MODULE 1: Sensors and Energy Systems

Sensors: Introduction, working, principle and applications of Conductometric sensors, Electrochemical sensors, Thermometric sensors (Flame photometry) and Optical sensors (colorimetry). Sensors for the measurement of dissolved oxygen (DO). Electrochemical sensors for the pharmaceuticals. Electrochemical gas sensors for SO_x and NO_x. Disposable sensors in the detection of biomolecules and pesticides.

Energy Systems: Introduction to batteries, construction, working and applications of Lithium ion and Sodium ion batteries. Quantum Dot Sensitized Solar Cells (QDSSC's)- Principle, Properties and Applications.

Self-learning: Types of electrochemical sensor, Gas sensor - O_2 sensor, Biosensor - Glucose sensors.

Sensors

Sensor is an object that detects signals from its surrounding environment and converts it to meaningful or quantifiable information. Eyes, ears, and nose are all different types of sensors that help you navigate your surroundings on a day-to-day basis by detecting and processing light, sound, and smell/taste.

Conductometric sensors

Principle:

The basic principle of conductometric detection involves a reaction that can change the concentration of ionic species. This reaction leads to changes in electrical conductivity or current flow. Conductometric biosensors can measure the change of the specific conductance/electrical conductivity of the analyte. In this method, two inert metal electrodes are used. The ions or electrons produces during an electrochemical reaction may change the conductivity or resistivity of the solution.

Working of conductometric sensor

The conductivity is result of dissociation an electrolyte, into ions. The migration of the ions is induced by an electrical field. When a potential difference is applied to the electrode, there is an electrical field within the electrolyte, so the positively charged ions move towards cathode and negatively charged ions are move towards anode (Figure). Thus, the current in the electrolyte is caused by the ion movement towards the electrodes where the ions are neutralized and isolated as neutral atoms (or molecules). This chemical change is recognized by working electrode and transducers converts this chemical change into electrical signal.

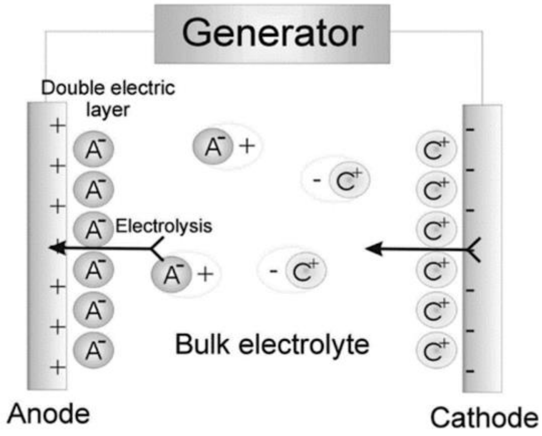


Figure 1. Construction of Conductometric sensor

Application of conductometric sensor

i. Aptamer Technology for the Detection of Foodborne Pathogens and Toxins
ii. Advanced Nanoparticle-Based Biosensors for Diagnosing Foodborne Pathogens
iii. Microfluidic electrochemical devices for pollution analysis.
iv. It is used for DNA Detection.
v. It is used in enzyme catalysis to determine analyte concentration and enzyme activity and selectivity.
vi. Screen-printed conductometric sensor with inter digital gold electrodes on glass substrate coated with molecularly imprinted polyurethane layers was fabricated to detect polycyclic aromatic hydrocarbons (PAHs) in water.
vii. A conductometric sensor consisting of a silicon substance with a pair of gold inter digitized and serpentine electrodes is used to determine urea.
viii. The conductometric biosensor based on inhibition analysis, was intended for the determination of organophosphorus pesticides.

Electrochemical Sensors:

Principle:

Electrochemical reactions take place at electrode-electrolyte interfaces and provide a switch for electricity to flow between two phases of different conductivity, i.e. the electrode (electrons or holes are the charge carriers) and solid or liquid electrolyte (ions are the main charge carriers). The reactions which occur at the interface of the surface of an electrode between the recognition element, and the target/binding analyte generate an electrical double layer and thus this potential is measured after transforming these chemical reactions into this measurable electrochemical signal by a recognition element, and a transducer of the sensor.

Construction and Working

- The fundamental concept in the detection of analytes by electrochemical sensors involves the measurement of electric current generated by chemical reactions in the electrochemical system.

- Electrochemical sensors are made up of three essential components: a receptor that binds the sample, the sample or analyte, and a transducer to convert the reaction into a measurable electrical signal. In the case of electrochemical sensors, the electrode acts as the transducer. Electrochemical sensing always requires a closed circuit. Current must flow to make a measurement In most electrochemical sensors. An electrode surface is used as the site of the reaction. The electrode will either oxidize or reduce the analyte of interest. The current that is produced from the reaction is monitored and used to calculate important data such as concentrations from the sample
- Electrochemical sensor's working mechanism involves the interaction of the target analyte material with the electrode surface and bringing the desired change as a consequence to a redox reaction, which generates an electrical signal that can be transformed to explore the nature of the analyte species.

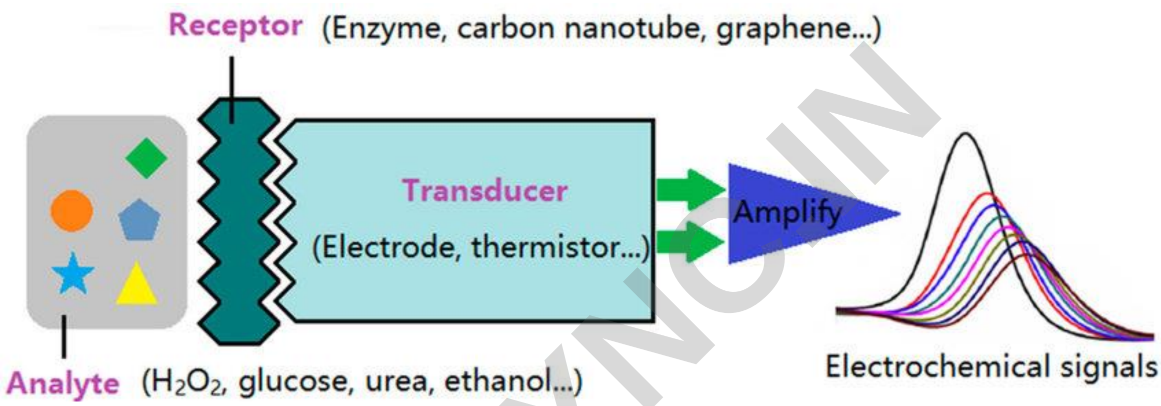


Figure 2. Electrochemical Sensor

Application Electrochemical sensors-

- Detection of important molecules or biomarkers that are used for the diagnosis of diseases and disorders.
- They are used for the monitoring toxic levels of different substances in food quality and environmental control.
- The biosensor application areas of these sensors extend to medical and biomedical applications, process control, bioreactors, quality control, agriculture, bacterial and viral diagnosis, industrial wastewater control.

