

# Module 4

## NATURE-BIOINSPIRED MATERIALS AND MECHANISMS

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 perfluorocarbons (PFCs).

### **Echolocation**

Echolocation is a biological or technological process that involves emitting sound waves and listening to the echoes that bounce back off of objects in the environment to determine their location, distance, and shape.

In biology, the use of echolocation by animals has been well documented for centuries. Ancient Greeks, for example, observed bats using echolocation to navigate and find food in the dark. The scientific study of echolocation in animals, however, only began in the early 20<sup>th</sup> century, with the pioneering work of British naturalist Donald Griffin. Griffin's research showed that bats were using echolocation to navigate and hunt and helped to lay the foundation for the modern study of biological echolocation.

A comparison of biological echolocation and technological echolocation is given below:

### **Biological Echolocation**

- Found in various animals such as bats, dolphins, and some species of whales. Relies on the emission of sound waves, usually in the form of clicks or vocalizations.
- Animals emit sound waves and listen for the echoes produced when the sound waves bounce off objects in their environment. By analysing the echoes, animals can determine the location, distance, and even the shape of objects around them.
- This ability is mainly used for navigation, hunting, and communication in the animal kingdom. Biological echolocation is a natural adaptation that has evolved over millions of years.

## **Technological Echolocation**

- Replicates the concept of biological echolocation using technological devices.
- Utilizes sound waves, typically generated by artificial sources such as sonar or ultrasonic sensors.
- These devices emit sound waves and analyse the echoes that bounce back from objects.
- The information from the echoes is processed and interpreted by the technology to generate useful data, such as distance, location, and object recognition.
- Technological echolocation has applications in various fields, including navigation, robotics, obstacle detection, and medical imaging.
- It is a human-engineered solution inspired by the natural abilities of animals.

## **Principle of Echolocation**

Both biological and technological echolocation rely on the same basic principle have the same underlying purpose: to determine the location, distance, and shape of object using sound waves and their echoes.

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

A concise explanation of the principle of echolocation is given below:

**Sound Emission:** The echolocating organism, whether biological or technological emit sound waves into its surroundings. In biological echolocation, this is typically achieved through vocalizations or clicks, while in technological echolocation, it is usually using 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 in the environment, such as obstacles or prey, 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:** The echolocating organism, whether biological or technological, has sensory receptors capable of detecting and processing the returning echoes.

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 contained in the echoes is analysed and interpreted by the organism or technology. This interpretation involves extracting relevant features from the echoes and 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.

## **ULTRASONOGRAPHY**

- Ultrasonography is a medical imaging technique that uses high-frequency sound waves to produce images of the internal organs and tissues of the body. It is also known as ultrasound imaging or sonography.
- The ultrasound machine emits high-frequency sound waves (usually in the range of 2 to 18 MHz) that travel through the body and bounce back off of the internal organs and tissues. The returning echoes are captured by the ultrasound machine and used to create images of the internal structures.
- Ultrasonography is a non-invasive, safe, and painless imaging method that can be used to visualize a wide range of structures within the body, including the organs of the abdomen, pelvis and chest, as well as the uterus, foetus, and other soft tissues. It is commonly used in prenatal care to monitor the growth and development of the foetus and to diagnose any potential problems.
- Ultrasonography has several advantages over other imaging methods, including its low cost, ease of use, and lack of ionizing radiation. It is also portable and can be used in a variety of settings, making it a valuable tool for medical professionals.

## **Uses of Ultrasonography**

Ultrasonography is a versatile imaging method that is used in a wide range of medical applications.

Some of the most common uses of ultrasonography include:

**Obstetrics and gynaecology:** Ultrasonography is commonly used to monitor the growth and development of a foetus during pregnancy, as well as to evaluate the reproductive organs and female pelvic organs for conditions such as ovarian cysts, fibroids, and endometrial cancer.

**Abdominal imaging:** Ultrasonography is used to image the organs of the abdomen, such as the liver, gallbladder, pancreas, spleen, and kidneys, to diagnose conditions such as liver disease, gallstones, pancreatitis, and kidney stones.

**Musculoskeletal imaging:** Ultrasonography is used to image the muscles, tendons, and ligaments to diagnose conditions such as muscle strains, tendonitis, and ligament sprains.

**Vascular imaging:** Ultrasonography is used to image blood vessels, such as the arteries and veins, to treat conditions such as blood clots, blockages.

**Eye and neck imaging:** Ultrasonography is used to image the eyes and neck.

**Emergency medicine:** Ultrasonography is often used in emergency medicine to quickly and accurately diagnose conditions such as appendicitis, pneumothorax, and fluid buildup in the abdomen or chest.

