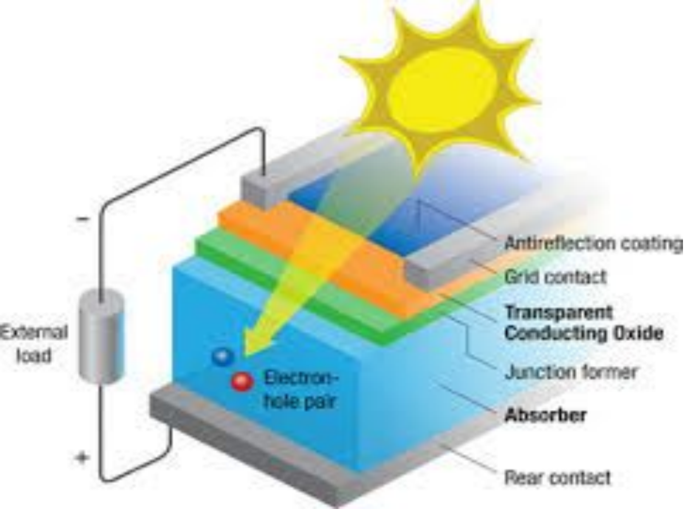
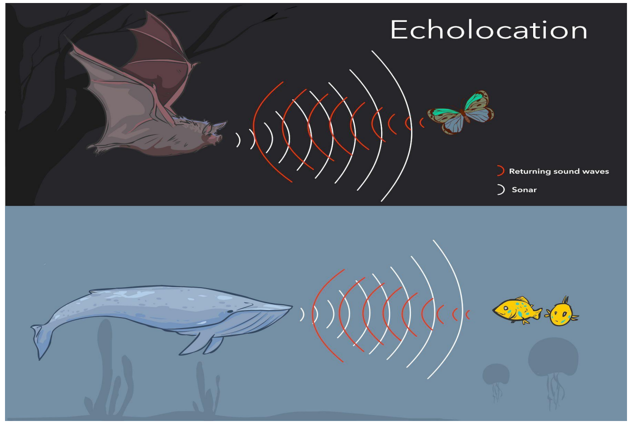


MODULE 4

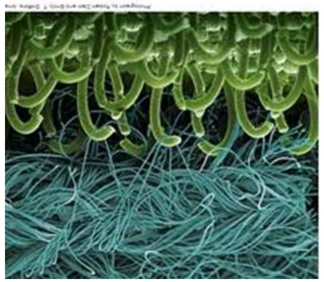


NATURE-BIOINSPIRED MATERIALS AND MECHANISMS :

Echolocation (ultrasonography, sonars), Photosynthesis (photovoltaic cells, bionic leaf), 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).

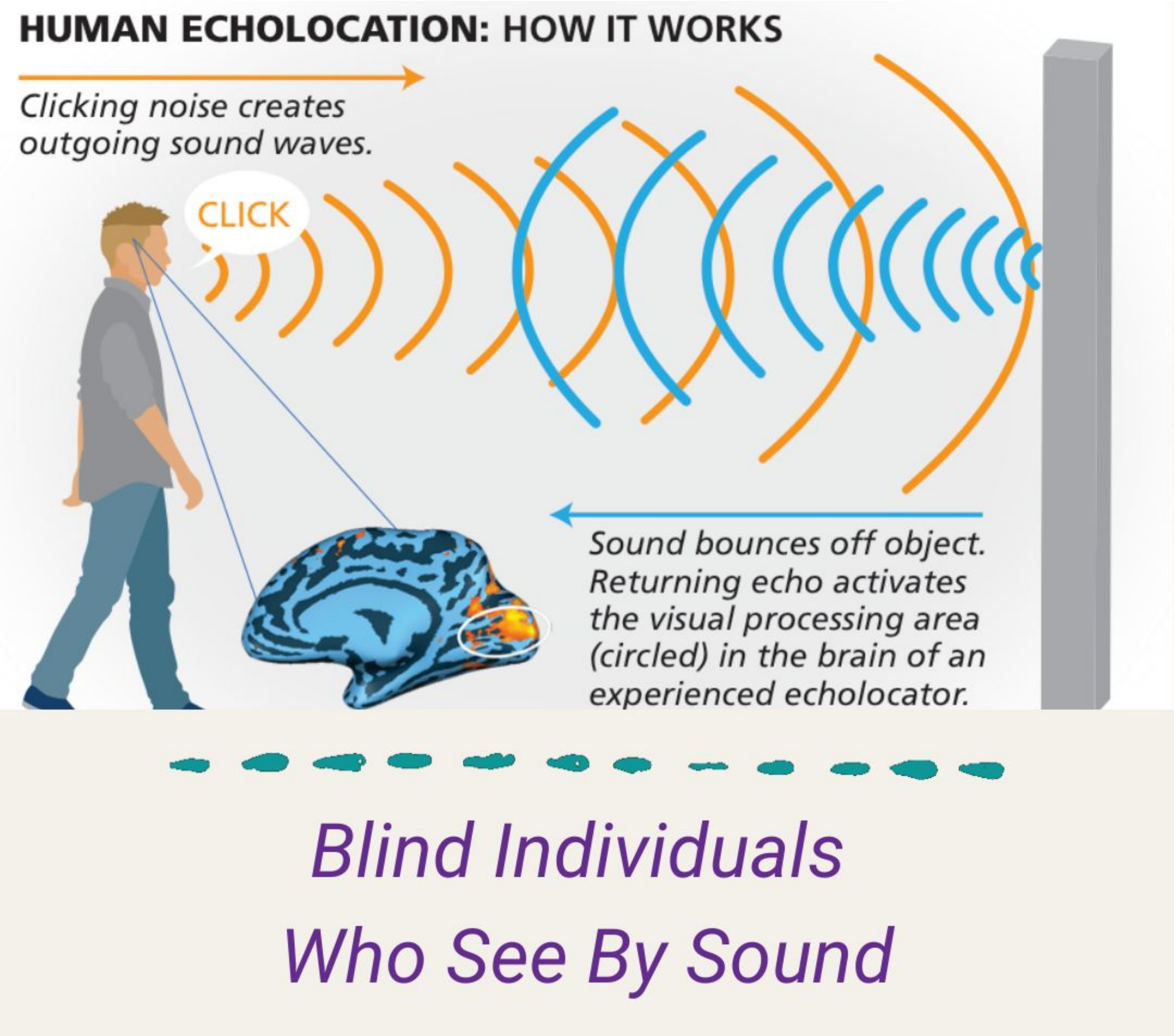
8 Hours

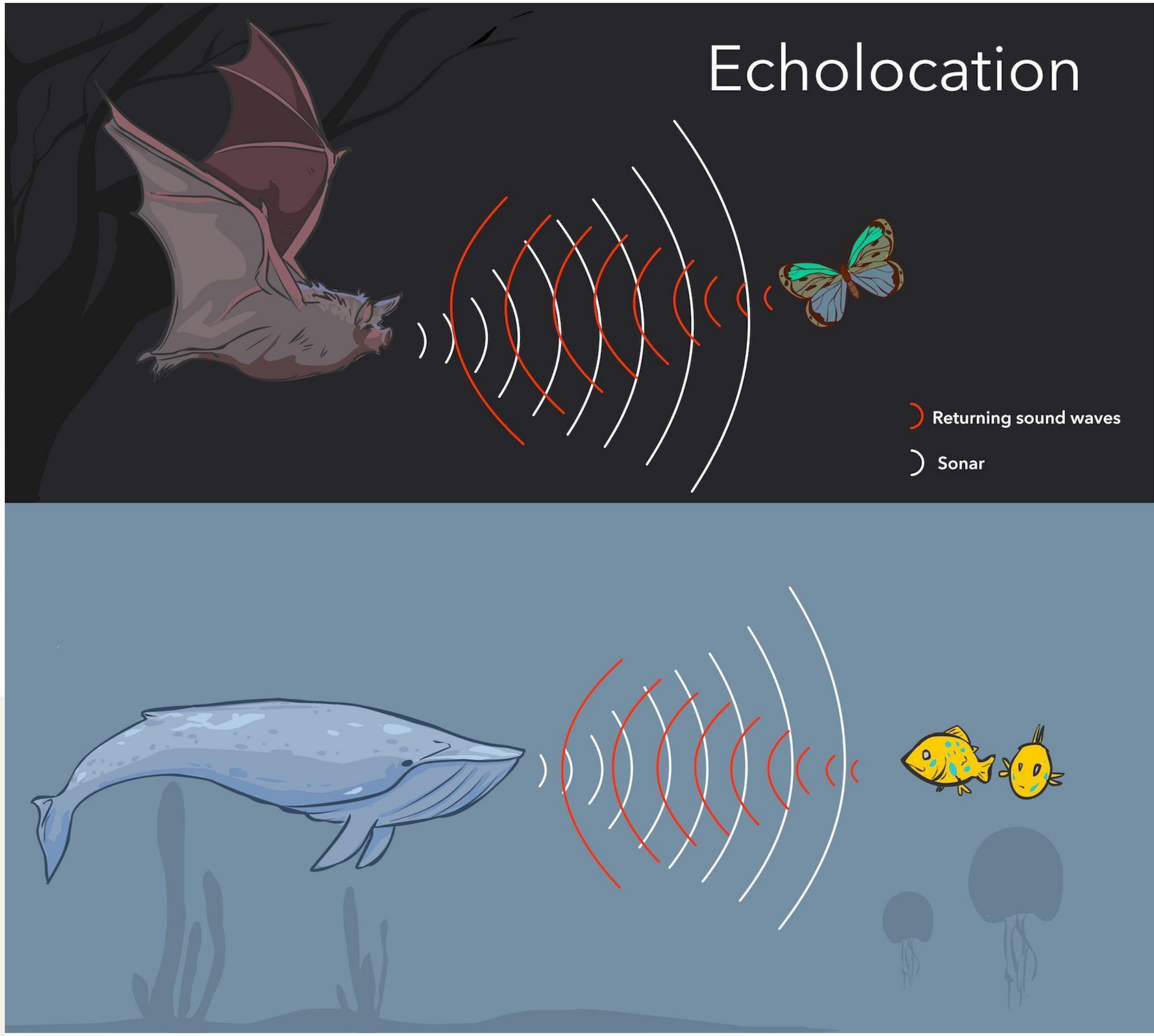
Plant Burrs and Textile



Hook & Loop "Velcro"

ECHOLOCATION:





Comparison of biological echo logical echolocation

ECHOLOCATION: Emitting sound waves and listening to the echoes

Biological Echolocation

- Animals such as bats, dolphins, whales.
- Sound waves, in the form of clicks or vocalizations and listen for the echoes.
- Determine the location, distance, and even the shape of objects around them.
- Navigation, hunting, and communication in the animal kingdom.

Technological Echolocation

- Technological devices.
- Sound waves,generated by artificial sources like sonar or ultrasonic sensors.
- Echoes is processed and interpreted to generate useful data, such as distance, location, and object recognition
- Applications in navigation, robotics, obstacle detection, and medical imaging.

Comparison of sound emission and sensory reception organs/ devices in biological and technological systems

	Biological System	Technological System
Sound Emission	Bats, and cetaceans have specialized sound emission organs to produce sound for echolocation. Bats Emits sound using larynx and modify the emitted sounds using structures like the nose leaf or mouth cavity. Dolphins and whales emit sounds through their blowholes, producing clicks.	Technological System rely on Artificial sound emission devices such as speakers or transducers to generate sound waves for echolocation. Ultrasonic sensors or sonar systems emits sound waves through these devices typically using piezoelectric elements transducers.
Sensory Reception	Biological organism posses specialized sensory reception organs that allow them to detect and interpret the returning echoes. Bats have Highly Sensitive ears designed to detect and analyse ultrasonic frequencies. Dolphins and some whales also receive echoes through their lower jaw. The jawbone conducts sound vibrations to the middle ear where they are converted into nerve impulse for interpretations by the brain.	Technologically System use Sensors and receivers to capture and process the returning echoes. Ultrasonic sensors are commonly employed which consist of a transducer that emits sound waves and receivers the echoes. Sonar system often incorporate hydrophones or other specialized underwater microphones to detect and interpret the echoes.

History of Technological Echolocation

❖ Early Sonar Development (late 19th century): First practical underwater sound detection device called the **hydrophone**.

Developed by **Reginald Fessenden** in the late 19th century, the hydrophone allowed for **the detection of underwater sounds**.

❖ **World War I** (early 20th century): During World War I, the need for detecting submarines led to Sonars.

Active sonar systems were developed, for the transmission of sound waves and the reception of echoes to detect submerged objects

.

❖ **Further Advancements** (mid-20th century): The mid-20th century saw continued advancements in sonar technology, driven by military and Scientific research. Application such **as submarine detection, underwater mapping and marine research**.

❖ **Ultrasonic Application (mid-20th century):** In parallel with underwater sonar ultrasonic technology began to find application in fields such as **medicine no destructive testing, detecting and ranging objects and industrial imaging**.

❖ Evolution of Echolocation Technologies **(late 20th century present:** Advancement in Signal processing, sensors and algorithm allowed for improved resolution, accuracy and interpretation of echoes.

❖ Echolocation technologies found application in various fields including **robotics autonomous vehicles healthcare and environmental monitoring**.

Principle of Echolocation:

Both biological and technological echolocation rely on the same basic principles and underlying purpose: **to determine the location, distance, and shape of objects in the environment using sound waves and their echoes.**

The principle of echolocation is based on the **emission of sound waves and the interpretation of the echoe**s that bounce back from objects in the environment.