Thermometric Sensors

A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor, or signal temperature changes. There are many different types of temperature sensors. The fundamental working of this sensor is based on the voltage in its diode. The temperature variation is directly related to the resistance of this diode. The resistance of the diode is detected and transformed into simple and readable values of temperature such as Fahrenheit, Kelvin, or Centigrade and demonstrated in meaningful formats instead of readout values. These temperature sensors are employed to sense the internal temperature of various structures like power plants.

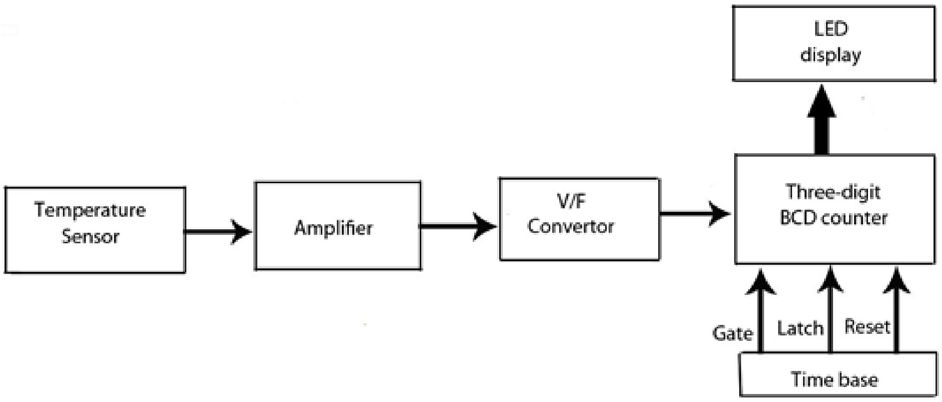


Figure 3. Thermometric sensor setup

A thermocouple is another common example of them. Thermocouple, is constructed from two different metals that produce an electrical output voltage in direct relation with the temperature modification.

1. Thermostats

- A thermostat is a contact type sensor containing a bi-metallic section constructed from two different metals such as aluminium, nickel, tungsten, or copper.
- The main principle of thermostats is based on the difference in the linear expansion coefficient of the metals. Therefore, it forces them to generate a mechanical movement due to heat rise.

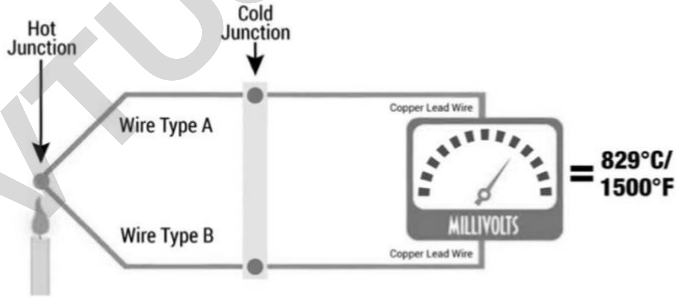


Figure 4. Thermostat sensor setup

2. Thermistors

- Thermally sensitive resistors or briefly thermistors are particular sensors because of the modification of their physical appearance due to the change in the temperature.
- The thermistors are constructed from ceramic substances like oxides of particular metals covered with glass. It will allow them to form simply.
- Some thermistors are NTCs and have a negative temperature coefficient but there are a lot of thermistors that have a positive temperature coefficient. They are introduced as PTCs, and their resistance increases by increasing the temperature.

Applications

- In hazardous locations like nuclear power plants.
- To identify the heat of hydration in concrete structures in geothermal control. They can also be employed to control the migration of seepage or groundwater.
- Detect rock temperatures in order to identify storage tanks of liquid gasses and the ground freezing process.

Optical sensors:

Optical sensors are electronic components designed to detect and convert incident light rays into electrical signals. Eg: Colorimetric Sensors. Optical sensors are divided into several subclasses such as resonance, dispersion, reflection, refraction, phosphorescence, infrared absorption, Raman scattering, fluorescence, and chemiluminescence.

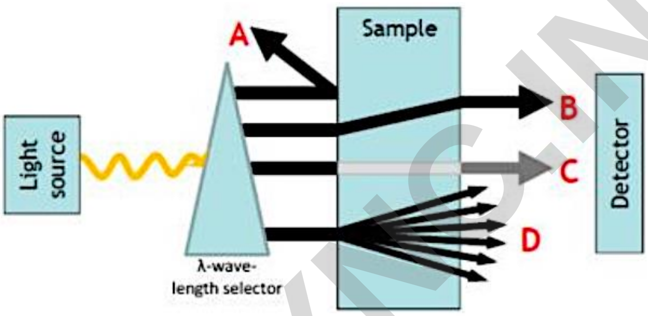


Figure 5. Optical sensor

Principle and Working-

- When a sample solution is interacted with a light of suitable wavelength, certain quantity of light is absorbed by the analyte solution and it is observed by a sensor. The transducer converts intensity of absorbed light into electrical signal. The change in intensity at certain wavelength within visible (400–800mm) range can be determined using special instrumentation.
- The relationship between the incident light intensity and the transmitted radiation is given by the Beer-Lambert law:

$$A\,(\lambda) = \log\frac{I_0}{I} = \varepsilon\,(\lambda)\cdot d\cdot c$$

where $A\,(\lambda) = \log\frac{I_0}{I}$ is the absorbance at a given wavelength A, ($I_0$and I are the incident and transmitted light intensities); ε is the molar absorptivity; d is the optical path through the absorbing sample and c is the molar concentration of absorbing analyte.

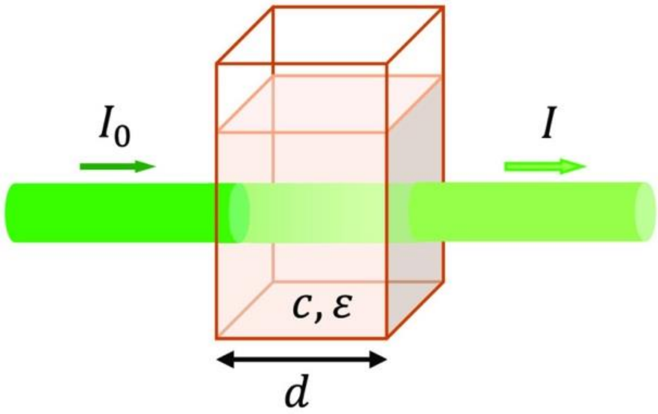


Figure 6. Beer-lamberts law

- What the detector monitors varies by technique (e.g., refractive index, scattering, diffraction, absorbance, reflectance, photoluminescence, chemiluminescence, etc.), can cover different regions of the electromagnetic spectrum, and can allow measurement of multiple properties.