Overall, ultrasonography is a widely used imaging method that provides valuable information for the diagnosis and treatment of a wide range of medical conditions. Its non-invasive nature, real-time imaging capability, and versatility make it an important tool for healthcare providers.

## **Working Principle of Ultrasonography**

The working principle of ultrasonography is based on the reflection of high-frequency sound waves.

**Transducer:** An ultrasonography machine consists of a transducer that is used to emit and receive high-frequency sound waves. The transducer is placed in direct contact with the skin or inserted into the body through a gel.

**Emission of sound waves:** The transducer emits high-frequency sound waves (usually in the range of 2 to 18 MHz) into the body. These sound waves travel

through the body and encounter different tissues and organs, which have different acoustic properties.

**Reflection of sound waves:** The sound waves encounter boundaries between different tissues and organs and bounce back, creating echoes. The strength of the echoes depends on the acoustic properties of the tissues and organs, such as density and stiffness.

**Reception of echoes:** The transducer in the ultrasonography machine receives the 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.

### **Advantages of Ultrasonography**

**Non-invasive:** Ultrasonography 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.

**Real-time imaging:** Ultrasonography provides real-time images that can be used to monitor the movement and function of internal organs and tissues in real-time.

**Portable:** Ultrasonography machines are portable and can be used in a variety of settings, making it a valuable tool for emergency and rural medicine.

**Cost-effective:** Ultrasonography is a cost-effective imaging method that does not require 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, foetus, and other soft tissues.

### **Limitations of Ultrasonography**

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

**Operator dependence:** The quality of the images produced by ultrasonography based 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.

### **Sonars**

Sonar, which stands for Sound Navigation and Ranging, is a technology that uses sound waves to detect and locate underwater objects.

### **Uses of Sonars**

Sonars are commonly used for a variety of purposes, including:

**Naval applications:** Sonars are used by naval vessels to detect and locate other submarines, and underwater obstacles, allowing them to navigate safely and avoid potential collisions.

**Fishery:** Sonars are used in the fishing industry to locate schools of fish and determine the depth of the water, allowing fishermen to more efficiently target their catch.

**Oceanography:** Sonars are used in 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.

Sonar technology works by emitting a series of sound pulses and listening for the echoes that bounce back from underwater objects. The time it takes for the echoes to return is used to calculate the distance to the objects, and the frequency and pattern of the echoes are used to determine their size and shape.

## **Working Principle of Sonars**

The working principle of sonar technology is based on the reflection of sound waves.

Here's how it works:

**Transmitter:** A sonar system consists of a transmitter that produces and emits a series of sound pulses into the water. These 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, travel the target object and bounce back as echoes. The speed of sound in water is slower than air, and it depends on the temperature, pressure, and salinity of the water.

**Receiver:** The sonar system also includes a receiver that listens for 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 and 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 its 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 measurement are typically displayed on a screen or other output device, allowing the operator to visualize the target object and its location.

## **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 images of underwater objects and structures.

### **Limitations of Sonar Technology**

**Limited visibility:** Sonar imaging is limited by the visibility of the water, which can be affected by factors such as sediment, algae, and water temperature. This can make it difficult to obtain clear and accurate images.

**Interference:** Sonar signals can be affected by interference from other underwater sources, such as ships, submarines, and natural underwater features, which can lead to false readings and reduced accuracy.

**Short range:** Sonar signals have a limited range, which can make it difficult to image larger underwater structures or objects that are located far away from the sonar system.

**Limited depth:** The depth to which sonar can effectively penetrate is limited, making it unsuitable for imaging objects or structures that are located at great depths.

**Acoustic noise:** The use of sonar technology can also generate acoustic noise, which can disturb marine life and harm marine ecosystems. This is particularly a concern for high-power, military-grade sonar systems, which have the potential to cause serious harm to marine life.

**Complex technology:** Sonar technology can be complex, requiring specialized skills and equipment to operate and maintain. This can limit its accessibility and increase the cost of implementation.

**Inaccurate readings:** Sonar readings can be inaccurate due to factors such as reflection, refraction, and absorption of sound waves, which can result in incorrect measurements and false readings.

### **Photosynthesis**

Photosynthesis is the process by which plants, algae, and some bacteria convert light energy from the sun into chemical energy stored in organic molecules. This process is critical for life on Earth, as it provides the primary source of energy for all living organisms.



