoltaic cell, it excites the electrons in the semiconductor material, causing them to move from the valence band to the conduction band. this movement of electrons creates a flow of electrical current, which can be harnessed as useful electrical energy.

Photovoltaic cells can be used in a variety of applications, ranging from small electronic devices like calculators and watches to large- scale power plants that generate electricity for communities. They are a clean and renewable energy source, which makes them an attractive alternative to traditional fossil fuels.

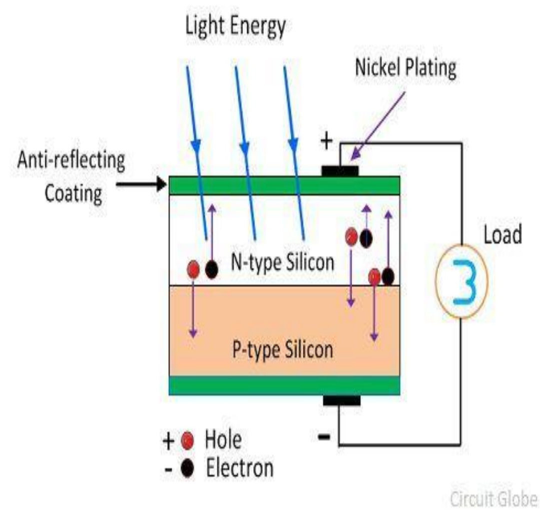
construction

The semiconductor materials like arsenide, indium, silicon, selenium and gallium are used for making the PV cells. Mostly silicon and selenium are used for making the cell.

Consider the figure shows the constructions of the silicon photovoltaic cell. The upper surface of the cell is made of the thin layer of the p-type material so that the light can easily enter into the material. The metal rings are placed around p-type and n-type material which acts as their positive and negative output terminals respectively.

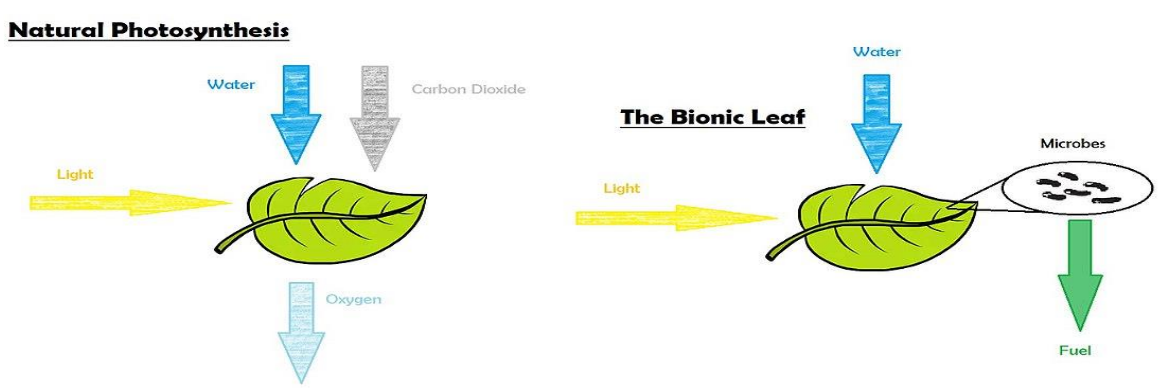
Working Principle of Solar Cell

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, ie. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.



Bionic Leaf:

Carbon dioxide, a greenhouse gas, traps heat in the atmosphere, the bionic leaf can potentially be used to reduce the carbon dioxide within the atmosphere. While the bionic leaf is running mimics photosynthesis by converting the carbon dioxide in air into fuels.



How bionic leaf works

Bacteria: The soil bacterium Ralstonia eutropha is an organism capable of growing mainly from H_2 and (CO_2) carbon dioxide. This is possible to use the hydrogen generated from the artificial leaf to drive the growth of Ralstonia. And from that bacteria's growth, we could get our desired product: a liquid fuel or chemical.