- **Sound Emission:** Biological(micro-organism) or technological, emits sound waves into its surroundings.
- In biological echolocation- **vocalizations or clicks**, while in technological echolocation, **through artificial sources such as sonar or ultrasonic sensors.**
- **Propagation of Sound Waves**: The emitted sound waves travel through the environment, spreading out in all directions.
- **Object Interaction**: When the sound waves encounter objects(obstacles or prey) in the environment, they interact with these objects. The interaction can involve **reflection, scattering, or absorption** of the sound waves.
- **Echo Reception**: Some of the sound waves that interact with objects bounce back or echo off them. These echoes carry information about the objects' distance, shape, composition, and other characteristics.
- **Sensory Reception:** In biological echolocation, this is typically **specialized organs or structures**, such as bat ears or dolphin melon, while in technological echolocation, it is achieved through **sensors and receivers.**
- **Echo Interpretation**: The information in echoes is analyzed and interpreted by the organism or technology- making sense of the spatial and temporal patterns present.
- **Perception and Response:** Based on the interpretation of the echoes, the organism or technology can perceive and understand the surrounding environment.

This perception enables the organism to navigate, locate objects, detect obstacles, or perform other relevant tasks

ULTRASONOGRAPH

- Medical imaging technique/ ultrasound imaging or sonography that uses high-frequency sound waves to produce images of the internal organs and tissues of the body.

- Emits high-frequency sound waves (usually in the range of 2 to 20 MHz) that travel through the body and bounce back off of the internal organs and tissue

- **The returning echoes are captured by the ultrasound machine and used to create images of the internal structures.**

- **Transducer:** Emit and receive high-frequency sound wavesThe transducer is placed in direct contact with the skin or inserted into the body through a gel.

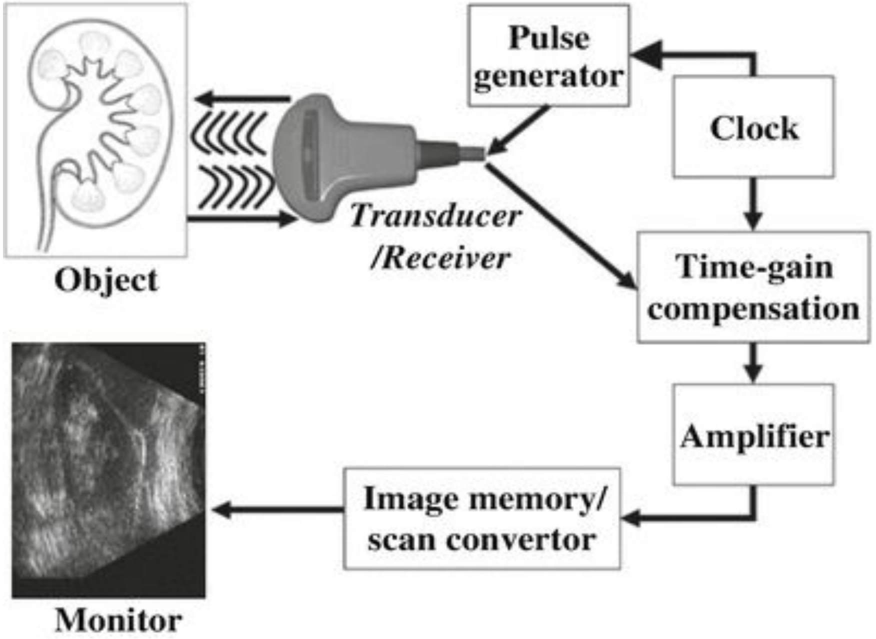
- **Emission of sound waves:** Emits high-frequency sound waves 2 to 18 MHz

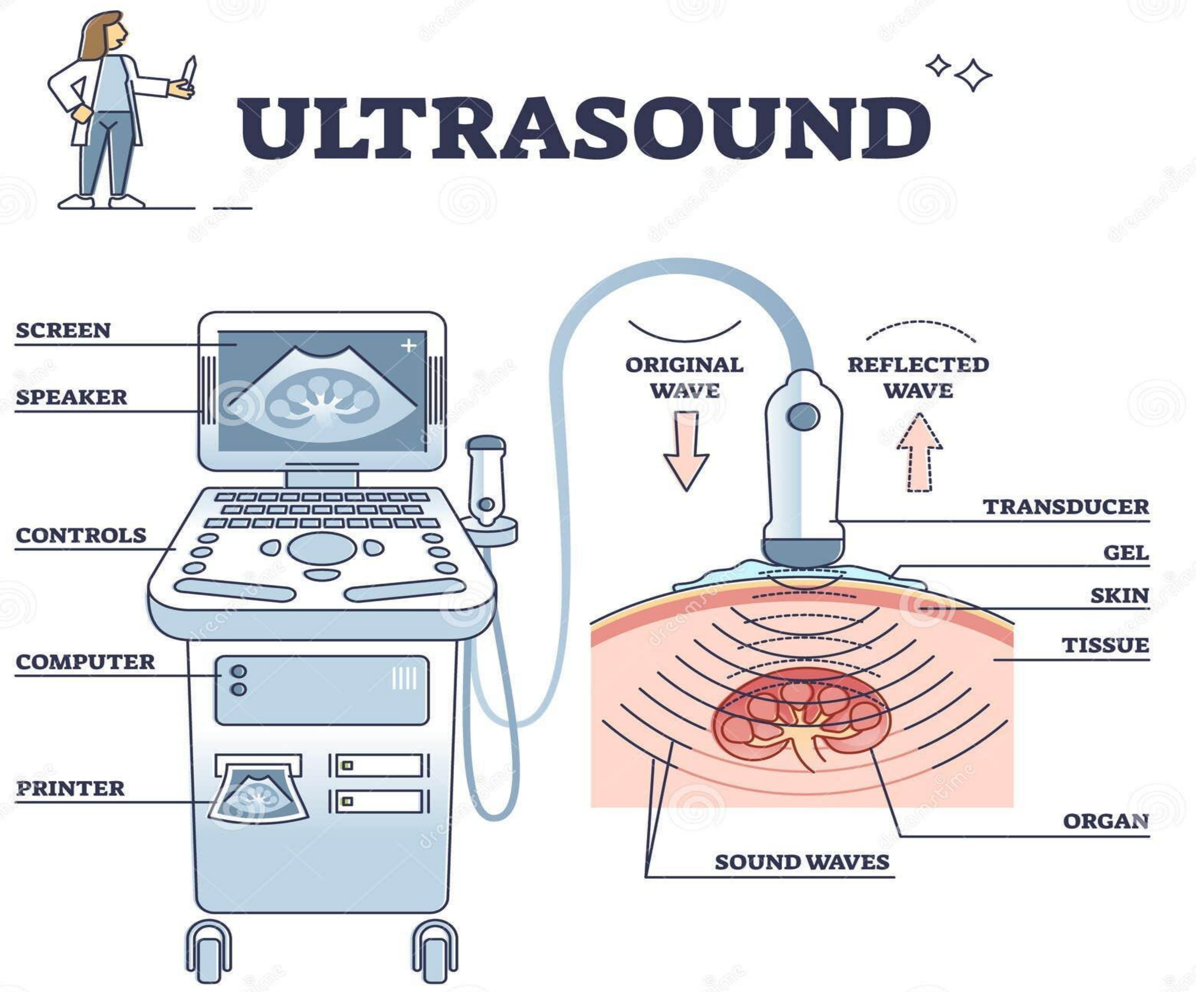
- **Reflection of sound waves:** Encounter boundaries between different tissues and organs and bounce back, creating echoes

- **Reception of echoes:** The transducer receives echoes and sends the information to a computer, which processes the data to create images.

- **Image formation:** The computer uses the information from the echoes to create images of the internal organs and tissues of the body. The images are displayed on a screen, allowing the operator to see the structure and movement of the internal organs and tissues.

Working Principle




ULTRASOUND
SCREEN
SPEAKER
CONTROLS
COMPUTER
PRINTER
ORIGINAL WAVE
REFLECTED WAVE
TRANSDUCER
GEL
SKIN
TISSUE
ORGAN
SOUND WAVES

ULTRASOUND

Advantages of Ultrasonography

- **Non-invasive:** Does not involve any incisions or injections, making it a safe and convenient imaging method.
- **No ionizing radiation:** Ultrasonography does not use ionizing radiation making it a safer option for patients, especially pregnant women and children. option for patients, especially pregnant women and children.
- **Real-time imaging:** Ultrasonography provides real-time images t can be used to monitor the movement and function of internal organs tssues.
- **Portable:** Ultrasonography machines are portable an making it a valuable tool for emergency and n
- **Cost-effective:** Ultrasonography is a cost-e any special preparation or recovery time
- **Versatile:** Ultrasonography can be used to image a wide range of structures within the body, including the organs of the abdomen pelvis, and chest, as well as the uterus, fetus, and other soft tissues.

Limitations of Ultrasonography

Limited depth: Ultrasonography has limited depth and is not as effective at imaging **deep structures** or those obscured by bones or gas.

Operator dependence: The quality of the images produced by ultrasonography depends heavily on the **skills and experience** of the operator.

Limited resolution: Ultrasonography has limited resolution compared to other imaging methods, making it less effective at **visualizing small structures** or detecting small changes in tissue.

Limitations in overweight patients: Ultrasonography may have limited usefulness in overweight patients due to the difficulty in obtaining clear images **through the layers of fat**.

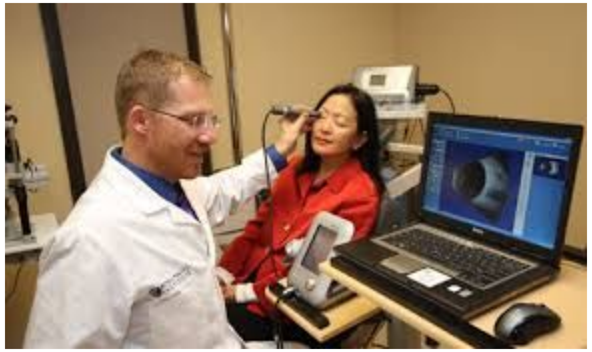
Limitations in detecting some types of cancer: Ultrasonography may not be as effective at detecting certain types of cancer, such as **pancreatic cancer, due to the lack of characteristic signs on ultrasound images.**

Uses of Ultrasonography

Obstetrics & gynecology

Abdominal imaging

Musculoskeletal imaging



Eye and neck imaging

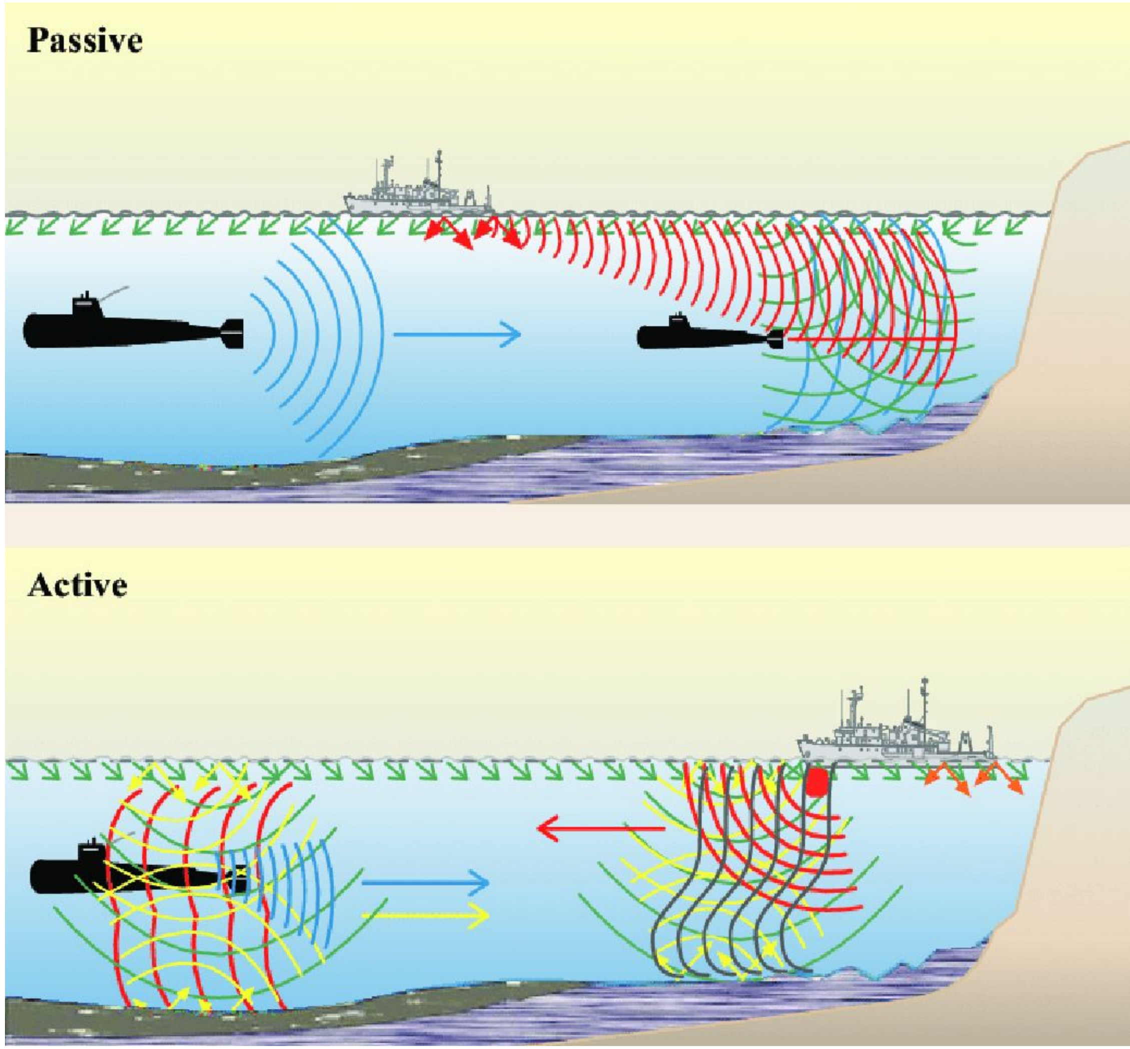
Emergency medicine

SONARS

SONAR-stands Sound Navigation and Ranging

A technology that uses ultrasound waves to determine the direction, distance and speed of an underwater object .