## The Process of Photosynthesis in Plants and in Some Animals

- The process of photosynthesis in plants and some animals differs in terms of the type of organisms involved and the specific details of the process. However, the basic principle of converting light energy into usable forms of energy is the same in both.
- In plants, photosynthesis takes place in the chloroplasts of the cells located in the leaves. The process starts with the absorption of light energy by pigments such as chlorophyll, which then excites electrons. These excited electrons are used to power the transfer of carbon dioxide into organic molecules, such as sugars and starches, through a series of chemical reactions. The end product of photosynthesis in plants is stored chemical energy in the form of organic compounds.
- In some animals, such as algae, photosynthesis also takes place in chloroplasts. The process is essentially the same as in plants, with the absorption of light energy and the conversion of carbon dioxide into organic molecules.
- In contrast, some animals such as jellyfish, have a symbiotic relationship with photosynthetic organisms, such as algae. In this relationship, the animal provides a safe and stable environment for the photosynthetic organism, while the photosynthetic organism provides energy in the form of organic compounds produced through photosynthesis.
- Light dependent reaction' and light independent reactions (also called Calvin cycle ) are two interconnected processes that occur in the chloroplasts of plants and algae during photosynthesis.

### Light dependent reactions

Light energy is absorbed by chlorophyll and other pigments in the thylakoid membranes of chloroplast .



Water molecules are split through a process called photolysis, releasing electrons, protons and oxygen.



The excited electrons from photolysis are captured by electron carriers, such as NADP<sup>+</sup> (Nicotinamide Adenine Dinucleotide Phosphate) and converted to NADPH (Nicotinamide Adenine Dinucleotide Phosphate).



Adenosine diphosphate (ADP) combines with inorganic phosphate (Pi) to form adenosine triphosphate (ATP). This process is known as phosphorylation and is a fundamental step in cellular energy metabolism.



Oxygen molecules (O<sub>2</sub>) generated from the splitting of water are released as a byproduct into the Atmosphere.

### **Light-Independent Reactions (Calvin Cycle):**

Carbon dioxide from the atmosphere enters the stroma of the chloroplasts.



Carbon fixation occurs and forms a unstable six-carbon compound



The resulting unstable six-carbon compound quickly breaks down into two molecules of 3-phospho glycerate(PGA).



ATP and NADPH, produced during the light-dependent reactions, provide energy and electrons for the reduction of PGA to glyceraldehyde-3-phosphate (G3P).



Some G3P molecules are used to produce glucose and other organic molecules.



The remaining G3P molecules are recycled and used in subsequent cycles of the Calvin cycle.



Glucose and other carbohydrates produced during the Calvin cycle can be stored for later use or utilized in metabolic processes to meet the energy and growth needs of the plant.

Overall, the process of photosynthesis is a critical aspect of life on Earth and provides the primary source of energy for all living organisms. While the specific details of the process may differ between plants, algae, and some animals, the basic principle of converting light energy into usable forms of energy remains the same.

### **Photovoltaic Cells**

- The connection between photosynthesis and photovoltaics lies in the conversion of energy into usable forms of energy. 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.
- However, the similarities between photosynthesis and photovoltaics go beyond just the conversion of light energy. Both 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.
- The development of photovoltaics has been heavily influenced by the natural process of photosynthesis, and many researchers have sought to mimic and improve upon the efficiency and effectiveness of photosynthesis in order to develop more advanced and efficient photovoltaic systems.

- The study of photosynthesis has thus played a significant role in the development of sustainable energy systems and continues to be an important area of research in the Photovoltaic Cells.

### **New Technology Photovoltaic Cells**

Photovoltaic cells, also known as solar cells, are devices that convert light energy from the sun into electrical energy. The technology behind photovoltaic cells has advanced significantly in recent years, leading to the development of new and improved photovoltaic cell designs and materials.

Some of the new technologies in photovoltaic cells include:

**Perovskite solar cells:** Perovskite solar cells are 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:** Thin-film photovoltaic cells are a type of photovoltaic cell that uses a thin layer of material, such as silicon or cadmium telluride to convert light based photovoltaic cells and are ideal for use in portable and flexible solar panels.

**Concentrator photovoltaic cells:** Concentrator photovoltaic cells are a type 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:** Multi-junction photovoltaic cells are 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 systems. These are just a few examples of the new technologies in photovoltaic cells. The field of photovoltaics is constantly evolving, and there are many ongoing efforts to develop new and improved photovoltaic cell designs and materials that are more efficient, affordable, and environmentally friendly.

### **Bionic Leaf**

- A bionic leaf is a system that uses artificial photosynthesis to convert sunlight into usable forms of energy, such as hydrogen or other biofuels. The bionic leaf is designed to 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.