The bionic leaf: this system converts sunlight shining on a solar panel to electricity. Electricity travels to a glass vial containing liquid where both Ralstonia and the water-splitting catalyst are immersed. The electricity drives the catalyst to generate O_2 and H_2, which Ralstonia consumes along with bubbled carbon dioxide to grow. In the lab, we piped in carbon dioxide from a tank; in a commercial situation, we could use carbon dioxide emissions from a polluter, such as a power plant. Just like plants, the bionic leaf converts sunlight into "biomass" or, biological material. Here, we produced the alcohol isopropanol, a compound which can be used for the production of fuels. Where many terrestrial plants convert sunlight to biomass at an efficiency of about 1%, the bionic leaf does so at an efficiency of up to 3.2%.

- The key to this efficiency is the increased light harvest from solar panels to drive water splitting. The solar photovoltaic panels act as a sort of amplifier, increasing the amount of solar energy delivered to the bacteria-growth medium than what a typical plant can harvest.
- Microbes, in contrast, can produce a wide range of high-value
- compounds but require constant "food" to grow - in this case, hydrogen, sunlight and CO2. By combining these technologies, solar energy produces the necessary molecules our Ralstonia require to grow and produce chemicals.

Bird Fly

Birds fly by flapping their wings, steering mainly with their tails. Compared to the parts of an airplane, a bird's wing acts as both wing and propeller. The basal part of the wing supplies most of the supporting surface, the wing tip most of the propelling force.

Birds flying GPS

Birds navigate through their inner GPS. Birds do not use recently developed GPS technology to navigate during flight, but rather rely on a combination of celestial, magnetic and visual cues to navigate and orient themselves.

Birds are able to use the position of the sun and stars, as well as the earth's magnetic field, to determine their position and direction. some species of birds also usual landmarks, such as coastlines or mountain ranges, to orient themselves during migration,

In addition to these cues, birds also have a role in navigation for some species.

For examples, homing pigeons have been shown to use olfactory cues to navigate back to their home loft. The navigation strategies of birds are complex still not fully understood. however ,their ability to navigate over long distances with remarkable precision and accuracy is a testament to the remarkable adaptability and resilience of those fascinating birds.

Birds flying-aircraft

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.

Various theories exist about how bird flight evolved, including flight from falling or gliding (the trees down hypothesis), from running or leaping (the ground up hypothesis), from wing-assisted incline running or from proavis (pouncing) behaviour

Basic mechanics of bird flight

Lift, drag and thrust

The fundamentals of bird flight are similar to those of aircraft, in which the aerodynamic forces sustaining flight are lift, drag, and thrust. Lift force is produced by the action of air flow on the wing, which is an air foil. The air foil is shaped such that the air provides a net upward force on the wing, while the movement of air is directed downward. 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.

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 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 (Super hydrophobic and self-cleaning surfaces)

1.This is one of the best-known means of designing surfaces with nanomaterials.

2.The name "Lotus-Effect" is evocative, conjuring up associations of beads of water droplets, and therefore the effect is often called "Easy- to-clean" surfaces or with photocatalysis, which is also self-cleaning.

3.Self-cleaning surfaces were investigated Common to them all is that they exhibit a microscopically rough water-repellent (hydrophobic) surface, which is covered with tiny knobbles or spikes so that there is little contact surface for water to settle on.

4.Due to this microstructure, surfaces that are already hydrophobic are even less wettable. The effect of the rough surface is strengthened still further by a combination of wax (which is also hydrophobic) on the tips of the knobbles on the Lotus leaves and self-healing mechanisms, which results in a perfect, super-hydrophobic self-cleaning surface.

5.Water forms tiny beads and rolls off the leaf, taking with it any deposited dirt. If leaves should be damaged, they heal on their own.

PLANT BURRS

A bur (also spelled burr) is a seed or dry fruit that has hooks or teeth. The main function of the bur is to spread the seeds of the bur plant. The hooks of the bur are used to handle onto fur or fabric, enabling the bur which contain seeds to be transported to another location for dispersal. Another use for the spines and hooks are physical protection against herbivores. The bur of burdock was the inspiration for hook and loop fastener, also known as Velcro.

One of the most well-known examples of a plant burr is the burdock plant (Arctium spp.), which has round and spiky burrs.