Eg: Colorimetry: a quantitative measurement of absorbance or reflectance spectra, is one of the oldest of analytical techniques. Optical sensors depends on the colour of the analyte with in the visible range (400-800nm). Its basic components include a light source, a wavelength selector, a photodetector and a read-out device. A block diagram of a typical instrumentation system employed colorimetry. A monochromatic light is made to pass through analyte solution where certain quantity of light is absorbed and it is a function of concentration of analyte. The change in the intensity of light is detected by photodetector (sensing). The light source generates an intense and stable radiation signal needed to probe an optical property of the molecular recognition element in the sensor. The amount of absorbance is governed by Beer- lamberts law.

Applications of Optical Sensors

- Computers
- motion detectors.
- copy machines (xerox machines)
- light fixtures that turn on automatically in the dark.
- alarm systems
- synchro for photographic flashes
- systems that can detect the presence of objects.

Sensors for the measurement of dissolved oxygen (DO)

The two methods for estimation of DO are optical method and electrochemical method.

(a) Optical method: Optical DO sensors are made of two parts, a sensor spot and a fibre optic reader. The sensor spot is attached to the interior of a cell culture vessel and contains a fluorescent dye suspended in a hydrogel. The external reader is connected to a computer or data hub and is responsible for sending and receiving optical signals to the sensor spot.

(b) Electrochemical Method: Electrochemical DO sensors, also known as amperometric or Clark-type sensors, measures dissolved oxygen concentration in water based on electrical current produced. Galvanic Sensor is a Electrochemical sensor, which is used to measure DO The following are the components:

- Cathode : Working electrode-Ag
- Anode : Zn, Pb or any other active metal
- Electrolyte: KOH, NaOH or any other inert electrolyte
- Membrane: Teflon

Working Principle

The difference in potential between the anode and the cathode should be at least 0.5V. DO sensor is immersed in water sample. Oxygen molecule diffuses across the oxygen-permeable membrane (Teflon) and the rate of diffusion is proportional to the pressure of oxygen in the water. Molecular Oxygen reduces to OH^- at cathode. This reaction produces an electrical current that is directly related to the oxygen concentration. This current is carried by the ions in the electrolyte and runs from the cathode to the anode.

$$\text{Anode (Pb): Oxidation: } 2Pb \rightarrow 2Pb^{2+} + 4e^-$$

$$\text{Cathode (Ag): Reduction: } O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$

$$\text{Overall: } 2Pb + O_2 + 2H_2O \rightarrow 2Pb(OH)_2$$

Electrochemical Sensors for-

1. Pharmaceuticals

a. for the analysis of diclofenac.

Diclofenac is a nonsteroidal anti-inflammatory drug (NSAID). This medicine works by reducing substances in the body that cause pain and inflammation. Diclofenac is used to treat mild to moderate pain, or signs and symptoms of arthritis.

Carbon based-electrodes are the most investigated electrodes in diclofenac analysis. Carbon nanotubes (CNTs) and graphene-based composites are the most efficient modifiers for diclofenac detection that allowed the detection of diclofenac up to picomolar levels. CNT-based electrochemical diclofenac sensors: Electrochemical sensors, in particular, are a class of chemical sensors in which an electrode is used as a transducer element in the presence of an analyte. The following are the components:

- Working electrode: Carbon Paste with MWCNT or Graphene
- Counter Electrode: Carbon Paste with MWCNT or Graphene
- Reference Electrode: Ag/AgCl
- Process: Screen Printing Technique on PVC substrate. Insulating ink was printed on the remaining PVC surface.

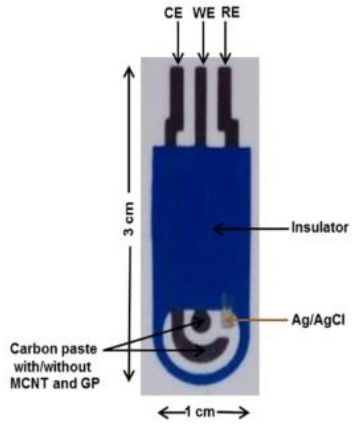
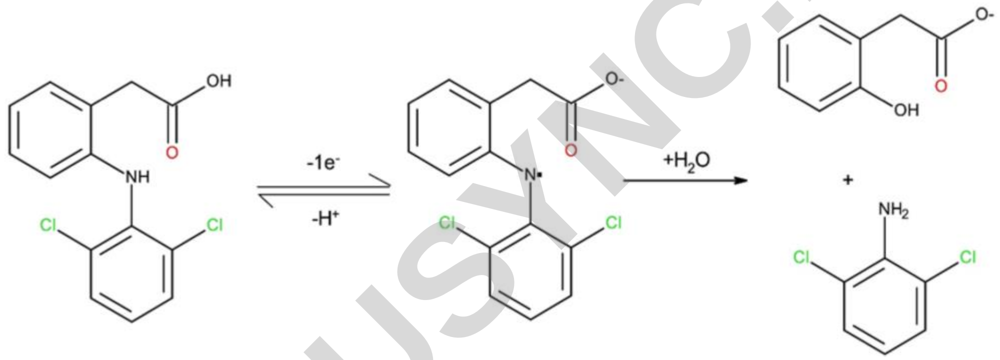


Figure 7. Printed sensor for Diclofenac

The electrochemical oxidation of DCF on carbon-based sensor at pH 7.0 is reversible reaction. Oxidation of Declofenac occurs at carbon electrode to release e^-, to form radical intermediates and followed by hydrolysis of radical intermediate species. The products formed are 2,6- dichloro aniline and 2-2-hydroxyphenyl acetic acid. Reactions on the electrode cause the current to flow. The intensity of this current is a function of the number of oxidized/reduced molecules.



Electro-oxidation mechanism of DCF

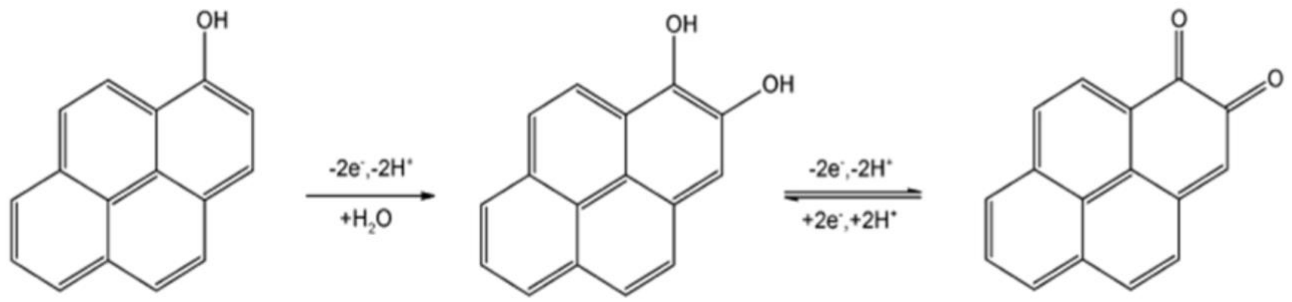
b. For the detection of hydrocarbons (1-hydroxypyrene):

Urinary 1-hydroxypyrene (1-OHP) is a widely used biomarker as an indicator of exposure to polycyclic aromatic hydrocarbons (PAHs). PAHs are a class of compounds found in crude oils, mineral oils and tars and are formed during the incomplete combustion of fossil fuels and oil products. These are genotoxic carcinogens. Hence their detection is necessary.