- The bionic leaf consists of a photovoltaic cell that captures sunlight and converts it into electrical energy, and 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.

### **Components of Bionic Leaf**

A bionic leaf is a biohybrid system that mimics the natural process of photosynthesis to convert sunlight into chemical energy. It typically consists of several key components that work together to facilitate this conversion. Here are the main components of a bionic leaf:

**Photosynthetic Organism:** The bionic leaf utilizes a photosynthetic organism, such as a cyanobacterium or a genetically modified plant, as the primary component. This organism 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 catalysing the conversion of carbon dioxide into fuels or other chemical compounds.

**Electron Transfer Pathway:** An electron transfer pathway is an essential component of the bionic leaf system. It 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.

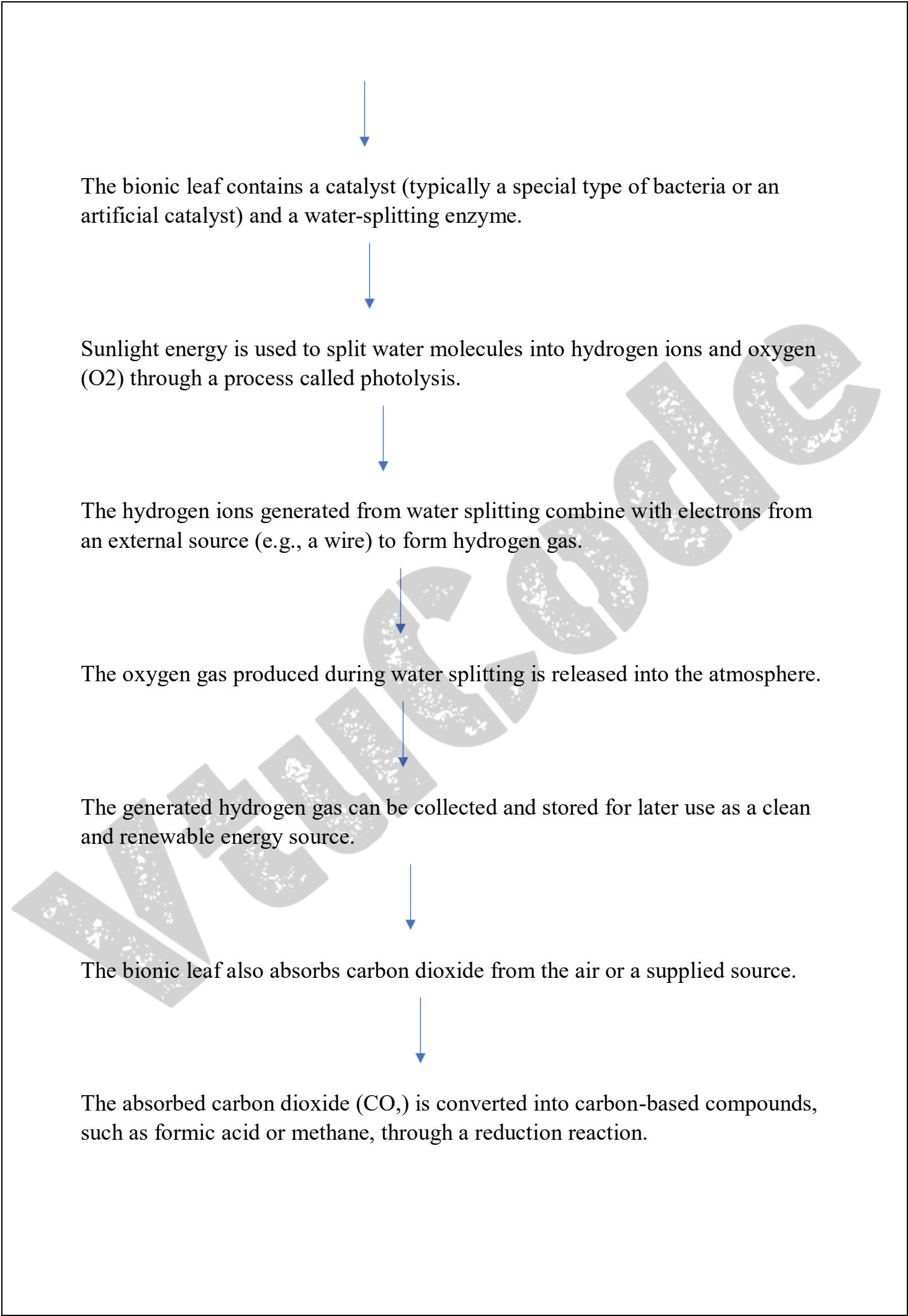
**Control and Monitoring System:** To optimize performance and ensure efficient operation, a bionic leaf typically incorporates a control and monitoring system. This system monitors various parameters such as light intensity, temperature, pH, and carbon dioxide levels, and allows for adjustments and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