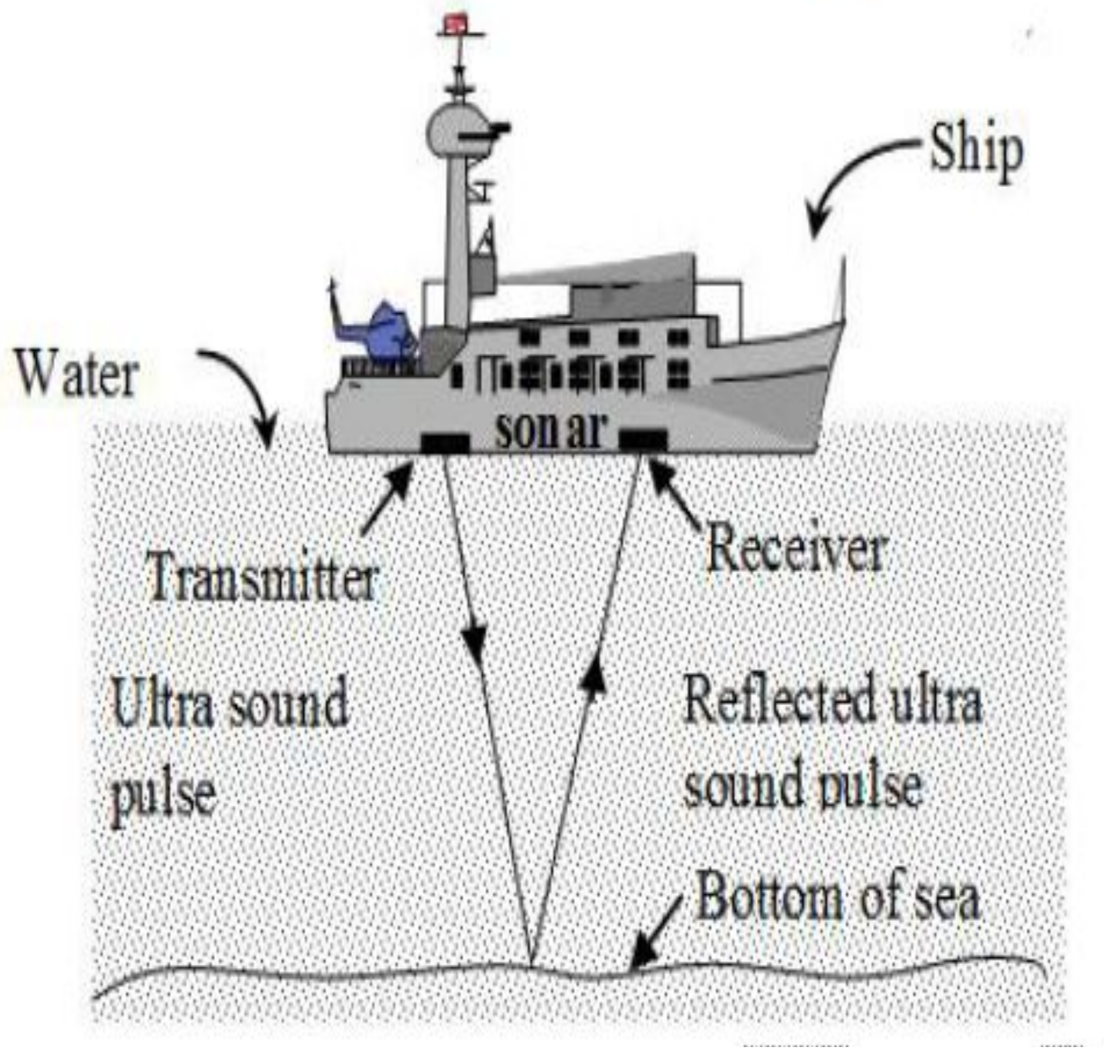
- ❖ Sonar technique uses sound propagation (usually underwater, as in submarine navigation)
- ❖ Used to navigate, measure distances (ranging), communicate with or detect objects on or under the surface of the water, such as other vessels.



"Sonar" can refer to one of two types of technology:

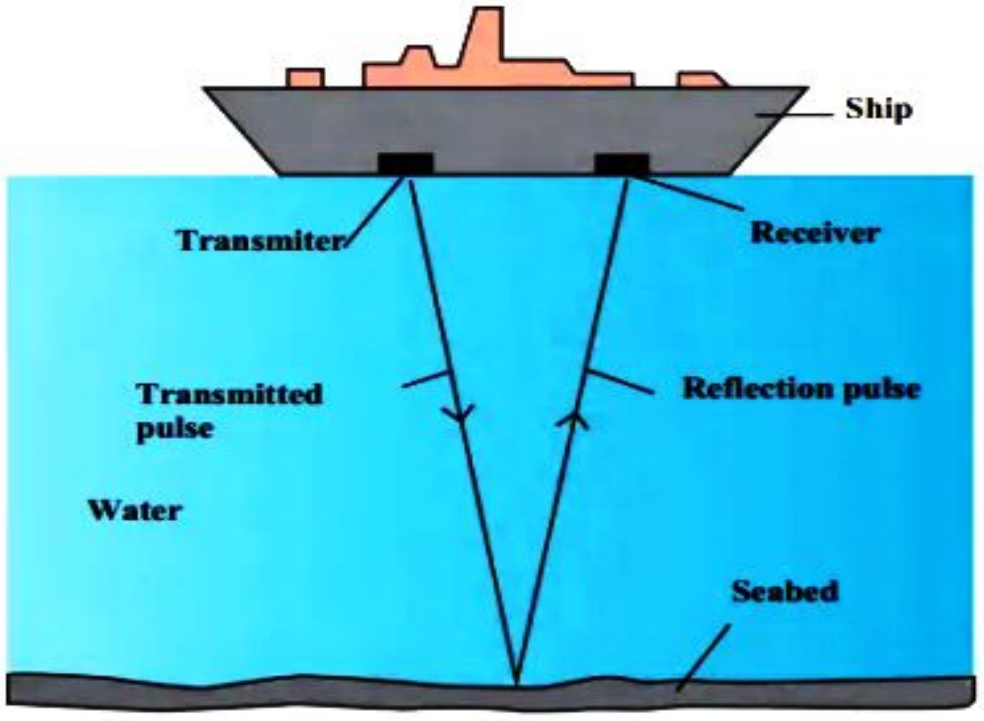
- **Passive sonar means** listening for the sound made by vessels
- **Active sonar** means **emitting pulses of sounds and listening for echoes**.

SONAR



- **Transmitter**
- **Propagation of sound waves**
- **Receiver**
- **Calculation of range**
- **Determination of target properties**
- **Display of results**

- **Transmitter:** Produces and emits a series of sound pulses into the water. These sound pulses are typically in the form of high frequency, low-power acoustic signals, known as "ping."
- **Propagation of sound waves:** The sound pulses propagate through the water, traveling to the target object and bouncing back as echoes. The speed of sound in water is slower than in air, and it depends on the temperature, pressure, and salinity of the water.
- **Receiver:** Listens to the returning echoes. The receiver is typically placed far away from the transmitter to minimize interference from the transmitted signals.
- **Calculation of range:** The time it takes for the echoes to return to the receiver is used to calculate the range to the target object. The range is simply the product of the speed of sound in water **X** the time it takes for the echoes to return.
- **Determination of target properties:** The Frequency and pattern of the echoes are used to determine the properties of the target object, such as it's size, shape, and composition.
- For example, a large, solid object will produce a strong, low-frequency echo, while a small, porous object will produce a weaker, high-frequency echo.
- **Display of Results:** The Results of the sonar measurements are typically displayed on a screen or other output device, allowing the operator to visualize the target object and its location.



The SONAR technique

SONAR has a **transmitter** and a **receiver**, which are fitted on ships or boats.

(i) **The transmitter** produces and transmits **ultrasonic sound waves.**

These waves travel through water, strike underwater objects and get reflected by them. The reflected waves are received by the receiver on the ship

(ii) The **receiver** converts the ultrasonic sound into electrical signals and these signals are properly interpreted.

(iii)The time difference between transmission and reception is noted.

This time and the velocity of sound in water give the distance from the ship, of the object which reflects the waves.

(iv) SONAR is used to determine the depth of the sea.

SONAR is also used to search underwater hills, valleys, submarines, icebergs, sunken ships.

Uses of Sonars:

Naval applications : Detect and locate other ships, submarines, and underwater obstacles, allowing them to navigate safely and avoid potential collisions.

Fishery : Determine the depth of the water, allowing fishermen to more efficiently target their catch.

Oceanography: To study the physical and biological properties of the ocean, including the structure of the ocean floor, the movement of currents, and the distribution of marine life.

Environmental monitoring: Sonars are used to monitor the health of marine ecosystems, track the migration patterns of whales and other marine mammals, and assess the impact of human activities on the ocean environment.

Advantages of Sonar Technology:

Versatility: Sonar technology is versatile and can be used in a variety of applications, such as underwater **navigation, mapping, and imaging** , as well as for military and scientific purposes.

Cost-effective: Compared to other underwater imaging technologies, sonar is relatively cost-effective and affordable.

Non-invasive : Unlike other imaging technologies, such as diving and remote-operated vehicles, sonar does **not physically disturb the underwater** environment, making it an ideal choice for environmental monitoring and scientific research.

Real-time imaging: Sonar provides real-time imaging, allowing operators to quickly and easily assess the underwater environment.

High resolution : Modern sonar systems have high-resolution capabilities, allowing for detailed

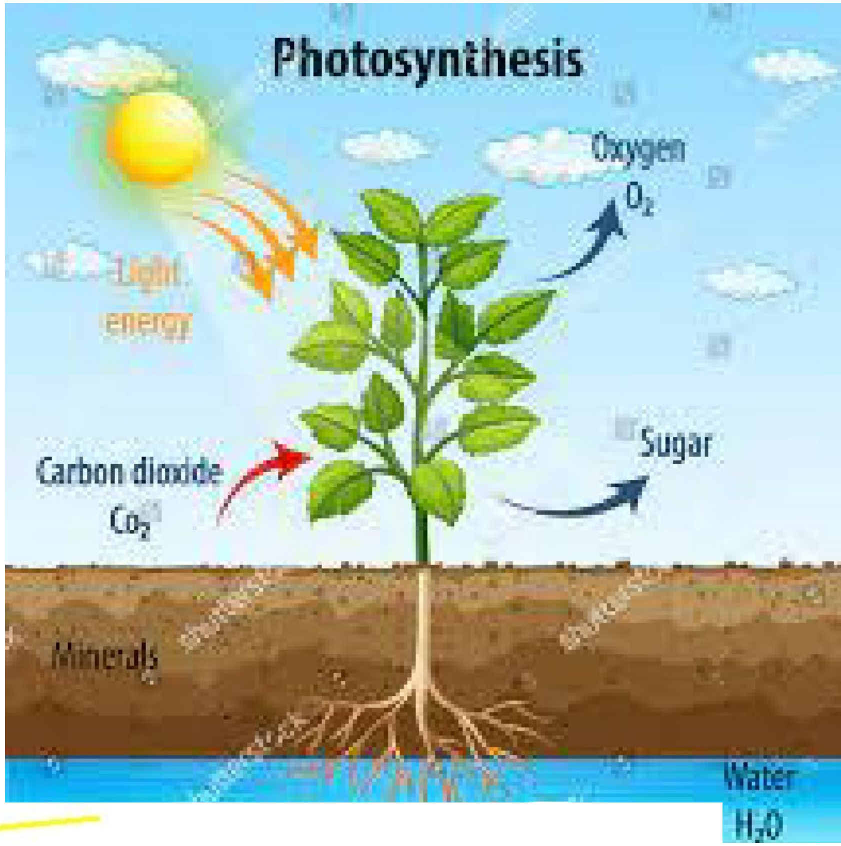
PHOTOSYNTHESIS :
Plants, Algae, Bacteria