The following are the components of the electrochemical sensor used for the detection of the hydrocarbons-

Working electrode: PAMAM/Cr-MOF/GO (Composite) [PAMAM: Dendrimer polyamidoamine Cr-MOF: Chromium-centered metal–organic framework GO: Graphene Oxide]
Counter Electrode: PAMAM/Cr-MOF/GO
Reference Electrode: Ag/AgCl
Operating Voltage: +0.7 to −0.5 V

Working: When this electrode is used to detect the sample containing 1-Hydroxypyrene (water sample) the following changes takes place: At the electrode surface electro-oxidation takes place to yield several hydroxylated species and then hydroquinone by losing $2e^-$ and $2H^+$. Reactions on the electrode cause the current to flow. The quantity of this current is a function of the number of oxidized/reduced molecules. Current produced is directly proportional to the concentration 1-Hydroxypyrene.



Electro-oxidation scheme of 1-hydroxypyrene

2. Electrochemical Gas Sensors:

(a) Detection of SO_x

Sulphur dioxide is one of the main substances that pollute the air. Sulfur oxides, SO_2 released from thermal power stations and other industrial plants, are gases harmful to the environment. It is very important to detect and control the concentrations of SOx in industrial processes. The attempt to detect sulphur dioxide in the air is a regular task of air inspection.

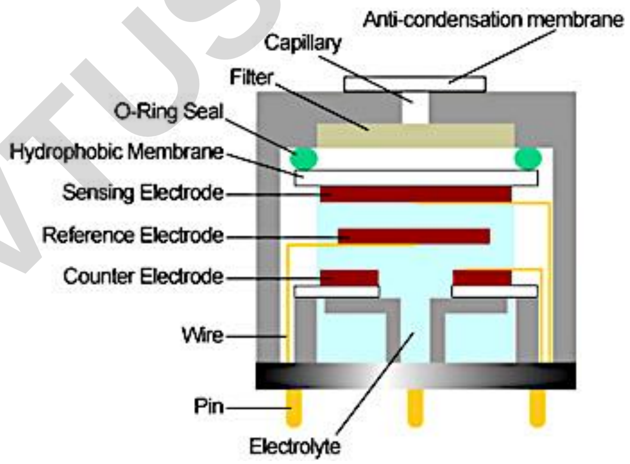


Figure 8. SO_x sensor

Gas sensors detect chemicals in the gas phase. The gas sensors operate by reacting with the gas of interest and producing an electrical signal proportional to the gas concentration. A typical electrochemical sensor consists of: a sensing electrode (or working electrode), counter electrode separated by a thin layer of electrolyte and a reference electrode. Gases diffuse through a membrane to be reduced or oxidized at an electrode. Initially the gas passes through a small capillary-type opening and then diffuses through a hydrophobic barrier, and eventually reaches the electrode surface. SO_x sensors utilizing a solid electrolyte such as K_2SO_4, Na_2SO_4, Li_2SO_4, Ag_2SO_4, Nasicon, Na-Al_2O_3 and

Ag-Al_2O_3, because this type of sensor has its own advantages like continuous quantitative measurement; high selectivity and sensitivity; easy operation and fast response; simple construction and low price.

Anode reaction: $\mathbf{2Ag \rightarrow 2Ag^+ + 2e^-}$

Cathode reaction: $\mathbf{2Ag^+ + SO_3 + {}^1/_2O_2 + 2e^- \rightarrow Ag_2SO_4}$

Total reaction was: $\mathbf{2Ag + SO_3 + {}^1/_2O_2 \rightarrow Ag_2SO_4}$.

SO_3 was produced by the reaction can be checked by sensor.

Applications:

1. It is used in thermal power plant.
2. It is used chemical industries to detect sulphur dioxide emission level

(b) Detection of NO_x

Nitrogen oxide is the general term for a gas mixture composed of various oxides of nitrogen, often referred as NO_x. The normal air is nitric oxide and nitrogen dioxide. In environmental analysis, nitrogen oxide generally refers to NO and NO_2. NO is an important vasodilator, and monitoring its levels becomes crucial in the diagnostics of cardiovascular complications.

Electrochemical sensors are made up of three essential components: a receptor that binds the sample, the sample or analyte, and a transducer to convert the reaction into a measurable electrical signal. In the case of electrochemical sensors, the electrode acts as the transducer.

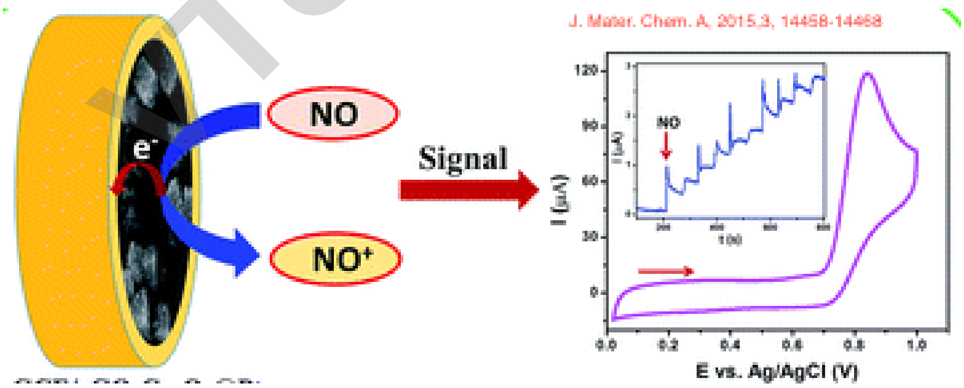


Figure 8. NO_x sensor

The electrode surface is used as the site of the reaction. The electrode will either oxidize or reduce the analyte of interest. The current that is produced from the reaction is monitored and used to calculate important data such as concentrations from the sample. The NO_x sensor monitors the oxidation of NO as it occurs on the electrode surface. In many instances of electrochemical sensors, the electrode surface can be modified with catalysts, membranes, or other metals to make the electrode more sensitive and/or more selective toward the analyte (in the instance below, the Glassy

Carbon (GC) electrode is modified with Cobalt (IV) Oxide and Platinum). The direct electro oxidation of NO in solutions follows the following 3 step reaction.

$$NO \rightarrow NO^+ + e^-$$

$$NO^+ + OH^- \rightarrow HNO_2$$

$$HNO_2 + H_2O \rightarrow NO_3^- + 2e^- + 3H^+$$

The ΔE for the overall process is +0.5V vs. a Ag/AgCl reference electrode. The reaction for the Ag/AgCl reference electrode is the following: $AgCl + e^- \leftrightarrow Ag + Cl^-$; E^o+0.222V

3. Disposable sensor for the detection of-

Disposable sensors: Disposable sensors are low-cost and easy-to-use sensing devices designed for short-term or rapid single-point measurements.