### **Working principle**

- The working principle of a bionic leaf is based on artificial photosynthesis, which mimics the process of photosynthesis in plants. The bionic leaf typically consists of a photovoltaic cell that captures sunlight and converts it into electrical energy, and a catalyst, such as a bacterium, that uses the electrical energy to split water molecules into hydrogen and oxygen. The photovoltaic cell is used to convert sunlight into electrical energy, which is then passed to the catalyst.
- The catalyst, in turn, uses the electrical energy to power the process of water splitting, where water molecules are separated into hydrogen and oxygen. This process is facilitated by the presence of enzymes or other catalysts that act as a bridge between the electrical energy and the water splitting reaction.
- 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.
- Additionally, the oxygen produced by the bionic leaf can be released into the atmosphere. Where it can help to mitigate the effects of climate change by reducing the levels of atmospheric carbon dioxide.

A flow chart of the 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 into hydrogen ions and oxygen (O<sub>2</sub>) through a process called photolysis.

The hydrogen ions generated from water splitting combine with electrons from an external source (e.g., a wire) to form hydrogen gas.

The oxygen gas produced during water splitting is released into the atmosphere.

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

The bionic leaf also absorbs carbon dioxide from the air or a supplied source.

The absorbed carbon dioxide (CO<sub>2</sub>) 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 during water splitting is reused by the catalyst in subsequent cycles.

### **Applications of Bionic Leaf Technology**

Here are some applications of bionic leaf technology:

**Renewable Energy Production:** One of the primary applications of bionic leaf technology is in the production of renewable energy. 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 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 off-grid 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.

### **Bird flying**

- Birds fly by flapping their wings and using their body weight and the movement of air to stay aloft. They navigate using a combination of visual cues, the Earth's magnetic field, and celestial navigation. Aircraft, on the other hand, use engines to generate thrust and lift from the wings to stay in the air.
- They navigate using a combination of instruments and systems including GPS (Global Positioning System), which uses satellite signals to determine the aircraft's position and help it navigate. Although birds and aircraft both fly, their mechanisms and methods of navigation are quite different.
- Birds flying influenced the invention of aircraft in that early aviation pioneers, such as the Wright brothers, observed and studied the flight of birds to develop their flying machines.
- They noted how birds used their wings and body to achieve lift and control their flight, and used this knowledge to design and improve aircraft.
- The development of GPS technology was not directly influenced by birds, but rather by the need for accurate and reliable navigation systems for various purposes, including aviation.
- GPS uses a network of satellites to provide location and time information, which is used by aircraft for navigation, communication, and safety purposes.

**The science behind the birds flies using its wings and holding their body weight in air**

- The ability of birds to fly and support their body weight in the air is a result of various anatomical and physiological adaptations. Here's a simplified explanation of the science behind bird flight:
- **Wing Shape:** Birds have specialized wings with a unique shape that generates lift. The wings are curved on the upper surface and flatter on the bottom, creating a pressure difference known as Bernoulli's principle. This pressure difference generates lift allowing birds to stay airborne.
- **Wing Muscles:** Birds have strong flight muscles attached to their wings, allowing them to flap their wings vigorously. The upstroke and downstroke motion of the wings generates thrust, propelling the bird forward through the air.
- **Hollow Bones:** Birds have lightweight bones that are hollow and filled with air sacs. Reducing their overall weight. This makes it easier for them to stay aloft.
- **Feathers:** Feathers play a crucial role in flight. They provide both lift and control. The primary feathers at the tips of the wings help generate lift, while the tail feathers assist in maneuvering and stabilizing during flight.
- **Respiratory System:** Birds have a unique respiratory system that allows for efficient oxygen exchange. Air flows unidirectionally through their lungs, as well as through a system of air sacs located throughout their body. This constant supply of oxygen fuels their high metabolic demands during flight.
- **Efficient Circulatory System:** Birds have a highly efficient circulatory system that delivers oxygen-rich blood to their muscles and organs. Their heart rate increases during flight, ensuring a steady supply of oxygen to meet the demands of their active muscles.
- **Flight Control:** Birds have remarkable coordination and control over their flight. They can adjust the angle and shape of their wings, control their speed and direction, and perform intricate aerial maneuvers using their tail, wings, and body movements.
- It's important to note that bird flight is a complex process influenced by several factors, including aerodynamics, muscle strength metabolic efficiency and specialized adaptations science behind bird flight continues to be an area of study and fascination for researchers and aviation engineers alike.