VELCRO

In 1948, de Mestral patented his invention, which he named "Velcro." Name is a combination of 2 French words "velours" (velvet) & "crochet" (hook).The result of his new invention was Velcro® brand fasteners.

It has two components present on the two different surfaces of material.

They are:

a) Hook side consists of tiny hooks made of a sturdy material like nylon polymer

b) Loop side is made of a softer material with small loops that can easily interlock with the hooks on the other side.

APLICATIONS OF VELCRO

Sports equipment: Includes gloves, pads, It can also be found in gym equipment such as straps. weightlifting belts & straps.

Automotive industry: Used to fasten seat covers, headliners & door panels in automobiles.

Medical industry: Used in medical devices such as braces, splints & prosthetics.

Home and office organization: Used to organize cables, cords, tools & can be found in office organizers, computer bags & backpacks.

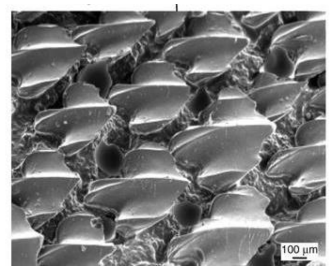
Military and defense: Used in military clothing & equipment, such as tactical vests and pouches, to provide a secure and easy-to-use fastening system.

Aerospace industry: Used in spacecraft and satellites to fasten equipment and hold components in place during launch and in zero-gravity environments.

SHARK SKIN (Friction reducing swim)

Shark skin refers to the dermal denticles that cover the body of sharks. These denticles are small, tooth-like scales that have a unique surface structure that is biomimetic, meaning it has inspired the development of many new technologies. The shark skin is covered in tiny ridges called riblets that reduce drag as the shark swims through water. This means that the shark can move more efficiently through the water, conserving energy and allowing it to swim faster and more quietly.

SHARK SKIN (Friction reducing swim suits)



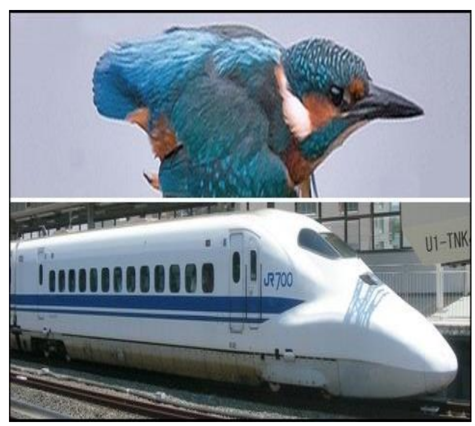
Has a unique structure consisting of "dermal denticles"/scales. These scales are arranged in a way that resembles the pattern of overlapping sands on a roof. Each scale is made up of a hard, tooth-like structure & is covered in ridges that run parallel to the long axis of the scale.

The shape and orientation of the scales help to minimize drag and turbulence as the shark moves through the water. The study of shark skin has led to the development of new materials and coatings, such as riblet coatings for ships.

Shark skin technology application in friction reducing swim suites:

Has been applied in creating friction-reducing swimsuits. The surface of shark skin has tiny, V-shaped scales, known as dermal denticles, which reduce drag and turbulence in the water, allowing sharks to swim more efficiently. Scientists & engineers have replicated this pattern in synthetic materials to create swimsuits that mimic the properties of shark skin. These swimsuits have been shown to reduce drag and improve swim times in competitive swimming.

Kingfisher beak



- The kingfisher is a type of bird known for its remarkable ability to dive in the water to catch fish.
- Its beak is a highly specialized structure, allows it to do so.
- Beak is long & straight, with a sharp, pointed tip.
- Much narrower & flatter than beaks of other birds.
- This streamlined shape helps reduce drag and allows bird to enter the water with minimal disturbance.
- The beak is also equipped with specialized sensors that allow the kingfisher to detect the exact location of the fish in the water.
- These sensors are highly sensitive to changes in water pressure, which the bird uses to calculate the distance to its prey.

Kingfisher beak (Bullet train)

- The Kingfisher beak has been used as a source of inspiration for the development of the bullet train in Japan.
- The beak of the Kingfisher has a unique shape that allows it to dive into water without making a splash.