Advantages of disposable sensors:

- They transduce physical, chemical, or biological changes in their environment to an analytical signal.
- Disposable sensors are biodegradable and sustainable
- They have a short duration of analysis and fast response times.
- It provide digitized chemical and biological information.
- Prevents the contamination of samples.

a. Biomolecules: Ascorbic acid

The desired biomolecules such as enzyme, hormones, antibodies etc. are immobilized via physisorption/chemisorption, which will cause an intimate contact with the transducer. The analyte of interest will selectively bind with the biomaterial that produces the measurable electronic response.

L-Ascorbic acid (AA) or adsorbate, commonly known as vitamin C, is an important water-soluble vitamin derived from green vegetables, fruits, and other dietary supplements. AA improves the immune system. It enables collagen synthesis, which is needed to maintain healthy bones, teeth, skins, cartilages, enhances antibody levels and acts as an antioxidant; reduces necrosis. However, abnormal AA levels in bodily fluids have been reported to cause cancer, cardiovascular diseases, and Alzheimer's and Parkinson's diseases. Extended use of AA could cause urinary oxalate calculus, increase infertility in a woman, and affect embryo development. Excessive AA use has been reported to cause diarrhoea, nausea, vomiting, headache, insomnia, gastric irritation, renal problems, loss of food taste, and vomiting.

Principle and Working of biosensor:

- It is comprising three disposable electrodes: one working electrode, one counter/auxiliary electrode, and one reference electrode.
- Each one includes a contact or terminal, a section and an active area. All electrodes have been manufactured by silkscreen printing with conductive material ink on a plastic polyester (PET) sheet.
- The active surfaces of the counter electrode and working electrode have been printed with a conductive ink of C (MWCNT) and modified with gold nanoparticles.
- Active surface of the reference electrode has been printed with an Ag/AgCl ink.
- Electrochemical biosensors, for instance, have an electrode surface that acts as the reaction site and as the transducer. In this case, electrodes, an enzyme to catalyse a reaction, and the sample would make up the biosensor. For example, the electrode is placed in a solution containing an enzyme (the bioreceptor) specific to the analyte—let's say in this case, glucose—and the change in potential is measured as the enzyme reacts with the glucose on the surface of the electrode, also known as the transducer.

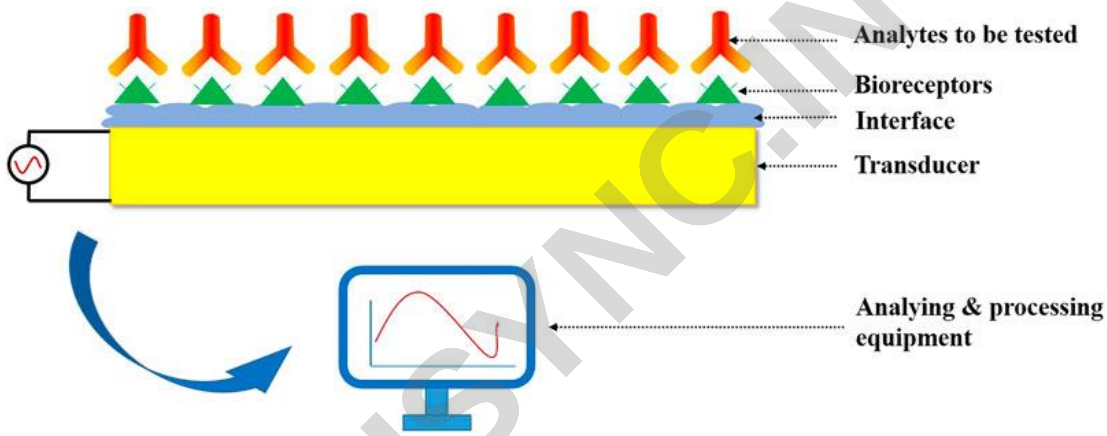
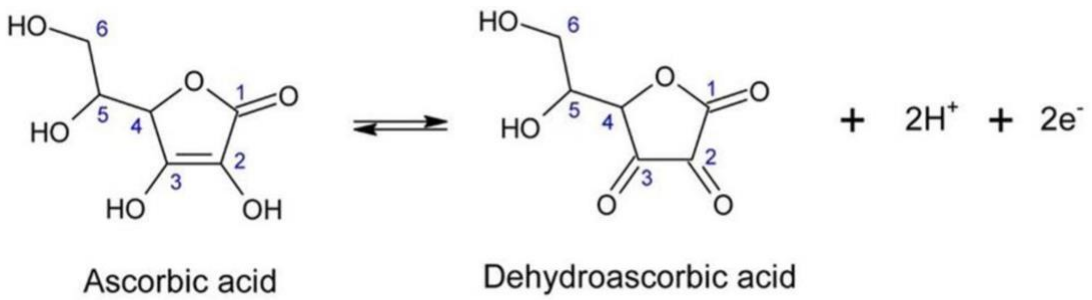


Figure 9. working of biomolecule sensor

- Depending on what electrochemical method is used, the current measured by the electrode or the change in potential caused by the redox reaction occurring on the electrode, is directly proportional to the concentration of a given sample. Example electrochemical oxidation of ascorbic acid and oxidation of glucose.



Oxidation of Ascorbic acid

Application of biosensors

1. Biomolecules/biological molecules are essential organic compounds present in all the living systems. They are the building blocks of the body and are responsible for maintenance and metabolic process. The major classes of biomolecules include carbohydrates, proteins, lipids, nucleic acids, enzymes, hormones, etc. Each class are vital in the day-to-day activities of every living organism.
2. In the medical field, patients' glucose and oxygen levels are often measured to help doctors diagnose and treat them. For instance, an individual might present with frequent urination, high levels of hunger, and fatigue. Without sensors and further testing, a number of diagnoses might be applicable to said patient (type these symptoms into WebMD and see for yourselves!). Glucose sensors, in particular, are important for confirming whether a patient is hyperglycemic (has high blood glucose), which may often be a result of diabetes. Today, glucose monitoring is possible through finger-pricking, which involves using the blood from the patient's pricked finger to measure blood glucose via test strips and glucometers.