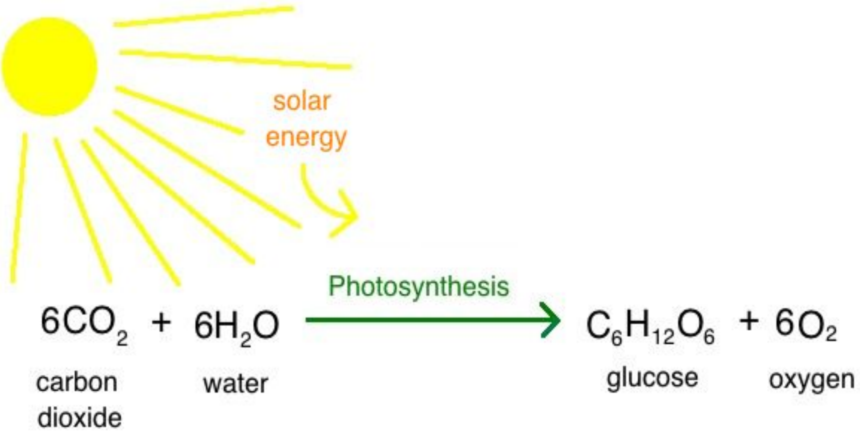
The Process:

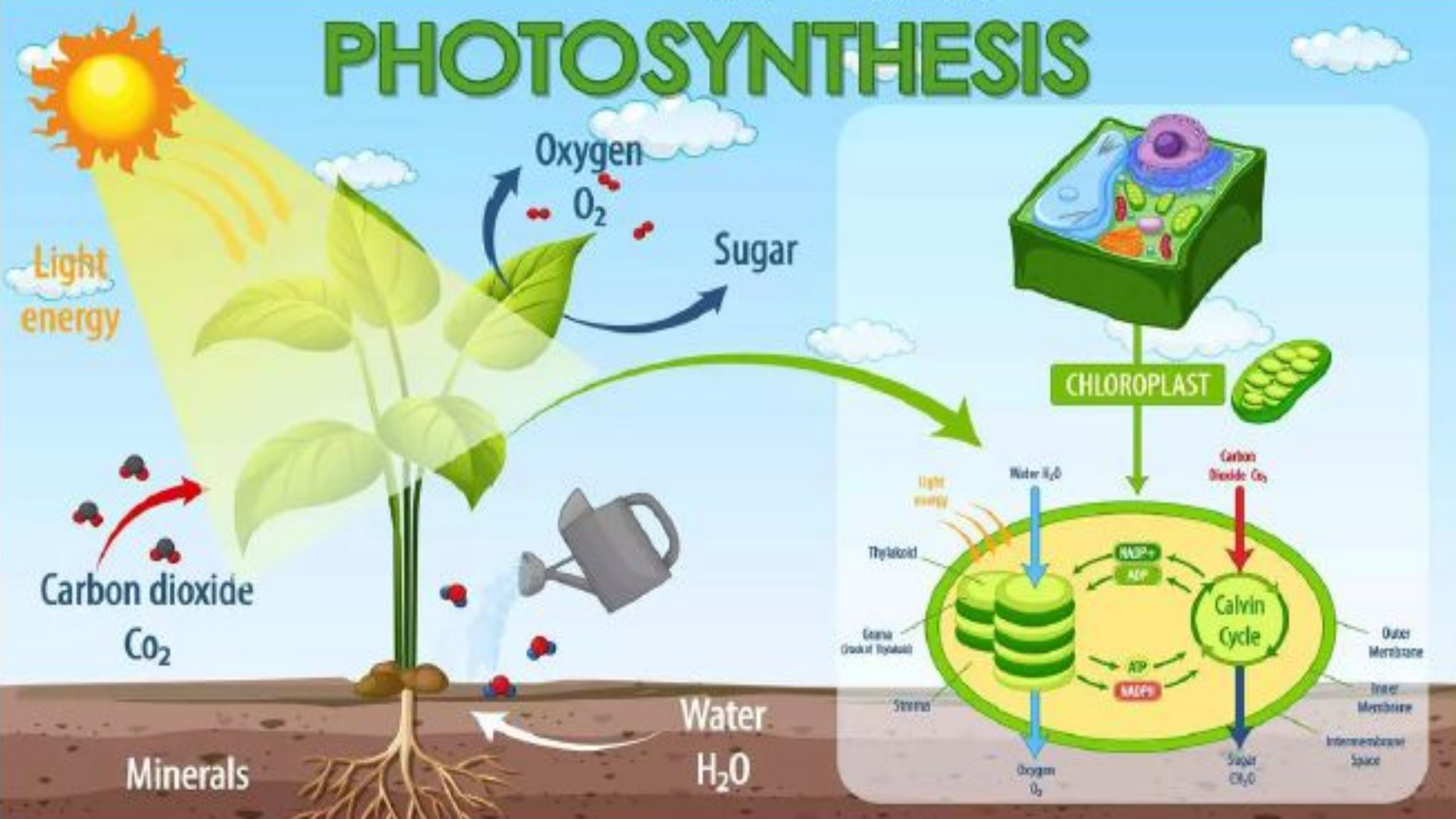
- During photosynthesis, plants take **in carbon dioxide (CO2) and water (H2O) from the air and soil.**
- Within the plant cell, the ***water is oxidized***, meaning it loses electrons, while the ***carbon dioxide is reduced***, meaning it gains electrons.
- This transforms the **water into oxygen** 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.



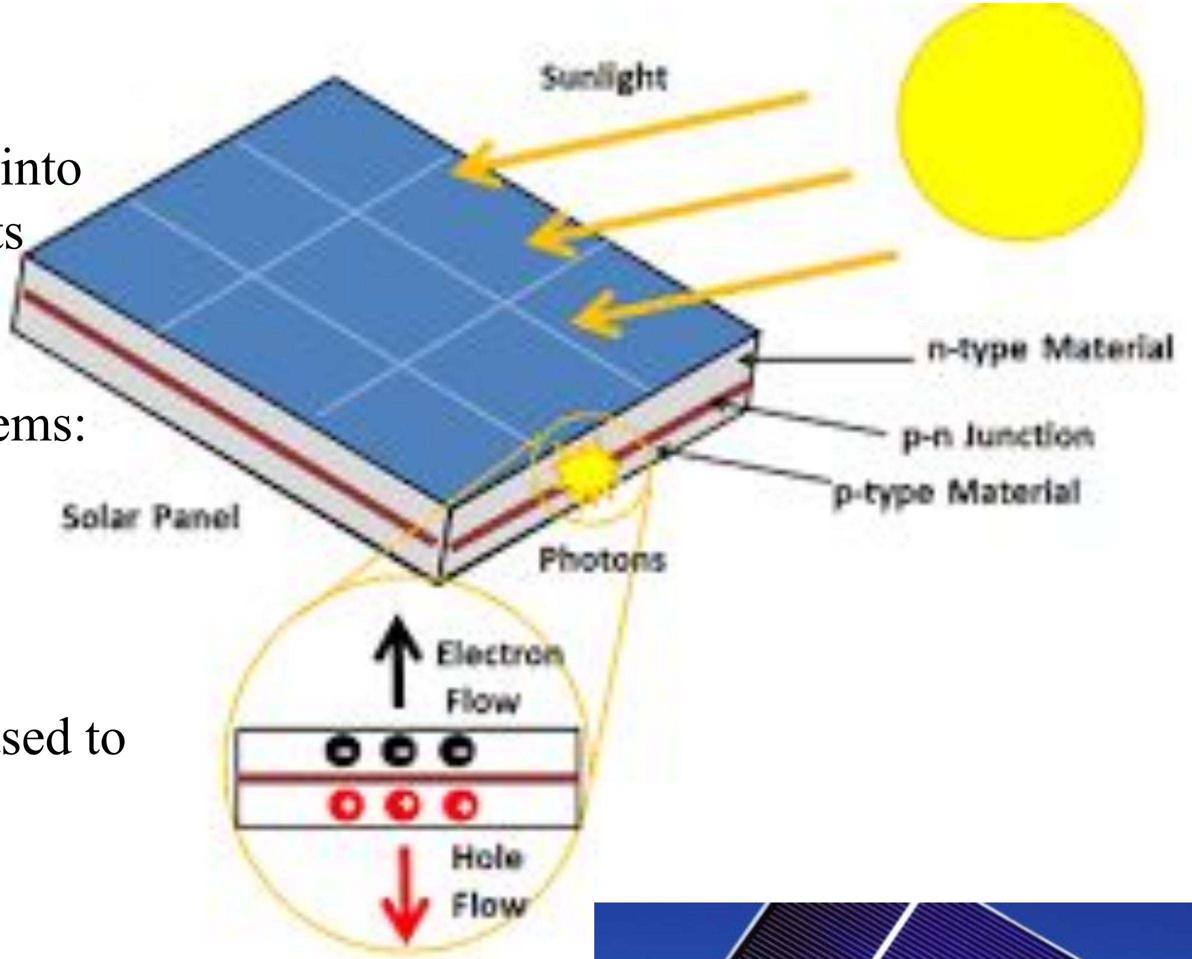




PHOTOSYNTHESIS
Light energy
Oxygen
O_2
Sugar
Carbon dioxide
Co_2
Minerals
Water
H_2O
CHLOROPLAST
Thylakoid
NADP+
ADP
ATP
Calvin Cycle
Outer Membrane

PHOTOVOLTAIC CELLS

An electronic device that converts the energy of light directly into electricity **Or** Solar cell, a non mechanical device that converts sunlight directly into electricity.
It's composed of semiconductor material.
The sun's copious energy is captured by two engineering systems:



Photosynthetic plant cells and

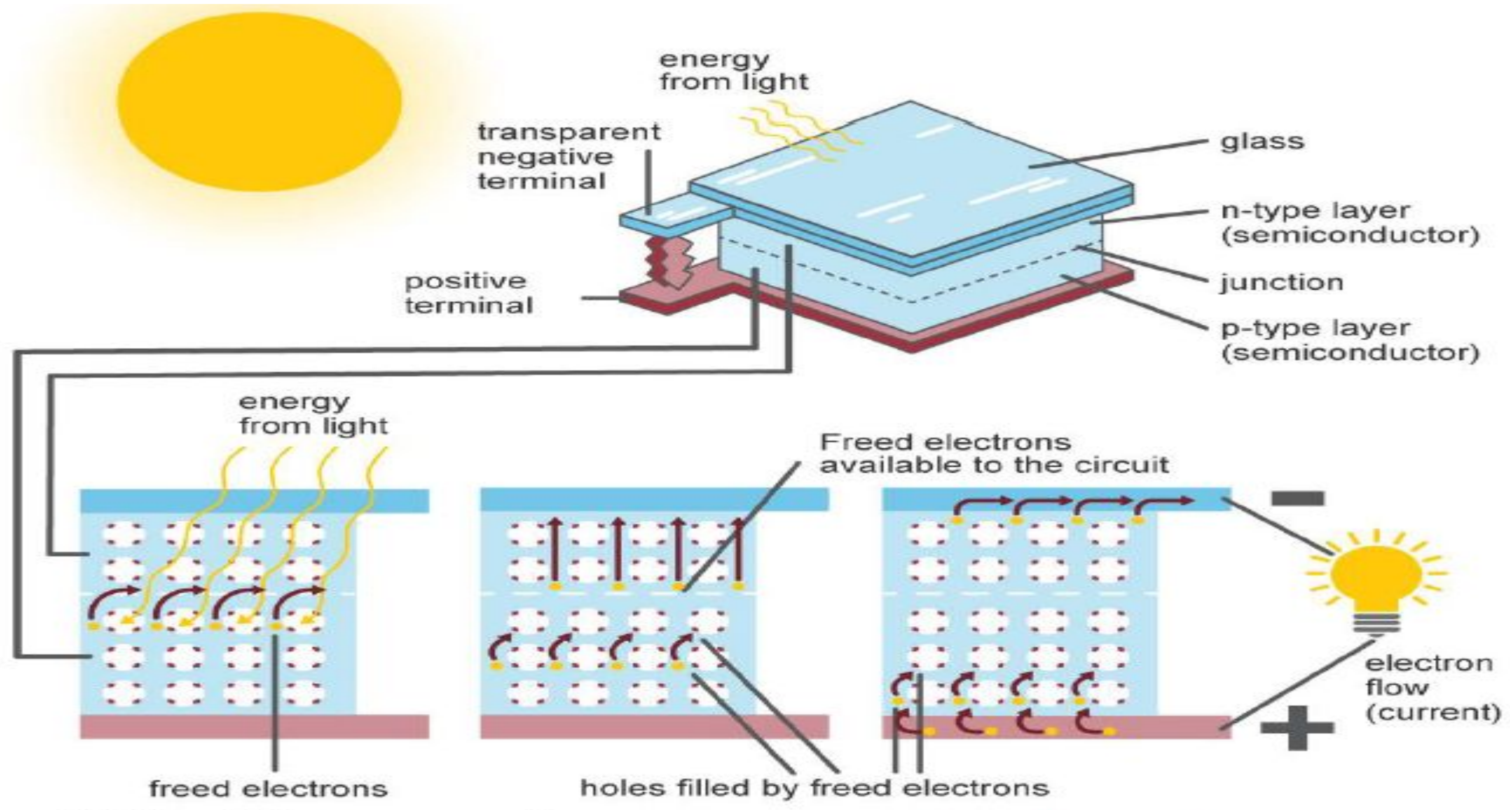
Photovoltaic cells (PV)

Photovoltaics turn it into electricity which can be stored and used to perform work.