### GPS Technology

GPS (Global Positioning System) is a technology that uses a network of satellite provide location and time information to users. The technology works by

measuring the time it takes for signals to travel from satellites to a receiver on the ground or in a vehicle, and using the information to calculate the user's position.

### **Here are some key components of GPS technology:**

**Satellites:** The GPS satellite network consists of 24-32 satellites orbiting the Earth. These satellites continuously broadcast signals containing information about their location, time, and status.

**Receivers:** GPS receivers, which are typically integrated into devices such as smartphones, navigation systems, and aircraft, receive signals from GPS satellites and use the information to calculate the user's position.

**Control segment:** The control segment consists of ground-based monitoring stations that track the GPS satellites, check the accuracy of their signals, and make adjustments as needed.

**User segment:** The user segment consists of the GPS receivers used by individuals and organizations to obtain location and time information.

GPS technology has a wide range of applications, including navigation, mapping, surveying, search and rescue, and military operations. The accuracy and reliability of GPS have improved over time, and the technology continues to evolve with new developments in satellite and receiver technology, as well as the integration of GPS with other technologies such as augmented reality and artificial intelligence.

### **Importance of GPS Technology in Aircrafts**

**Positioning and Navigation:** GPS helps aircraft accurately determine their position and follow precise routes. Signals from satellites are received by GPS receivers onboard, allowing the system to calculate the aircraft's position.

**Flight Planning:** GPS assists pilots and planners in creating optimal flight plans, considering waypoints, altitudes, and current information on navigation aids, weather, and airspace restrictions.

**Approach and Landing:** GPS-based navigation systems provide precise guidance during approach and landing, even in low visibility. This enhances safety and reduces reliance on ground-based navigation aids.

**Air Traffic Management:** GPS is integrated into air traffic management systems, improving airspace efficiency, reducing congestion, optimizing

routing, and enhancing aircraft tracking and situational awareness for controllers.

**Collision Avoidance:** GPS contributes to collision avoidance systems like TCAS and ADS-B. These systems use GPS data to track nearby aircraft, provide alerts, and ensure safe separation.

**Flight Data Recording:** GPS data is often recorded by flight data recording systems, aiding post-flight analysis, accident investigation, and overall flight safety improvements. GPS technology has revolutionized aircraft navigation and has become an integral part of modern aviation. It provides accurate positioning, enhances safety, improves operational efficiency, and contributes to the overall advancement of the aviation industry. Comparing Birds and Aircrafts with GPS Technology for Navigation

### **Aircraft Technology**

Aircraft technology has advanced significantly since the first powered flight by the Wright brothers in 1903. Here are some key components of modern aircraft technology:

**Aerodynamics:** Modern aircraft are designed to be more aerodynamic, with wing shapes optimized for lift and efficiency. Advanced materials and manufacturing techniques have also been developed to reduce weight and improve durability.

**Jet engines:** Jet engines, which use the principles of Newton's third law of motion to produce thrust, have replaced propeller engines in most modern aircraft. These engines are more powerful, fuel-efficient, and reliable.

**Avionics:** Avionics, or aviation electronics, have advanced significantly with the development of digital technology. Flight instruments, navigation systems, and communication systems have become more precise, reliable, and sophisticated.

**Safety systems:** Aircraft safety systems have been developed to reduce the risk of accidents and improve passenger safety. These include systems for collision avoidance, weather detection, and emergency response.

### **Bio Mimicking Birds Fly for Aircraft Technology**

Biomimicry, or the practice of using designs and processes found in nature to solve human problems, has led to the development of various technologies inspired by birds' flight. Some examples include:

**Wing design:** The shape of bird wings has inspired the design of aircraft wings, which mimicking the way birds and insects fly. These drones can be used for v

applications, such as monitoring crops and wildlife, inspecting buildings and infrastructure, and search and rescue operations.

**Landing gear:** The legs and feet of birds have inspired the design of landing gear for aircraft, with shock-absorbing and retractable structures that help absorb impact upon. The future of transportation through the air. The future of transportation through the air holds exciting possibilities with emergence of new technologies and concepts. Here are some potential modes transportation that could shape the future:

**Electric Vertical Take off and Landing (VTOL) Aircraft:** These are electric-powered aircraft that can take off and land vertically, similar to helicopters. They are being designed for urban air mobility and short-distance transportation, offering a more efficient and environmentally friendly alternative to traditional helicopters.