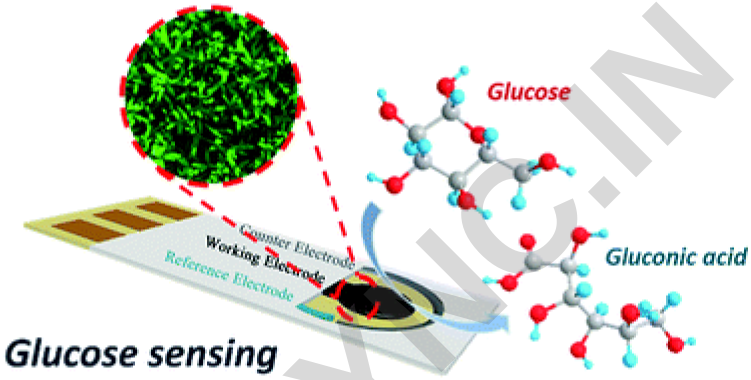


Figure 10. disposable Biosensor

b. Pesticides

To achieve improved cultivation in agricultural fields, farmers started to use large amount of (more than prescribed ppm/ppb levels) harmful synthetic/chemical pesticides instead of organic manure. These synthetic pesticides also have a direct impact on the soil as well as the agro-products. The accumulation of pesticides into the vegetables lead to a poisoning effect. Pesticides in the cultivated agro-products can induce a number of diseases such as asthma, diabetes, birth defects, reproductive dysfunction, etc. They do this by suppressing the activity of many enzymes in the human system. Therefore, monitoring the level of pesticides in soil, water and cultivated agro-products is one of the best ways to detect the abuse of pesticides.

Working: One of the most commonly used pesticides is glyphosate. Glyphosate has the ability to attach to the soil colloids and degraded by the soil microorganisms. As glyphosate led to the appearance of resistant species, the pesticide was used more intensively. As a consequence of the heavy use of glyphosate, residues of this compound are increasingly observed in food and water. Recent studies reported a direct link between glyphosate and chronic effects such as tetrogenic, tumorigenic. Electrochemical Sensor for Glyphosate Detection The sensor is a silicon- based chip comprising of three-electrode system. It is fabricated by electro deposition technique. The following are the components –

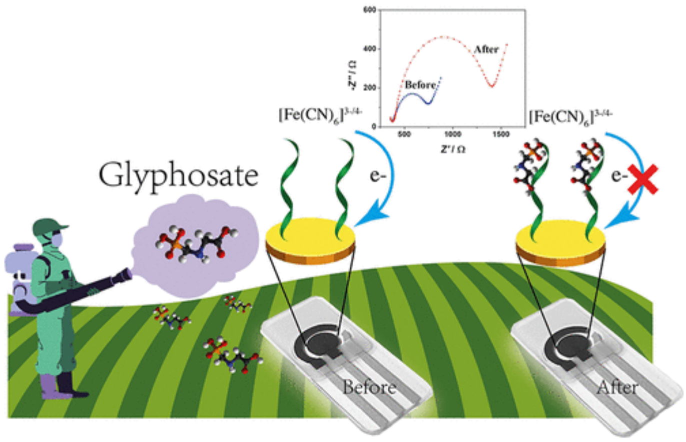
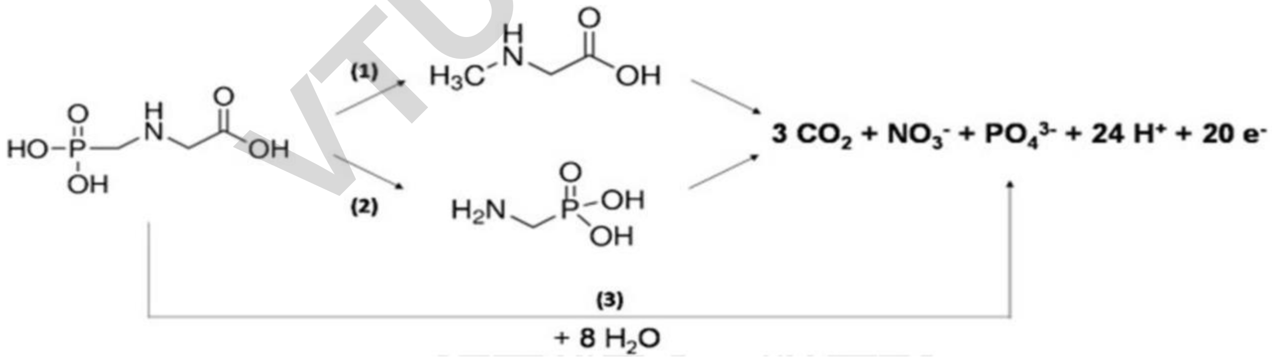


Figure 11. Working of sensor for pesticide detection

- Working Electrode: A gold electrode of 4 mm diameter coated with 200nm thickness gold nanoparticles
- Counter electrode: A gold electrode of 4 mm diameter coated with 20nm thickness gold nanoparticles
- Reference Electrode: $Ag/AgCl/Cl^-$
- Electrolytes are added to increase the conductivity of the solution and minimizes the resistance between the working and counter electrode.

The electrochemical detection is based on the oxidation of Glyphosate on gold working electrode. A potential of 0.78V is applied on working electrode, there is a interaction between analyte and electrode surface. Glyphosate oxidizes on the working electrode brings a change in current in the electrolyte medium. The change in the current is a measure of concentration of Glyphosate.



Electrochemical oxidation of glyphosate

Energy Systems

Batteries

Conversion of chemical energy into electrical energy is the function involved in cells. One of galvanic cells that convert chemical energy into electrical energy. In general battery is a combination of galvanic cells neither in series (or) parallel both in order to get the required amount of electrical energy. Battery is a device which transforms chemical energy of a redox reaction into electrical energy. Example: Zn-Air battery, lead acid battery, lithium batteries, etc. The following are the components of batteries-

- Anode: The anode (-ve electrode) is oxidized during the electrochemical reaction and liberates electrons of the external circuit.

$$M \rightarrow M^{n+} + e^{-} \text{ Metal}$$

- Cathode: The cathode (Positive electrode) is reduced during the electrochemical reaction which accepts electrons from external circuit.
- Electrolyte: The electrolyte which provide the medium for transfer of ions inside the cell between the anode and cathode. The electrolyte must have good ionic conductivity and resistance to the electrode materials.
- Separator: The separator: the material that electronically isolates the anode and the cathode in a battery to prevent internal short-circuiting.
  Example: Cellulose, Vinyl polymer, Polyolefins

Classification of batteries:

Batteries are classified as (a) Primary, (b) secondary and (c) reserve batteries.