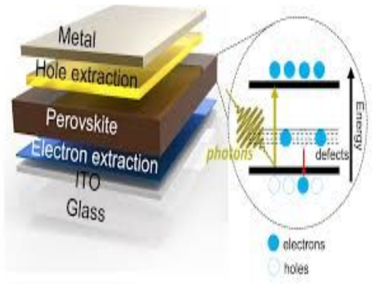
Application:

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

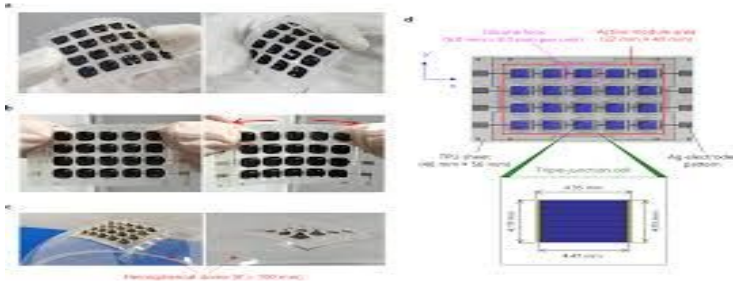
Photovoltaic Cells

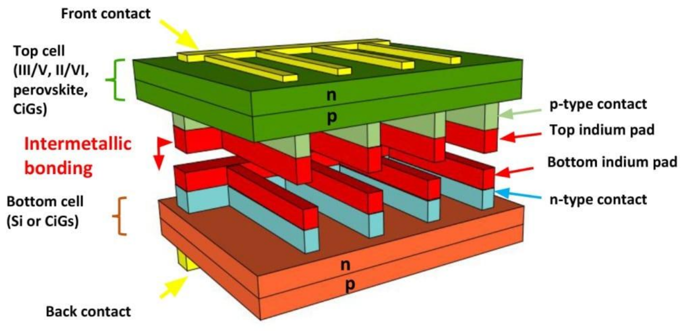


- ❖ In photosynthesis, light energy from the sun is converted into chemical energy stored in organic molecules, such as sugars and starches.
- ❖ In photovoltaics, light energy is converted into electrical energy.
- ❖ Both photosynthesis and photovoltaics use the same basic principle of converting light energy into usable forms of energy, but the end products are different.
- ❖ *In photosynthesis*, the end product is stored chemical energy, while *in photovoltaics*, the end product is electrical energy.
- ❖ The connection between photosynthesis and photovoltaics lies in **converting light energy into usable forms of energy.**
- ❖ Both photosynthesis and photovoltaic processes also involve the use of specialized components and materials, such as **chlorophyll in photosynthesis** and **silicon in photovoltaics**, to absorb and convert light energy into usable forms of energy.



New Technology Photovoltaic Cells





photovoltaic material, a conductive sheet and a protective layer.

- **Perovskite solar cells:** A new type of photovoltaic cell that use a crystalline material made of perovskite to convert light energy into electrical energy. They are highly efficient and have the potential to be more affordable than traditional silicon-based photovoltaic cells.

- **Thin-film photovoltaic cells:** Type of photovoltaic cell that uses a thin layer of material, such as silicon or cadmium telluride, to convert light energy into electrical energy. They are lighter and more flexible than traditional silicon-based photovoltaic cells and are ideal for use in portable and flexible solar panels.

- **Concentrator photovoltaic cells: T**ype of photovoltaic cell that uses a lens or mirror to concentrate sunlight onto a small area, increasing the amount of light energy that can be captured and converted into electrical energy.

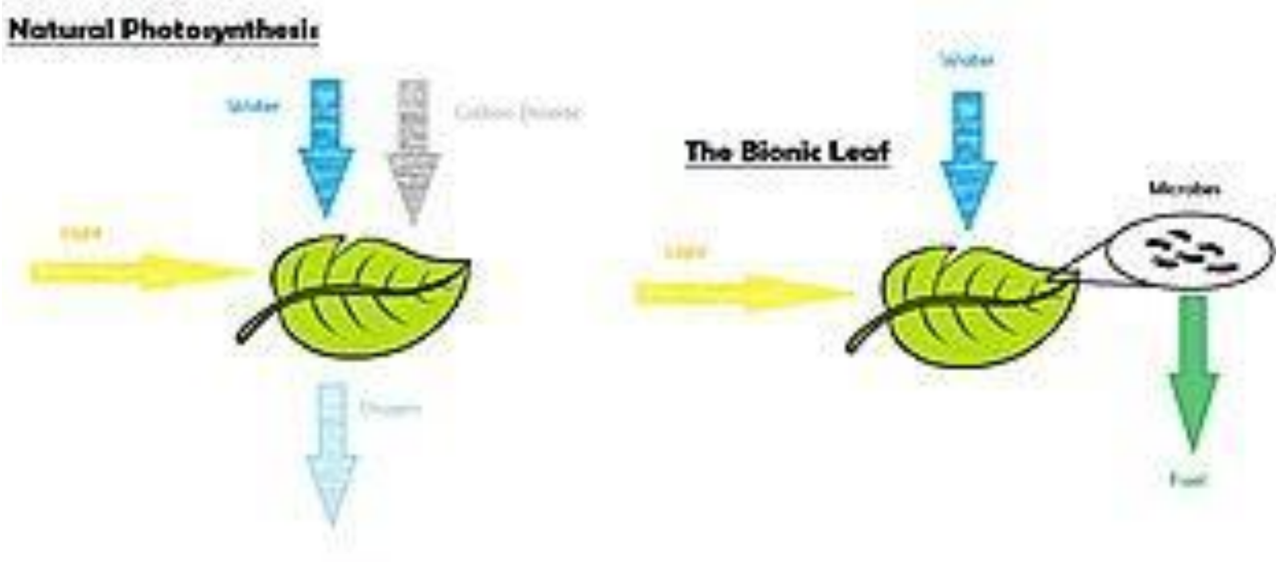
- **Multi junction photovoltaic cells:** A type of photovoltaic cell that uses multiple layers of different materials, each optimized for different wavelengths of light, to convert light energy into electrical energy. They are highly efficient and ideal for use in concentrated solar power system.

BIONIC LEAF

- 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.
- 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 useful alcohol fuels, like **isopropanol and isobutanol**
- The Bionic Leaf can be implemented in communities (urbanized areas) to provide clean air as well as providing needed clean energy.

Applications:

- □ **Agriculture**
- □ **Atmosphere**
- □ **Bionic Facades**



Bionic Leaf

- **Artificial photosynthesis** to convert sunlight into usable forms of energy, such as hydrogen or other biofuels.

- Mimic the process of photosynthesis in plants, where light energy is used to split water molecules **into hydrogen and oxygen**, and the hydrogen can then be used as a source of energy.

- It consists of **a photovoltaic cell that captures sunlight and converts it into electrical energy, and a catalyst, such as a bacteria**, that uses the electrical energy to split water molecules into hydrogen and oxygen.

- **The hydrogen produced by the bionic leaf can then be stored and used as a source of energy for a variety of applications, such as powering vehicles or generating electricity.**

- The bionic leaf has the potential to be a highly sustainable and environmentally friendly energy source, as it uses renewable resources, such as sunlight and water, to produce energy.

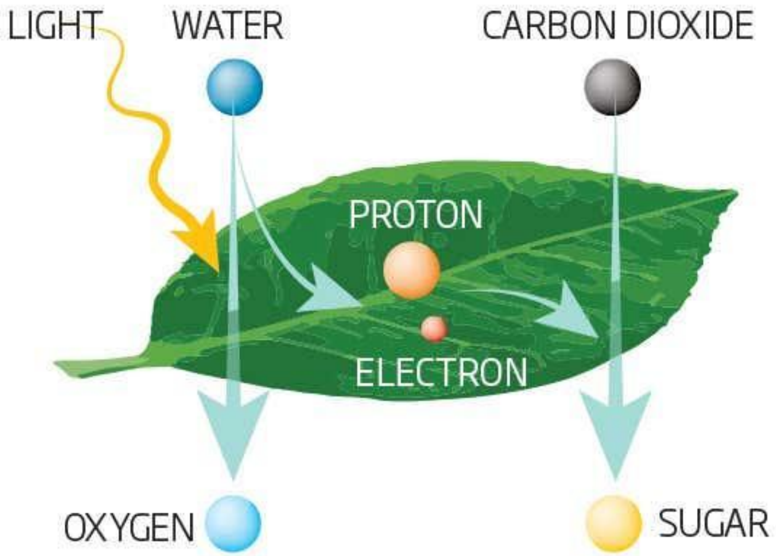
- Additionally, the bionic leaf can be used in remote locations where there is limited access to electricity, and it can help to reduce our reliance on fossil fuels and mitigate the effects of climate change.

Green machines

A new generation of sunlight harvesters will be more useful than ever before

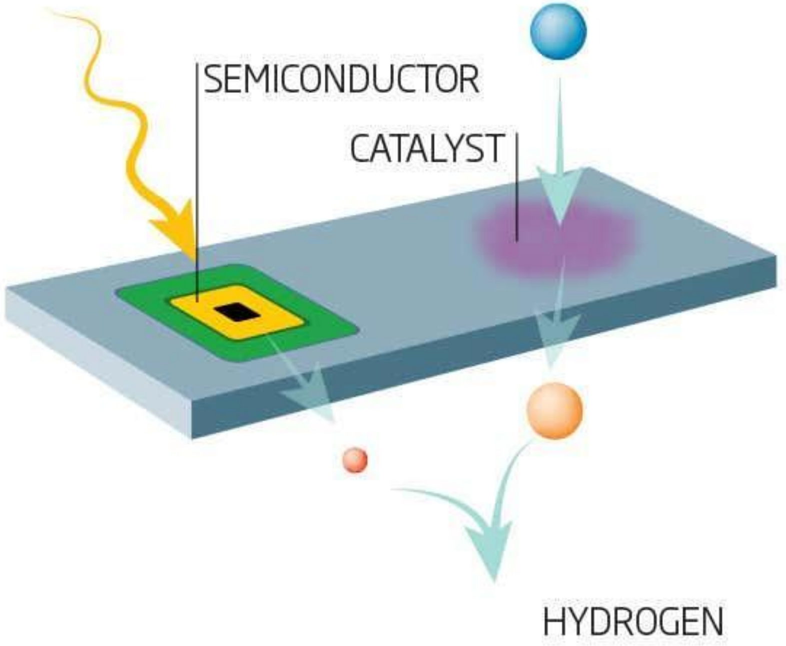
Natural leaf

During the day, plants take in water and carbon dioxide. They use light and a menagerie of enzymes to convert these into oxygen and sugar



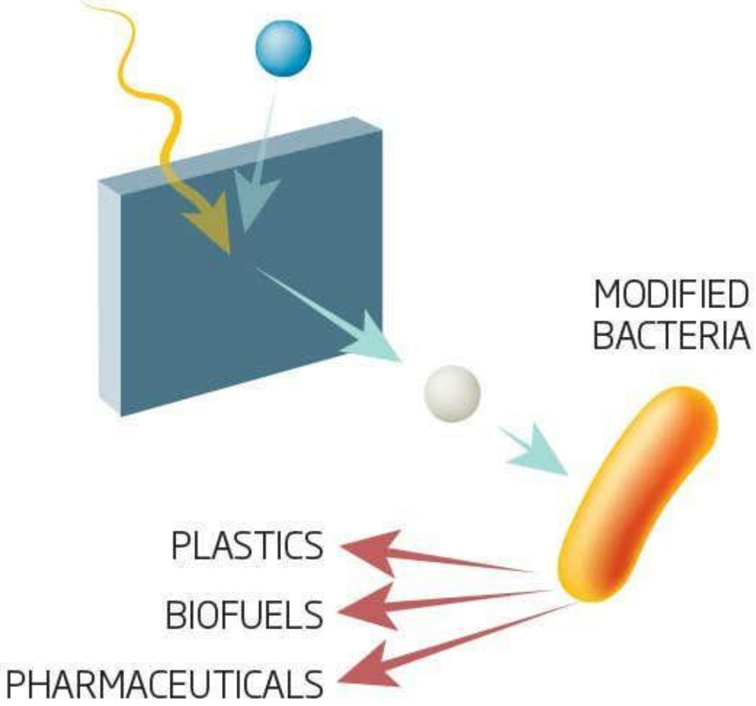
Artificial leaf

Synthetic leaves have a semiconductor to generate electrons from light, and a catalyst to steal protons from water. These are combined to make hydrogen



Bionic leaf

These combine light-harvesting tech with microbes. In one design, hydrogen from an artificial leaf is passed to microbes, which then produce useful chemicals



Components of Bionic Leaf :

- **Photosynthetic Organism:** The bionic leaf utilizes a photosynthetic organism (cyanobacterium or a genetically modified plant), which contains chlorophyll or other light-absorbing pigments that capture solar energy and initiate the photosynthetic process.

- **Light Harvesting System:** The bionic leaf includes a light harvesting system, which can be artificial or natural, to efficiently capture sunlight. In some designs, light-absorbing dyes or semiconductor materials are incorporated to enhance light absorption and conversion efficiency

- **Catalysts:** The bionic leaf incorporates catalysts, such as enzymes (Examples: Hydrogenase, Nitrogenase, etc.) or synthetic catalysts (Example: Rubisco (Ribulose-1,5- bisphosphate carboxylase/oxygenase)), to facilitate the chemical reactions involved in photosynthesis. These catalysts play a crucial role in splitting water molecules, generating electrons, and catalyzing the conversion of carbon dioxide into fuels or other chemical compounds.

- **Electron Transfer Pathway:** Bionic leaf system with electron transfer pathway allows the generated electrons from water splitting to be efficiently transported to the catalysts involved in carbon dioxide reduction or other chemical reactions. This pathway ensures the flow of electrons necessary for fuel production or other desired chemical transformations.