**Autonomous Flying Vehicles:** Autonomous drones and flying taxis are being developed for various applications, including transportation of people and goods. These vehicles would operate without a pilot and rely on advanced sensors, artificial intelligence, and automation to navigate safely.

**High-Speed Air Travel:** Supersonic and hypersonic aircraft are being explored to revolutionize long-distance travel. These aircraft would travel at extremely high speeds, significantly reducing travel times and opening up new possibilities for global connectivity.

**Personal Air Vehicles (PAVs):** PAVs are compact flying vehicles designed for individual use. They could potentially serve as a convenient mode of transportation for short-distance travel within cities, similar to personal cars but in the air.

**Hyperloop Transportation:** While not strictly an air-based mode of transportation, the Hyperloop concept involves high-speed capsules traveling through low-pressure tubes, offering near-supersonic speeds. This mode of transportation could connect distant cities and regions in a fast, energy-efficient manner.

### **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 repellence 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 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 AND VELCRO**

Plat burrs such as those found on burdock, inspired the invention of Velcro a popular hook and loop fastening system.

- 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 examined the burrs under a microscope and found that they had small hooks that could latch onto loops in fabric.

- De Mestral spent years experimenting with different materials before finally developing Velcro, which consists of two strips of nylon fabric, one with tiny hooks and the other with small loops. When pressed together, the hooks latch onto the loops, creating a strong bond that can be easily detached by pulling the two strips apart. Velcro has a wide range of applications, including in clothing, shoes, bags, and medical devices. It has become a popular alternative to traditional fasteners, such as buttons and zippers, due to its ease of use and versatility.
- The name "Velcro" is actually an combination of the words "velvet" and "crochet," as the fabric strips resemble velvet and are hooked together like crochet. Velcro has since become a popular alternative to traditional fasteners, such as buttons and zippers, due to its ease of use and versatility.
- Velcro is used in medical devices such as braces, splints, and compression garments because of 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.
- Sports equipment: secure and adjustable fit. Velcro is used in sports equipment, such as helmets and gloves. for its ability to provide a

### **Shark Skin and Friction Reducing Swim Suits**

The denticles on shark skin have evolved over millions of years to reduce drag and increase swimming efficiency. These structures disrupt the flow of water around the shark's body, reducing turbulence and minimizing the formation of vortices. As a result, sharks can swim faster and with less effort compared to other fish.

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. This disruption reduces the resistance the shark experiences as it swim, allowing it to move faster and with less effort.

### **Turbulence in Water**

Turbulence is when a fluid, like water or air, becomes chaotic and unpredictable. Instead of flowing smoothly, it swirls and forms irregular patterns. This turbulence creates resistance or drag, which makes it harder for things to move through the fluid. In swimming, reducing turbulence is important because it helps to minimize resistance, allowing swimmers to move more easily and efficiently through the water.

## **Reducing Drag**

When a shark swims through the water, the water normally flows smoothly over it. However, the denticles on the shark's skin disrupt this smooth flow. They create small disturbances in the water, which helps to break up turbulent currents that can slow the shark down. By reducing turbulence, the denticles make the flow of water around the shark's body smoother. This smoother flow reduces the resistance allowing it to swim more efficiently.

## **Frictionless Swim Suits**

Shark skin has inspired the development of friction-reducing swim suits, which are designed to improve the performance of swimmers by reducing drag in the water. Friction-reducing swim suits 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 swim suits inspired by shark skin include:

**Polyurethane:** A type of polymer that is commonly used in the production of swim suits, as it is durable and can be moulded into a variety of shapes.

**Lycra/Spandex:** Lycra and spandex are made from the same synthetic fibre, which is technically called elastane. Elastane fibres are typically composed of a polymer called polyurethane which is then blended with other fibres like nylon polyester, or cotton) that is known for its stretch and flexibility.

**High-tech fabrics:** A range of high-tech fabrics have been developed specifically for use in swim suits. These fabrics are designed to be lightweight, water-repellent, and hydrodynamic.

## **Kingfisher beak and bullet train**



The kingfisher beak is an excellent example of nature's design for efficient diving and fishing. Its unique shape and structure enable the kingfisher to minimize the impact of water resistance and achieve a successful dive.

## **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. The streamlined shape allows the kingfisher to smoothly cut through the air and minimize the energy required for the dive.

When the kingfisher hits the water, it encounters the resistance caused by surface tension.

Surface tension is the cohesive force between water molecules that creates a "skin" on the water's surface. The sharp beak of the kingfisher helps to pierce through the water's surface, breaking the surface tension and reducing the force required to enter the water.