a. Primary batteries

In primary batteries, the chemical energy is converted into electrical energy as long as the chemical components are active. These batteries the reaction occurs only once and after that they must be discarded. These batteries cannot be recharged as the chemical reactions which occur within the primary batteries are irreversible. Examples: Zn- air battery, Dry cell, Leclanche cell (Zn-MnO_2), Li-MnO_2 battery, Magnesium cell (Mg- MnO_2)

b. Secondary batteries

Secondary batteries are those which after discharging can be recharged. These batteries chemical reactions taking place are reversible. The redox reaction which converts chemical energy into electrical energy can be reversed by passage of current. The electric energy is stored in the form of chemical energy these batteries are also known a storage cell. Examples: Lead storage battery, Nickel-cadmium battery, Nickel-metal hydride battery and Lithium-ion battery.

c. Reserve Batteries

These batteries one of the components is isolated and incorporated into the battery when required. The electrolyte is the component that is isolated, but some water activated batteries contain the electrolyte solute and water is added for activation. They are used to deliver high power for relatively short periods of time in application such as radiosondes (air borne instruments to send to meteorological information back to earth by radio).Examples: Mg batteries activated by water (Mg-AgCl, Mg-CuCl), Zn-Ag_2O batteries etc

Li-ion Battery

Construction & Working: Li-ion cell consists of a

(a) cathode (positive electrode): e.g., $LiCoO_2$, $LiFePO_4$, Lithium manganese oxide, Nickel cobalt aluminium, Lithium nickel manganese cobalt oxide
(b) anode (negative electrode): e.g., carbon or graphite which are contacted by an electrolyte containing lithium ions. The electrodes are isolated from each other by a separator, typically microporous polymer membrane, which allows the exchange of Li-ions between the two electrodes but not electrons.
(c) Electrolyte: A lithium salt such as $LiPF_6$, $LiAsF_6$, $LiClO_4$, $LiBF_4$ dissolved in an organic solvent such as ethylene carbonate dimethyl carbonate or dimethoxy ethane.
(d) Separator: Microporous polyethylene or polypropylene

- Li-ion batteries use a process known as intercalation, in which lithium ions are incorporated into the structure of the electrode materials.
- Inside the cell, lithium ions move from the positive to the negative electrode during charging and from the negative to the positive electrode as the battery is discharged.
- In this way the external energy are electrochemically stored in the battery in the form of chemical energy in the anode and cathode materials with different chemical potentials.
- Electrons move through an external circuit in the same direction as the lithium ions, driven by an external charger (when charging) or by the stored potential chemical energy (available to drive a load) when the battery is discharging.

The Li-ion cell is represented as: Li | Li^+, C | $LiPF_6$ (in ethylene carbonate) | $LiCoO_2$

The cell reaction during discharge or charging are:

At anode: $Li_xC_6 \rightleftarrows xLi^+ + xe^- + 6C$

At cathode: $Li_{1-x}CoO_2 + xLi^+ + xe^- \rightleftarrows LiCoO_2$

Overall reaction: $Li_xC + Li_{1-x}CoO_2 \rightleftarrows LiCoO_2 + C$

Typical Li-ion cell provides a potential of 3.7 V.

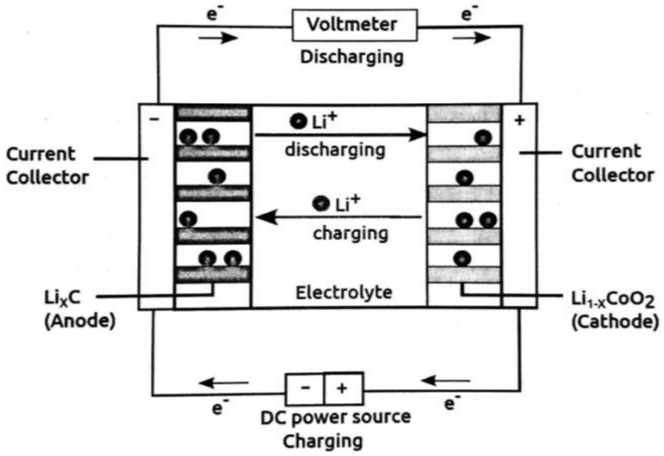


Figure 12(a) Charging/discharging in Li-ion battery

Advantages:

- High energy density
- relatively low self-discharge
- high cell voltage (3.7 V)

Disadvantages:

- Require protection from being over-charged or over-discharged.
- Require cool storage area
- Expensive

Applications:

a. electric-powered vehicles
b. buffer the intermittent and fluctuating green energy supply from renewable resources, such as solar and wind
c. grid application
d. cell phones
e. powering hybrid electric vehicles (HEVs)
f. plug-in hybrid electric vehicles (PHEVs)
g. electric vehicles (EVs)

Na-ion Battery

Construction and Working:

The components of Na-ion batteries are-

(a) Anode materials (negative electrode): carbon-based (hard-carbon), transition metals, and their alloy compounds.

(b) Cathode materials (positive electrode): Metal oxides, Layered oxides, Polyanion phosphate compounds
(c) Electrolyte: Sodium-Ion aqueous electrolyte, Sodium-ion solid polymer electrolyte, Ion electrolyte of SIB
(d) Porous Separator

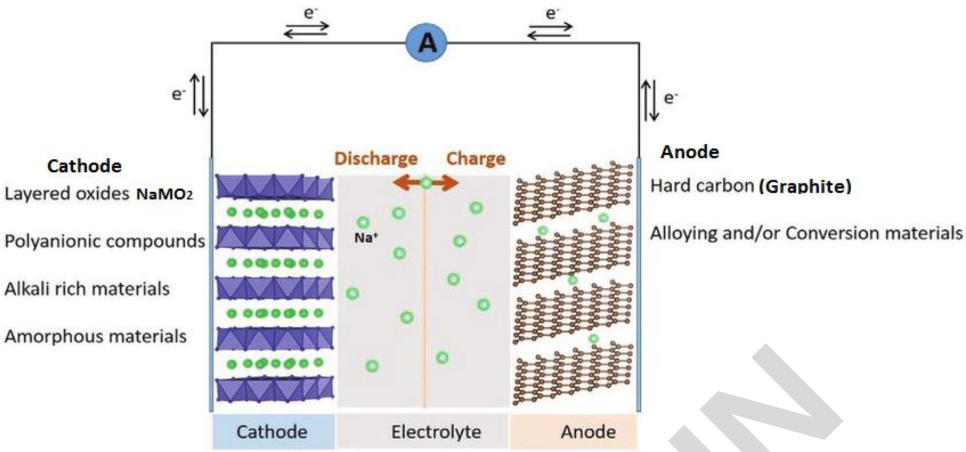


Figure 13. Na-ion Battery

It stores energy in the chemical bonds of anode. When battery is recharging sodium ions moves from cathode to the anode. Meanwhile charge balancing electrons pass from the cathode through the external circuit containing the charger and into the anode During discharge process electrons move from and anode to external circuit, it can be used for various applications. Meanwhile, Na+ ions move from anode to the cathode. Voltage obtained from every sodium ion cell is 3.6 V. The electrode reactions are as follow,

Anode: $2Na \rightleftarrows 2Na^+ + 2e^-$

Cathode: $nS + 2Na^+ + 2e^- \rightleftarrows Na_2S_n$

Overall cell reaction: $nS + 2Na \rightleftarrows Na_2S_n$

The $NaCoO_2$ cathode, like $LiCoO_2$, is initially brought into the Na-ion cell in the discharged state, and the cell is activated by charging first to form the Na intercalated anode and Na deintercalated cathode in the fully charged cell.