- **Carbon Dioxide Source:** To sustain the photosynthetic process, a Bionic leaf requires a source of carbon dioxide. This can be obtained from various sources, including ambient air, industrial emissions, or concentrated carbon dioxide solutions.

- **Energy Storage or Conversion System:** The bionic leaf includes an energy storage or conversion system to capture and store the chemical energy produced during photosynthesis. This can involve the production of hydrogen gas, liquid fuels, or other energy-rich compounds that can be stored and used as needed.

- **Control and Monitoring System:** To optimize performance and ensure efficient operation, a bionic leaf typically incorporates a control and monitoring system. This system monitors various parameters such as light intensity, temperature, pH, and carbon dioxide levels, and allows for adjustments and optimization of the overall process.

Working principle of bionic leaf is given below:

Sunlight is captured and directed to the bionic leaf.

The bionic leaf contains a **catalyst** (typically a special type of bacteria or an artificial catalyst) and a water-splitting enzyme.

↓

Sunlight energy is used to split water molecules (H_2O) into hydrogen ions (H^+) and oxygen (O_2) through a process called **photolysis.**

↓

The hydrogen ions (H^+) generated from water splitting combine with electrons from an external source (e.g., a wire) to form hydrogen gas (H_2). The oxygen gas (O2) produced during water splitting is released into the atmosphere.

↓

The **generated hydrogen gas** (H_2) can be collected and stored for later use as a clean and renewable energy source.

↓

The bionic leaf also absorbs **carbon dioxide** (CO_2) from the air or a supplied source.

↓

The absorbed carbon dioxide (CO_2) is converted into carbon-based compounds, such as **formic acid or methane**, through a reduction reaction.

↓

The carbon-based compounds can be used as a fuel or converted into other useful chemicals.

↓

The bionic leaf operates in a closed-loop system, where the produced oxygen (O_2) during water splitting is reused by the catalyst in subsequent cycles.

Applications of Bionic Leaf Technology

- **Renewable Energy Production:** Bionic leaf systems can harness solar energy and convert it into chemical energy in the form of hydrogen gas or other carbon-based fuels. These fuels can be used as clean energy sources for various applications, **including transportation, electricity generation, and heating**.

- **Carbon-dioxide Reduction:** Bionic leaf technology offers a promising solution for mitigating the rising levels of carbon dioxide in the atmosphere.
  By capturing and utilizing carbon dioxide as a feedstock, bionic leaf systems can potentially help reduce greenhouse gas emissions and combat climate change.
  This application holds significant potential for carbon capture and utilization (CCU) strategies.

- **Sustainable Chemical Production:** Bionic leaf systems can be utilized for sustainable chemical production.

  By utilizing carbon dioxide and renewable energy, these systems can produce a wide range of valuable chemicals, such as fertilizers, plastics, and pharmaceuticals.

  This application offers a more environmentally friendly and resource-efficient approach to chemical synthesis.

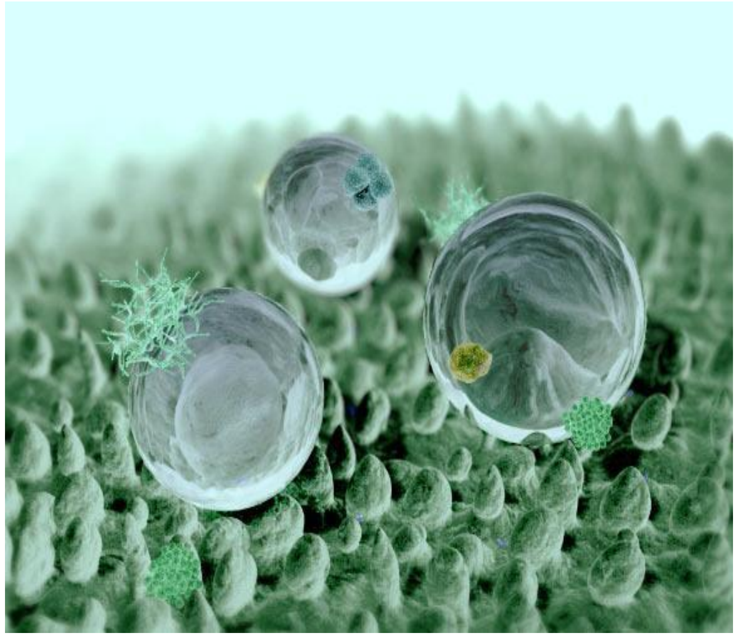
- **Agriculture and Food Production:** Bionic leaf technology can have applications in agriculture and food production. By utilizing sunlight and carbon dioxide, bionic leaf systems can generate oxygen and energy-rich compounds that can enhance plant growth and improve crop yields. This technology can potentially contribute to sustainable agriculture practices and help address global food security challenges.

- **Remote and Off-Grid Areas:** Bionic leaf systems can provide a decentralized and offgrid energy solution for remote or underdeveloped areas. By harnessing solar energy and producing clean fuels, these systems can offer sustainable power sources for communities without access to conventional energy infrastructure. enabling them to meet their energy needs and improve their quality of life.

- **Environmental Remediation:** Bionic leaf technology has the potential to aid in environmental remediation efforts. By utilizing the energy generated from sunlight, bionic leaf systems can power processes that remove pollutants or contaminants from air, water, or soil, contributing to the restoration and preservation of ecosystems.

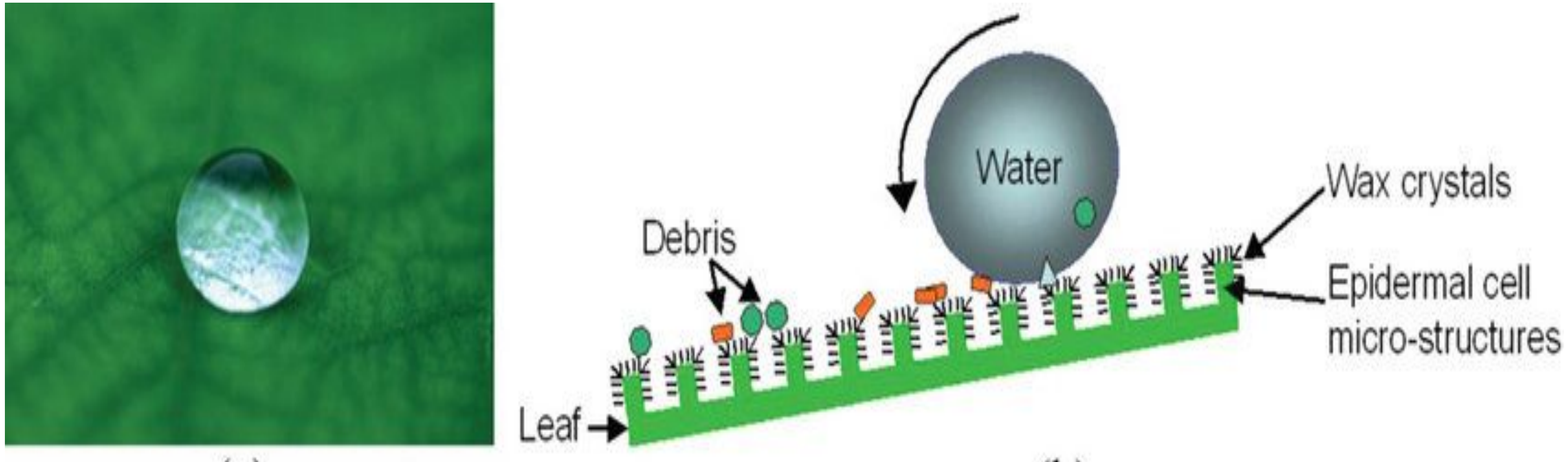
LOTUS LEAF EFFECT

- The lotus leaf is well-known for having a highly **water-repellent, or superhydrophobic**.
- **Self-cleaning materials**, and it has been studied in both natural and artificial systems.
- It has a **microscale and nanoscale structure** that consists of numerous small wax-coated hair.



SUPERHYDROPHOBIC AND SELF-CLEANING SURFACES

- Self cleaning properties that are result of ultra hydrophobicity.
- High surface tension leads to droplets assuming spherical shape.
- Contact angle 170 degrees, 0.6% contact area



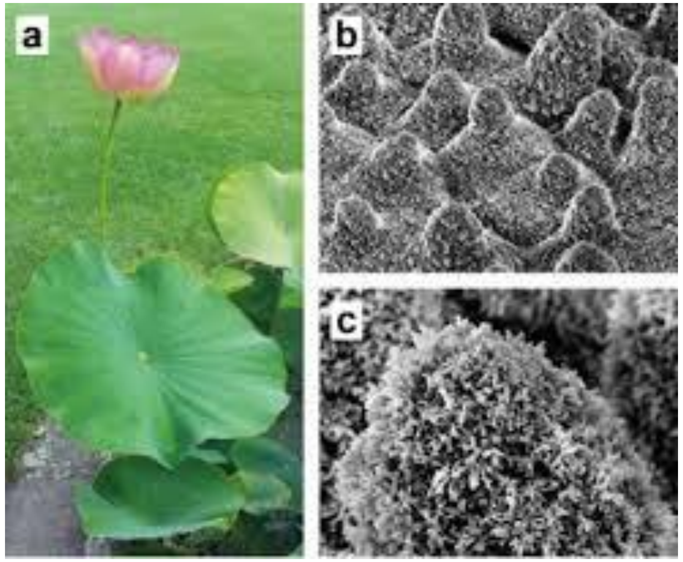
(a) (b)

Super Hydrophobic Effect

- Super hydrophobic and self-cleaning surfaces have applications in industries such as ***aerospace, automotive, building materials, and medical devices***.

LOTUS LEAF EFFECT

- Ability of lotus leaves to **repel water** and **self-clean** through their unique surface structure.
- This effect has inspired the development of **superhydrophobic and self-cleaning surfaces.**
- It has a **microscale and nanoscale structure** that consists of numerous small wax-coated hair.
- This structure creates a **high contact angle** between the water droplets and the surface, causing the droplets to roll off and carry away any dirt or debris.
- This self-cleaning property is due to the lotus leaf's ability to repel water and resist adhesion.



a) Photo of a lotus plant.

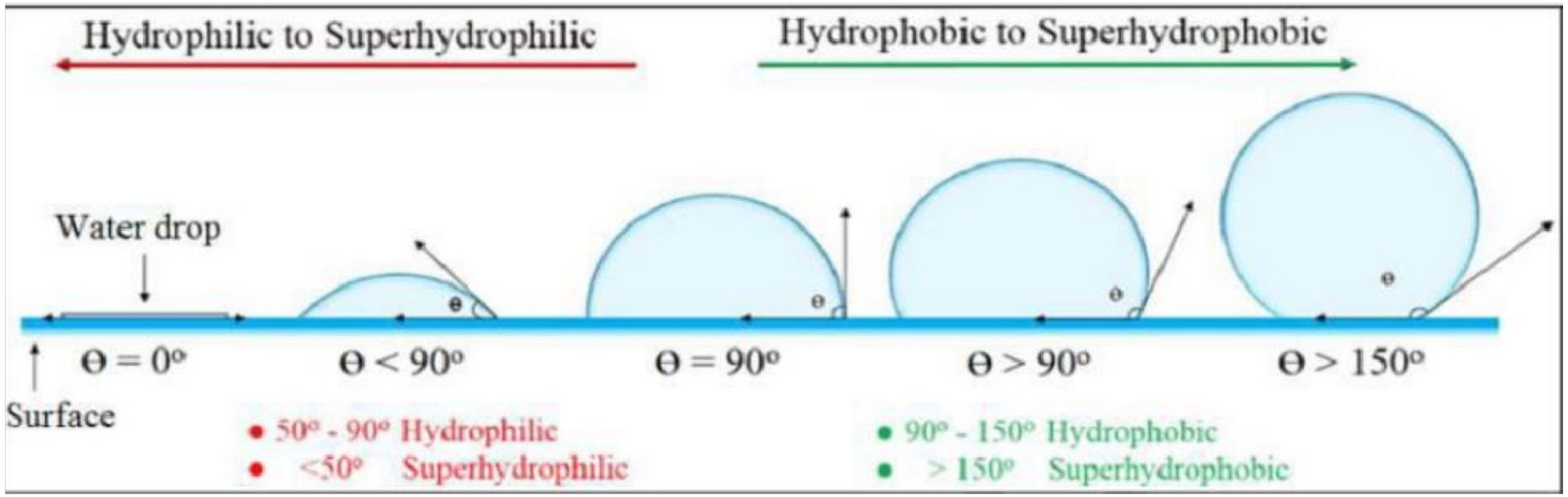
b) Scanning electron microscopy (SEM) image.

c) This structure is covered by wax crystals, leading to the extreme superhydrophobicity of the surface.

Super Hydrophobic Effect

Mechanism:

It is characterized by a high contact angle between water droplets and the surface, typically over 150 degrees, and a low contact angle hysteresis, meaning that the droplets roll off the surface with ease.



These techniques create a surface structure that traps air between the surface and the water droplets, reducing the contact area between them and making it more difficult for the droplets to wet the surface.

Materials and Examples

Super-hydrophobic surfaces are created by modifying the surface chemistry and structure of materials to achieve extremely high water repellency.

Several materials and coating techniques are used to prepare superhydrophobic surfaces.