- The shape of the beak reduces drag and turbulence, which inspired engineers to design the front of the bullet train in a similar way to reduce air resistance and noise.
- This design has helped to increase the speed of the train and reduce noise levels, making it more efficient and comfortable.
- The engineers designed the front part of the train to mimic the beak of a kingfisher bird.
- The modified front of the bullet train is more streamlined, with a long & thin nose, helps reduce the air pressure waves created by the train.

As a result, the noise generated by the train is significantly reduced, providing a quieter and more comfortable.

Human blood substitutes

- Artificial substances used to replace lost blood volume & O_2 carrying capacity.
- Used in situations where the normal blood supply has been compromised.
- Two main types of human blood substitutes: oxygen carriers & plasma expanders.
- Oxygen carriers are designed to carry & deliver oxygen to the body's tissues, much like haemoglobin in red blood cells.
- Plasma expanders are designed to increase blood volume & maintain BP without carrying oxygen.
- Examples of oxygen carriers are perfluorocarbons, which are synthetic molecules which are derived from human or animal hemoglobin.
- Examples of plasma expanders include saline solutions, & hydroxyethyl starch.
- Human blood substitutes have the potential to be life-saving in emergency situations.

Functioning haemoglobin based oxygen carriers (HBOCs):

- HBOCs are designed to work as a substitute for RBCs in carrying O_2 to us throughout the body.
- HBOCs are composed of haemoglobin, the protein found in a RBC that carries O_2, which is extracted and purified from donated human blood.
- The purified haemoglobin is then chemically modified to prevent it from breaking down & causing toxicity in the body.
- Once infused into the bloodstream, the HBOCs dissolve & release haemoglobin, which binds with O_2 in the lungs & transports it to the tissues that need it
- HBOCs have a shorter lifespan & can be manufactured in large quantities, making them potentially useful for treating conditions such as severe anaemia, trauma & haemorrhagic shock.
- HBOCs also have several limitations including the risk of causing side effects such as increased BP, oxidative stress & impaired kidney function.

Perfluorocarbons (PFCs):

- These are a group of synthetic chemicals that are chemically stable, non-toxic, & have the ability to dissolve and transport oxygen.

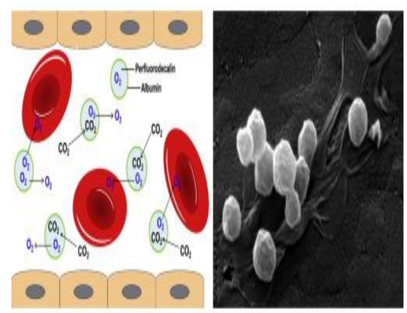
- They are composed of C and F molecules, & are similar in structure to hydrocarbons, which are commonly found in natural gas and petroleum.
- PFCs have a high capacity for carrying oxygen, which makes them useful in medical applications such as blood substitutes and in the treatment of certain respiratory diseases.
- They are also used in other industries such as electronics, aerospace & firefighting.

PFCs are stable & inert, which makes them resistant to chemical & biological degradation, but also means that they can persist in the environment for a long time

Examples of perflurocarbons:

- Fluosol-DA (perfluorodecalin), Perforan (perfluoro decalin, perfluoro methyl-cyclohexyl piperidine), Oxygent (perfluorooctyl bromide), Oxyfluor (perfluoro dichloro octane), Oxycyte (tertbutyl perfluoro cyclohexane).

Perfluorocarbons carry oxygen:



- PFCs are synthetic compounds that have been used as an alternative to blood for carrying O_2. PFCs are chemically inert and have the ability to dissolve large amounts of gases like O_2 & CO_2. When PFCs are infused into the bloodstream, they are taken up by RBC & transport O_2 from the lungs to the body tissues.
- Unlike HBOCS, PFCs do not bind to O_2 but instead physically dissolve it.
- This means that PFCs do not cause the same problems with vasoconstriction & O_2 release that can occur with HBOCs.
- However, PFCs have some limitations, such as the need for large amounts of the compound to be effective & the potential for toxic side effects at high doses.