Advantages

- Sodium resources are more abundant
- The cost of sodium-ion batteries is about 30% lower than that of lithium batteries
- Sodium-ion batteries are safer and are not easy to produce lithium dendrites.

Disadvantages:

- Lower energy density of sodium ion batteries
- short cycle life

- The industrial chain is still incomplete

Applications:

a. Power backup: Data and telecom sectors heavily rely on battery powered infrastructures and operations to drive to the global economy. Na-ion batteries can provide on demand power to ensure safe and seamless power supply.
b. Automobiles and Transportation: In electric vehicles including electric cars and buses.
c. Grid-level applications: Na-ion batteries can help optimise the solar and wind energy to meet grid energy storage requirements.
d. Industrial mobility: Na-ion batteries can maximize asset utilization and minimize operating cost with constant state of readiness and powerful peak power.

Quantum dots sensitized solar cells (QDSSC's)

The concept of a ''sensitized semiconductor,'' in which a wide- band-gap semiconductor is sensitized with a narrow band gap semiconductor to harvest sunlight and to generate charge carriers.

Principle: Upon light irradiation, the sensitizer is photoexcited. The excited electrons of QDs are injected into the conduction band of the TiO_2. The electrons penetrate through the nanocrystalline TiO_2 film to the back contact of the conducting substrate, and flow through an external circuit to the CEs. At the CEs, the oxidized component of redox couple in the electrolyte is reduced. The oxidized form of the sensitizer is finally regenerated by the reduced component of redox couple in the electrolyte. The external load is connected to the cell to complete the circuit through electron migration. When the cell is irradiated with sunlight, the potential difference between the photo-electrode (due to the Fermi level of the electrons) and electrolyte (due to the redox potential) produces a voltage across the load, and the solar energy conversion efficiency (η) of the cells is obtained as follow.

$$\eta = \frac{J_m \bullet V_m \bullet FF}{P}$$

where P is the power density at the operating point, and J_m and V_m represent current density and voltage, respectively, at the actual maximum power.

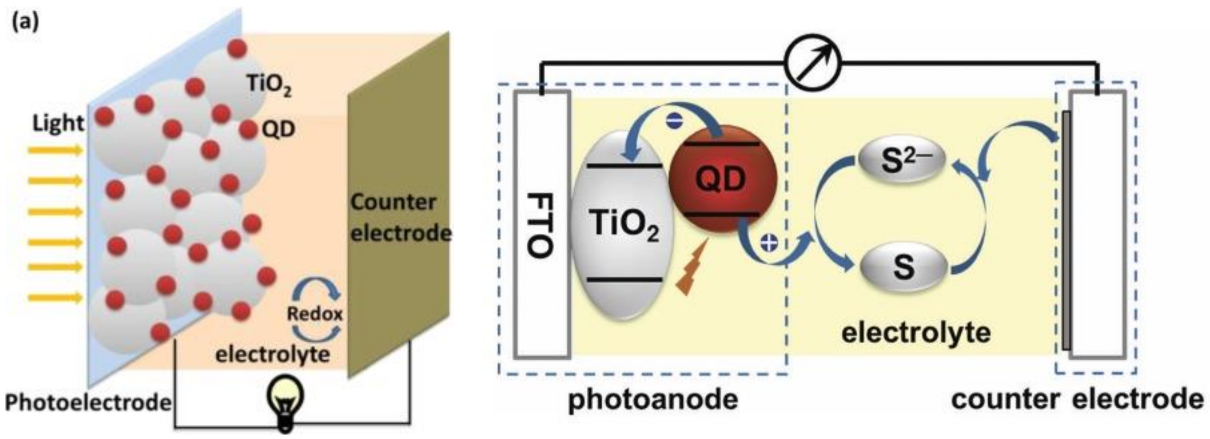


Figure 14. Complete setup of QDSSC

Construction and working: The following are the components of QDSSC: photoanode, sensitizer, counter electrode and electrolyte.

(a) Photoanode: Photoanode usually consists of semiconducting metal oxide deposited on a transparent conducting oxide substrate. Eg: Metal oxide electron-transporting/acceptor materials (TiO_2, ZnO, ZrO_2, PbS-based photoanodes)

(b) QD sensitizers: To maximize the harvesting efficiency of the incident light, it should possess a high absorption coefficient and appropriate band-gap energy. Eg: ZnS, ZnSe, Ag_2S, Bi_2S_3, CdS, CdSe, CdTe, InAs, In_2S_3, InP, PbS, PbSe, Si, Graphene, Cu-ZnS, and halides

(c) Counter electrodes (CE): transfers electrons from the external circuit into electrolyte and catalyses the reduction reaction of the oxidized electrolytes at the electrolyte/CE interface. Eg: Noble metals (Pt), Metal chalcogenides, Carbon materials (graphene, carbon fiber, carbon black, multiwalled carbon nanotubes)

(d) Electrolyte: Redox electrolytes enhances the efficiency and stability of QDSSCs. It is a medium which transfers charges between counter electrodes and photoanodes for the regeneration of oxidized QDs. Eg: iodide/triiodide (I^-/I^{3-}) electrolyte

Advantages of QDSCCs: The following are the benefits of quantum dot solar cells.

- They have a favourable power to weight ratio with high efficiency.
- Their power consumption is low.
- There is an increase of electrical performance at low production costs.
- Their use is versatile and can be used in windows, not just rooftops.

Disadvantages of QDSC.

- Cadmium selenide-based quantum dot solar cells are highly toxic in nature and require a very stable polymer shell.
- Cadmium and selenium ions which are used in the core of quantum dots are known to be cytotoxic.

Applications:

a. DSSCs as the photosensitizer instead of organic dyes to form QDSSCs
b. larger scale, flexible solar panels can be used to cover tents to power sophisticated equipment. Lightweight wearable solar panels could power and recharge the electrical devices the military carry, eliminating the need for extra battery packs in the field or bags full of batteries.
c. portable power systems
d. architecture, interior applications
e. electronic devices: mobile phones, e-books, cameras, and portable LED lighting systems.
f. biological labelling
g. Imaging, and detection and as efficient fluorescence resonance energy transfer donors.
h. It is used as light-emitting Diodes
i. It is used as Photoconductors and photodectors
j. It is used in Biomedicine and environment.

k. It is used in catalysis