Examples:

Fluoropolymers:

Fluoropolymer-based coatings lower surface energy and **water-repellent properties** Example: polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP) coatings.

Silica-based Nanoparticles:

These nanoparticles create a rough surface structure that **traps air pockets**, preventing water from wetting the surface. Examples include silica nanoparticles coated with hydrophobic agents like alkyl silanes.

Carbon-based Materials:

Carbon nanotubes (CNTs), **graphene, and carbon nanofibers** are used to create superhydrophobic surfaces. These materials can be aligned or randomly distributed to form a rough surface with hydrophobic properties.

Metal-based Materials:

One approach involves creating micro/nanostructured surfaces using etching techniques, such as **chemical etching** or **electrochemical etching**, on metals like aluminum, copper, or stainless steel. These structures, combined with appropriate surface treatments, enhance water repellency.

Natural Materials:

Lotus leaves and butterfly wings, have inherently super hydrophobic properties. Researchers have studied the surface structures and chemical composition of these natural surfaces to replicate them artificially. Mimicking the hierarchical structures and utilizing hydrophobic coatings can create superhydrophobic surfaces.

Polymer-based Materials:

Polymers exhibit superhydrophobic properties.

Example, polydimethylsiloxane (PDMS) can be modified and structured to create rough surfaces with low surface energy.

Hybrid Materials:

Combinations of different materials are often used to create super hydrophobic surfaces and synergistic effects (nanoparticles, polymers, and other materials)

Photocatalytic Coatings: Photocatalyst material, such as titanium dioxide (TiO_2), can be used as coating on surfaces to create self-cleaning properties.

When exposed to ultraviolet (UV) light, the photocatalytic surfaces generate reactive oxygen species that break down organic matter, resulting in the decomposition of dirt and pollutants

Engineering Applications of Super Hydrophobic Surfaces

Electronics Industry:

- **Waterproofing Electronics:** Protect electronic components(circuit boards, connectors, and other sensitive electronic parts) from water damage and improves the reliability and durability of electronic devices.
- **Moisture Resistance:** Electronic devices exposed to humid environments or moisture-prone conditions prevent moisture, reducing the risk of short circuits, corrosion   malfunction.
- **Self-Cleaning Displays:** Super hydrophobic coatings applied to displays and touch screens repel water, oils, and fingerprints, making them easier to clean, improves the visibility and functionality of electronic displays, especially in outdoor or light-touch application.

Automobile Industry

- **Anti-Fogging Windows and Minors:** Used on automobile windows and mirrors to prevent fogging or condensation formation. The water-repellent property helps maintain clear visibility, enhancing driver safety and comfort in humid or cold weather conditions.
- **Self-Cleaning Surfaces:** Applying super hydrophobic coatings to the exterior surfaces of vehicles can facilitate self-cleaning by repelling water, dirt, and contaminants. This reduces the need for frequent washing and maintenance, keeping the vehicle cleaner and improving its appearance.
- **Fuel Efficiency:** Reduces drag and frictional resistance on vehicle surfaces, leading to improved aerodynamics and fuel efficiency and prevent the accumulation of water droplets on the vehicle's exterior, decreasing drag

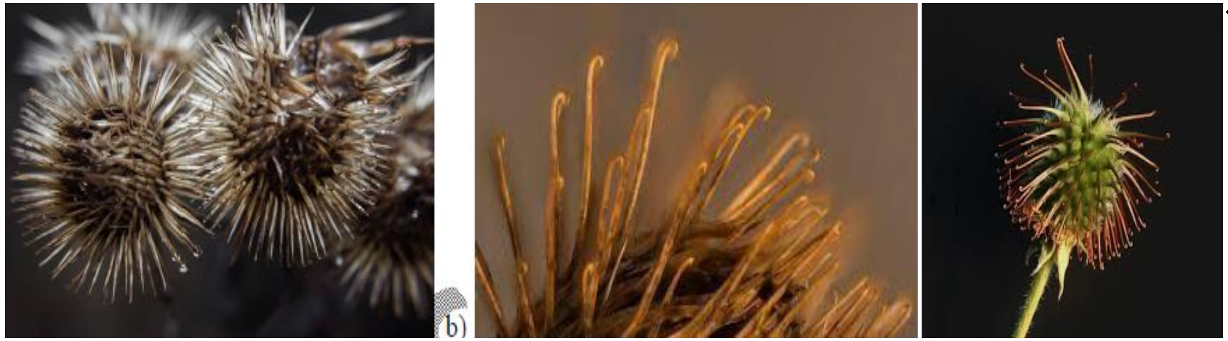
Aerospace Industry:

- **Anti-Icing and Deicing:** Can prevent ice formation or facilitate ice removal. This is particularly important for critical areas such as wings, engine components, and sensors, helping to ensure safe operations and reducing the risk of ice-related incidents.
- **Drag Reduction:** Minimize frictional drag on aircraft surfaces during flight, leading to improved fuel efficiency and reduced emissions. The water-repellent property helps maintain a smooth airflow over the surface, optimizing aerodynamic performance.
- **Corrosion Resistance:** Protects aerospace components from corrosion caused by exposure to moisture, rain, or harsh environments by repelling water and reducing surface contact with corrosive agents these coating help preserve the structural integrity and lifespan of aerospace equipment.

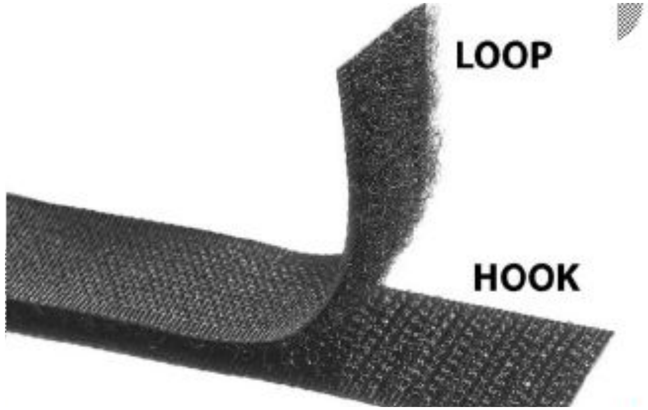
Application of Self-cleaning surfaces and coatings

- **Architecture and Building Materials, Solar Panels** and **Electronics**
- **Textiles**
- **Medical Equipment**.
- **Kitchen and Bathroom Surfaces**.
- **Outdoor Signage and Billboards**
- **Air Conditioning and Ventilation Systems**
- **Food and Beverage Industry**

PLANT BURRS-VELCRO TECHNOLOGY



a)The globular flower heads of burdock, b) indicating the hook shape

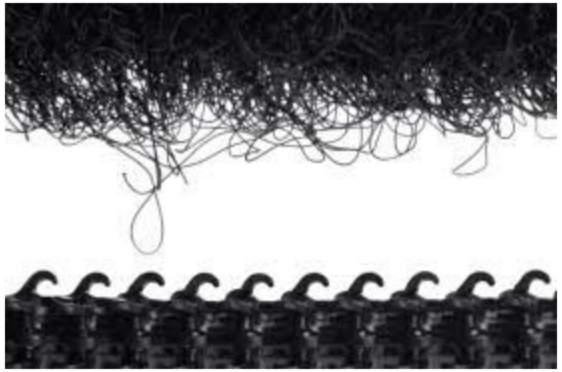


a) hook and loops normal view of Velcro, b) microscopic view of hooks and loops of velcro

- Plant burrs, found on burdock, inspired the invention of Velcro, a popular **hook-and-loop fastening system.**
- A **bur** is a seed or dry fruit that has **hooks or teeth**
- The burrs have small hooks that can latch onto clothing, fur, or feathers, allowing them to disperse their seeds over a wider area
- Velcro was invented by **Swiss engineer George De Mestral** in 1941, after he became fascinated by the way burrs clung to his clothes and his dog's fur during a walk.
- He observed burrs under a microscope, that they had small hooks that could latch onto loops in fabric.
- Velcro consists of two strips of nylon fabric, one with tiny hooks and the other with small loops
- Velcro has a wide range of applications, **including clothing, shoes, bags, and medical devices** and also popular alternative to traditional fasteners, such as buttons and zippers.

It's a combination of the French words "velour" (velvet) and "crochet" (hook), essentially meaning "hooked velvet

Materials Used in Velcro Technology



- ➔ Velcro technology uses two main materials:
- ➔ **Nylon** and **Polyester**.
- ➔ The nylon is extruded to create **tiny hooks** that are then cut and shaped into the familiar hook shape.
- ➔ These hooks are designed to latch onto the loop side of the Velcro.

a. Hook

b. **Loop**

Engineering Applications of Velcro Technology

a. Clothing and footwear

b. medical devices

c. Aerospace equipment

d. Packing industry

Engineering Applications of Velcro Technology

Clothing and footwear:

Velcro is commonly used in clothing and footwear for closures and adjustable straps. It can be easily opened and closed, making it convenient for users.

Medical devices:

Velcro is used in medical devices such as braces, splints, and compression garments for its adjustable and secure fastening capabilities.

Aerospace equipment:

Velcro is used in aerospace equipment, such as satellites and spacecraft, to secure components in place and prevent them from vibrating or shifting during launch or flight.

Automotive industry:

Velcro is used in the automotive industry for a range of applications, such as securing carpets and headliners, and attaching door panels and seat cushions.

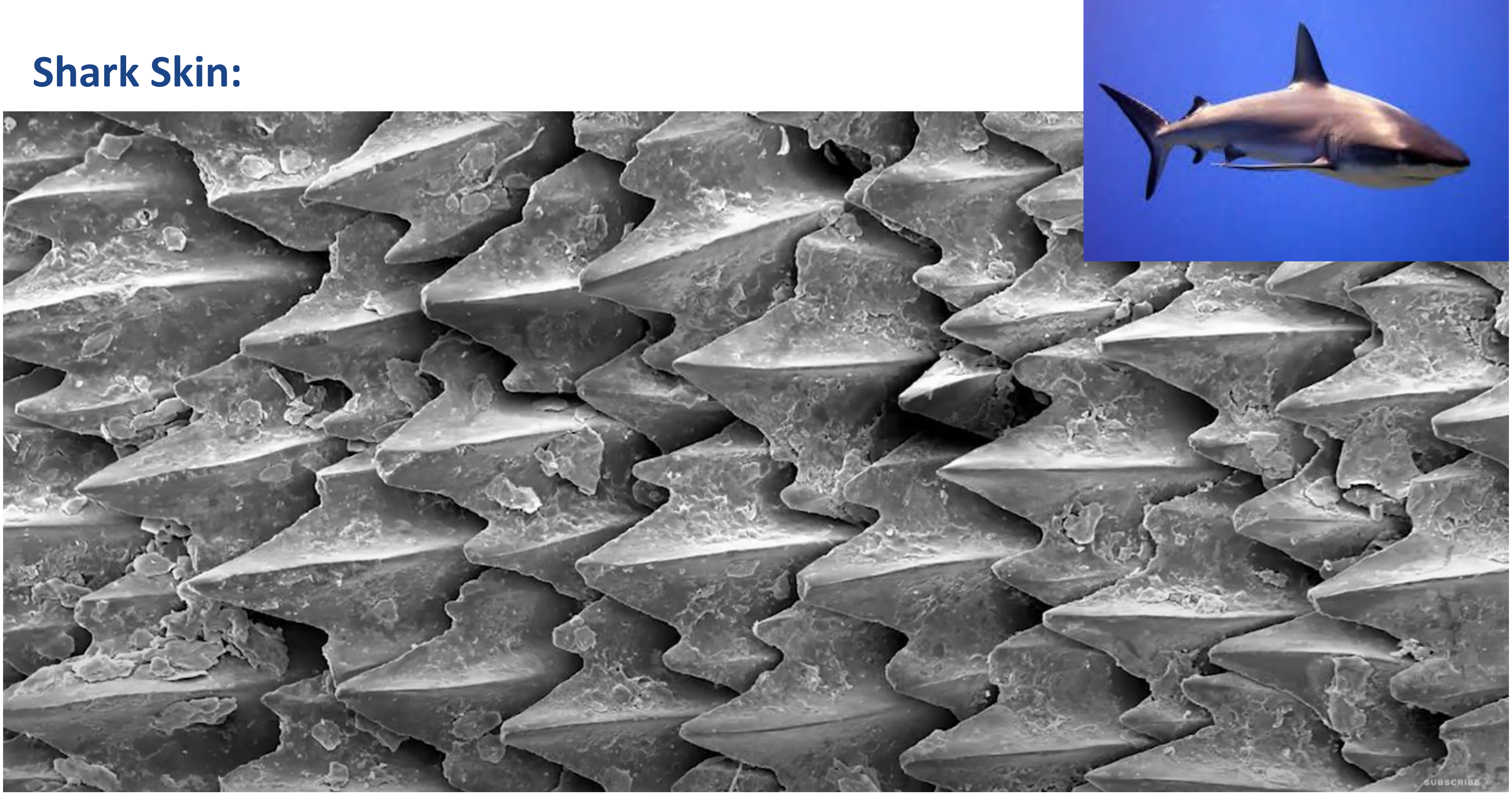
Packaging industry:

Velcro is used in the packaging industry for resealable closures on bags, pouches, and other types of packaging.