### **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.

### **Technological Importance**

The use of the kingfisher beak as a design inspiration for the front of the bullet train example of how nature-inspired engineering can lead to innovative solutions that improve performance and efficiency of machines. Shinkansen bullet train of Japan is the best example which used the biomimicry of kingfisher's beak.

### **Aerodynamic Design:**

The streamlined design minimizes drag as the train travels at high speeds, allowing it to maintain stability and efficiency. The smooth, tapered shape reduces the pressure difference between the front and rear of the train, reducing noise and vibration.

**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 is designed to reduce these pressure waves by effectively managing airflow and minimising the compression and expansion of air as the train enters and exits tunnels. This reduces the noise level and enhances passenger comfort.

## **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. This is a fundamental function of natural blood that any substitute should be able to replicate or improve upon.

Safety and Compatibility:

Blood substitutes should be safe for use in the human body and well tolerated by the recipient. They should not cause any adverse reactions. They should not interfere with normal blood clotting and any other physiological process.

Storage and Transport:

Human blood substitutes should be stable and capable of being stored and transported easily. This is particularly important in emergency situations or areas where access to blood products may be limited. 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. They should be affordable 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 - hemoglobin-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 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 are synthetic molecules that are similar in structure to the hemoglobin molecule. However, 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.

## **Hemoglobin-Based Oxygen Carriers**

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.

Availability in remote or challenging settings:

In remote or underdeveloped areas where access to safe blood transfusions may be limited, HBOCs can potentially provide a viable alternative for oxygen delivery. This can be particularly beneficial in military settings, disaster relief efforts, or during transport of patients where immediate access to blood is not feasible.

#### Short half-life:

HBOCs tend to have a shorter half-life in the body compared to natural red blood cells. This means that the HBOCs may be rapidly cleared from circulation, reducing their effectiveness and requiring more frequent doses or infusions.

#### Nitric oxide scavenging:

HBOCs have a tendency to scavenge nitric oxide, a molecule important for regulating blood vessel dilation and maintaining normal blood flow. Excessive nitric oxide scavenging by HBOCs can lead to vasoconstriction, impairing blood flow to vital organs and potentially causing adverse cardiovascular effects.

#### Renal toxicity:

Some HBOCs have shown a potential for renal toxicity, causing damage to the kidneys. This can be a significant concern as the kidneys play a crucial role in filtering and excreting waste products from the body.

#### Immunogenicity and adverse reactions:

HBOCs can trigger immune responses in the body, potentially leading to allergic reactions or other adverse events. Immunogenicity can vary between different HBO products and individuals, and careful monitoring is necessary to identify and manage any potential adverse reactions.

## **QUESTION BANK**

### **L-1**

1. Define echolocation.
2. What is ultrasonography.
3. What are sonars?
4. What is photosynthesis?
5. Define bionic leaf.

### **L-2**

1. Explain the working principle of ultrasonography and discuss its advantages and limitations in medical imaging.
2. Compare and contrast biological echolocation and technological echolocation, highlighting their applications and significance in navigation and detection.
3. Discuss the different types of bioprinting materials, such as hydrogels, cell-laden aggregates, decellularized extracellular matrix (dECM), synthetic polymer-based bioinks, and composite bioinks. Explain how these materials mimic the natural environment for cells and tissues.
4. Describe the working principle of a bionic leaf and explain how it mimics the process of photosynthesis. Discuss its potential applications in renewable energy production and carbon dioxide reduction.
5. Explain the components and working principle of a bionic leaf system. Discuss its applications in sustainable chemical production, agriculture, and environmental remediation.
6. Discuss the advancements in photovoltaic cell technology, including perovskite solar cells, thin-film photovoltaic cells, concentrator photovoltaic cells, and multi-junction photovoltaic cells. Explain how these technologies contribute to the development of sustainable and efficient solar energy systems.
7. Explain the importance of GPS technology in aircraft navigation and its evolution over time. Discuss its applications in flight planning, approach and landing, and air traffic management.
8. Discuss the advancements in aircraft technology, including aerodynamics, jet engines, avionics, safety systems, and automation. Explain how biomimicry has contributed to aircraft design inspired by bird flight.

9. Explore the future of air transportation, including electric vertical takeoff and landing (eVTOL) aircraft, autonomous flying vehicles, high-speed air travel, personal air vehicles (PAVs), and the Hyperloop concept. Discuss the potential benefits and challenges associated with these emerging technologies.
10. Explain the lotus leaf effect and its application in creating super hydrophobic and self-cleaning surfaces. Provide examples of industries where these surfaces are utilized and discuss their benefits.

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