Sports equipment:

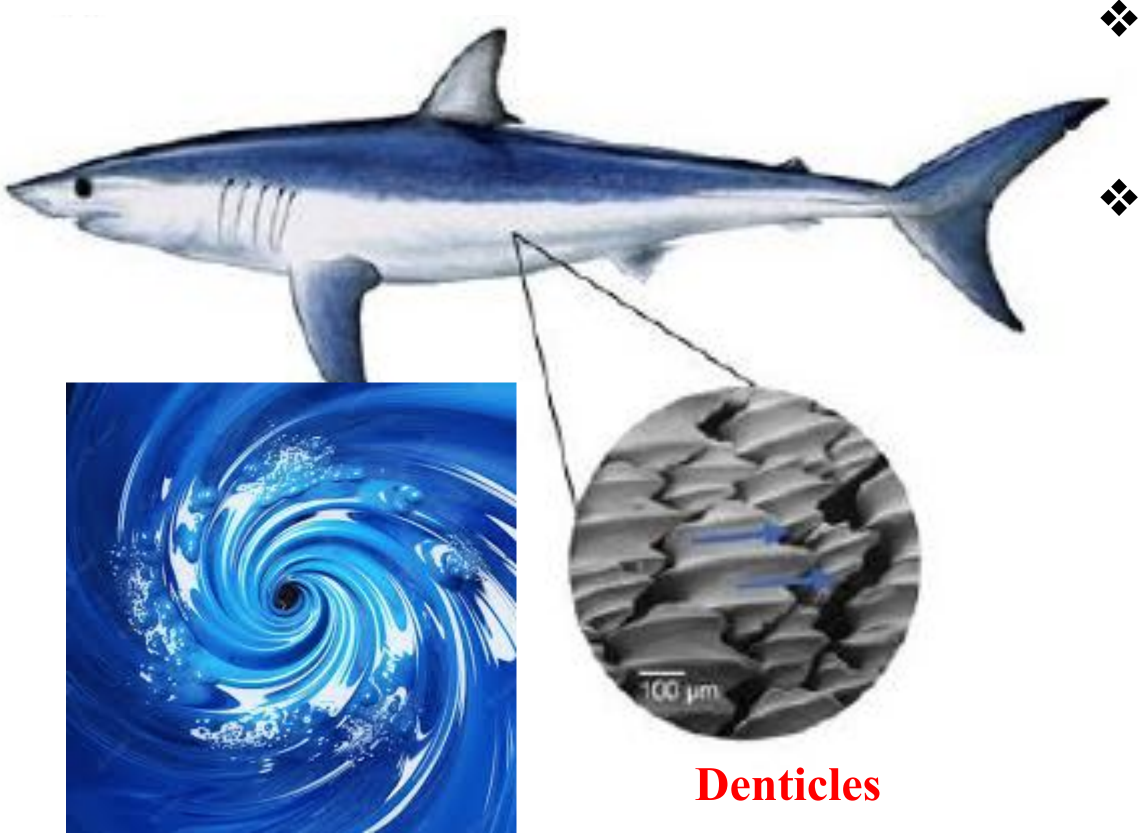
Velcro is used in sports equipment, such as helmets and gloves, for its ability to provide a secure and adjustable fit

Shark Skin:



Shark Skin and Friction Reducing Swimsuits

- The **denticles** on shark skin have evolved over millions of years to reduce, drag and increase swimming efficiency.
- Scaly structures disrupt the flow of water around the shark's body, reducing turbulence and minimizing the formation of vortices.
- Denticles on shark skin are like tiny bumps or ridges. They disrupt the flow of water around the shark's body, making it smoother and reducing turbulence
- Sharks can swim faster and with less effort compared to other fish.

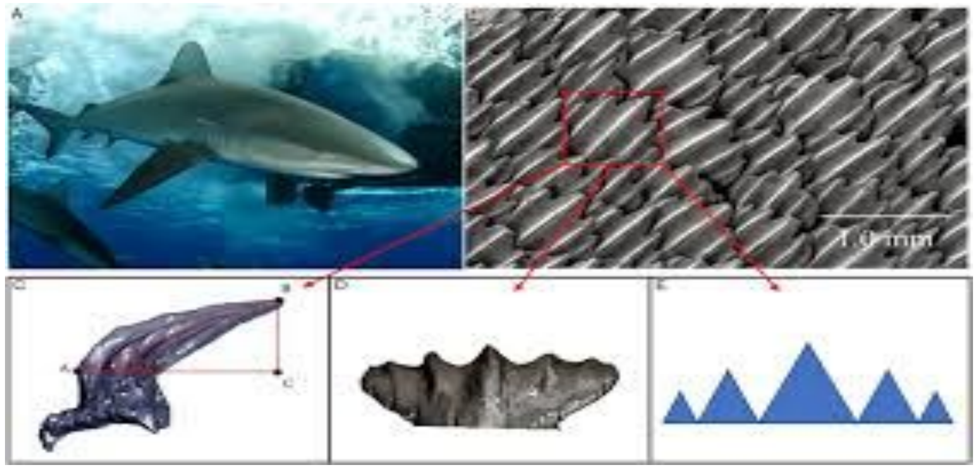


Denticles

vortices

Frictionless Swimsuits

- Friction-reducing swimsuits use a similar structure to that of shark skin to reduce drag and improve swimmer performance.
- These suits are made from high-tech materials that mimic the properties of shark skin, such as the shape and size of the denticles.



Materials Used:

The materials used to create friction-reducing swimsuits inspired by shark skin include:

Polyurethane:

A type of polymer that is commonly used in the **production of swimsuits**, as it is durable and can be **molded into a variety of shapes**.

Lycra/Spandex:

They are made from the same synthetic fiber, which is technically called elastane. Elastin fibers are typically composed of a polymer called polyurethane, which is then blended with other fibers like nylon, polyester, or cotton) that is known for its stretch and flexibility.

High-tech fabrics:

These fabrics are designed to be lightweight, water-repellent, and hydrodynamic, and often incorporate materials such as silicone or Teflon to reduce drag.

Examples:

Speedo Fastskin: This swim suit was designed based on the structure of shark skin and is made from a high-tech fabric that incorporates a range of materials to reduce drag and turbulence in the water.

Arena Powerskin Carbon Ultra: Another example of a friction-reducing swimsuit, the Arena Powerskin Carbon Ultra is made from a combination of polyurethane and high-tech fabrics to provide a hydrodynamic and form-fitting design.

TYR Venzo: The TYR Venzo is a friction-reducing swimsuit that incorporates a unique surface structure inspired by shark skin, as well as other advanced materials to improve swimmer performance.

Speedo Fastskin

Arena Power skin Carbon Ultra

TYR Venzo

KINGFISHER BEAK

Shape similarities of kingfisher beak and design of the front of the bullet train

- The kingfishers have **long, slender, and sharply pointed, which helps reduce drag or air resistance as the bird dives into the water.**

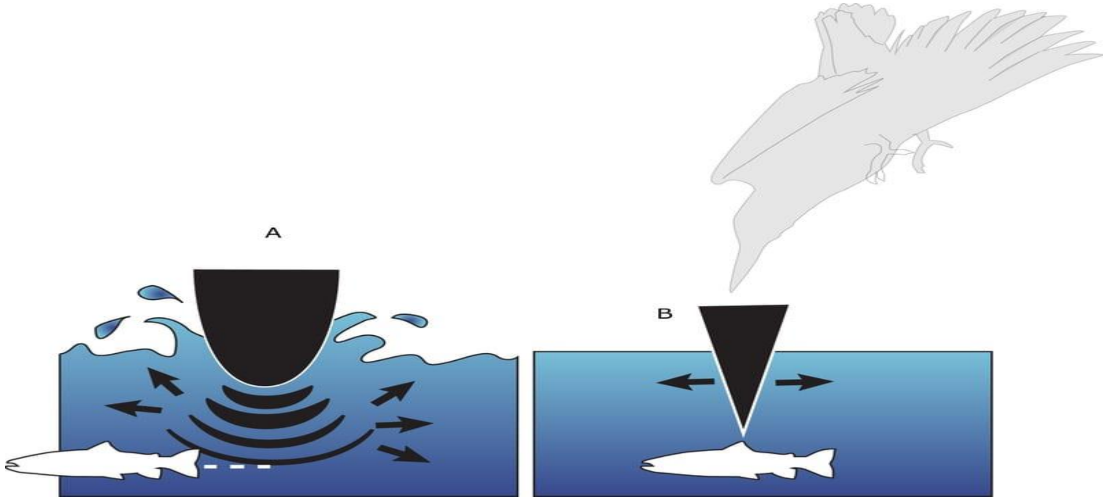
- The bill is usually longer and more compressed in species that hunt fish, and shorter and broader in species.

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 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.

The Physics Behind the Kingfisher Beak

Streamlining:

The beak of a kingfisher is long, slender, and sharply pointed, which helps reduce drag or air resistance as the bird dives into the water.

Surface Tension:

When the kingfisher hits the water, it encounters resistance caused by surface tension. Surface tension is the cohesive force between water molecules that creates a "skin" on the water’s surface.

Minimizing Splash:

As the kingfisher dives, it needs to enter the water with **minimal disturbance to avoid scaring away the fish it intends to catch.**

The shape of the beak helps to reduce the splash generated upon entry.

The beak's narrow and pointed design helps create a smooth entry by minimizing the disturbance of the water surface, allowing the kingfisher to enter silently and effectively.

Pressure Wave Reduction:

When a high-speed train moves through a tunnel, it creates pressure waves that can cause noise and discomfort for passengers.

The nose of the Shinkansen is designed to reduce these pressure waves by effectively managing airflow and minimizing the compression and expansion of air as the train enters and exits tunnels.

This reduces the noise level and enhances passenger comfort.

Hemoglobin-Based Oxygen Carriers (HBOCs)

- Hemoglobin-based oxygen carriers (HBOCs) are a type of human blood substitute that is designed to carry and deliver oxygen to the body's tissues.
- They are made by isolating hemoglobin, the protein responsible for carrying oxygen in red blood cells, and formulating it into a solution or suspension that can be infused into a patient's bloodstream.

Advantages of hemoglobin-based oxygen carriers

Increased oxygen-carrying capacity: HBOCs can potentially carry more oxygen per unit volume than whole blood. This can be advantageous in situations where there is a need for rapid oxygen delivery or when there is limited availability of blood for transfusion.

Universal compatibility:
Unlike blood transfusions, which require blood typing and cross-matching to ensure compatibility, HBOCs can potentially be universally compatible with any blood type. This can be particularly useful in emergency situations or in areas where blood matching facilities are limited.

Longer shelf life:
HBOCs have the potential for longer storage and shelf life compared to donated blood, which has a limited lifespan. This can improve the availability of oxygen-carrying substitutes in critical situations and reduce the need for frequent blood donations.

Reduced risk of infections:
Blood transfusions carry a small risk of transmitting infections, such as viruses or bacteria, from the donor to the recipient. Since HBOCs are synthetic and do not rely on human donors, the risk of infections associated with transfusion can be significantly reduced.

HUMAN BLOOD SUBSTITUTES

Human blood substitutes are synthetic products that are designed to act as a replacement for blood in the human body.

Basic Requirement for Human Blood Substitutes:

Effective Oxygen Transport:

Human blood substitutes must be capable of efficiently carrying and delivering oxygen to the body's tissues.

Safety and Compatibility:

Blood substitutes should be safe for use in the human body and **well-tolerated by the recipient.** They should **not cause significant adverse reactions**, toxicity, immune responses, normal blood clotting, or other essential physiological processes.

Storage and Transport:

Human blood substitutes should be stable and capable of being stored and transported easily
The ability to store and transport substitutes effectively ensures their availability when needed.

Cost-Effectiveness and Scalability:

Blood substitutes should be cost-effective and scalable for widespread use in medical settings and feasible to produce in large quantities, meeting the potential demand for blood products.

Types of HBS

There are two types of human blood substitutes - **Haemoglobin-based oxygen carriers (HBOCs) and perfluorocarbons (PFCs).**

- HBOCs are based on the hemoglobin molecule, which is the protein in red blood cells that carries oxygen to the body's tissues.
- Hemoglobin is extracted from human or animal blood and then modified to create a stable, synthetic version.
- When introduced into the body, HBOCs can help to increase the amount of oxygen available to the tissues, which can be important in situations where the body is unable to produce or transport enough red blood cells.

PFCs (Perfluorocarbons)are

- Synthetic molecules that are similar in structure to the hemoglobin molecule.
- Unlike HBOCs, they do not require modification from natural sources.
- PFCs are able to dissolve oxygen and transport it throughout the body, similar to the way that red blood cells work

Examples of HBOCs

There are several examples of hemoglobin-based oxygen carriers (HBOCs) that have been developed or are currently in development.
Here are a few examples:

Hemopure: Hemopure is an HBOC that is made from bovine hemoglobin. It has been approved for use in South Africa, Russia, and some other countries.

Oxyglobin: Oxyglobin is another HBOC that is made from bovine hemoglobin. It is approved for veterinary use in the United States and has been used to treat anemia in dogs.

Hemospan: Hemospan is an HBOC that is being developed by Sangart Inc. It is currently in clinical trials and has shown promise in increasing oxygen delivery to tissues.

MP4OX: MP4OX is an HBOC that is being developed by Baxter Healthcare. It is designed to increase oxygen delivery to tissues and also to scavenge harmful free radicals in the bloodstream.

Hemolink: Hemolink is an HBOC that is being developed by Hemosol Inc. It is designed to be used in trauma and surgical settings and has shown promise in improving oxygen delivery to tissues.
(Note: Many countries have not yet given regulatory approval for clinical usage of HBOCs)