# Light Harvesting Complexes
## (Constituents and Mechanism)

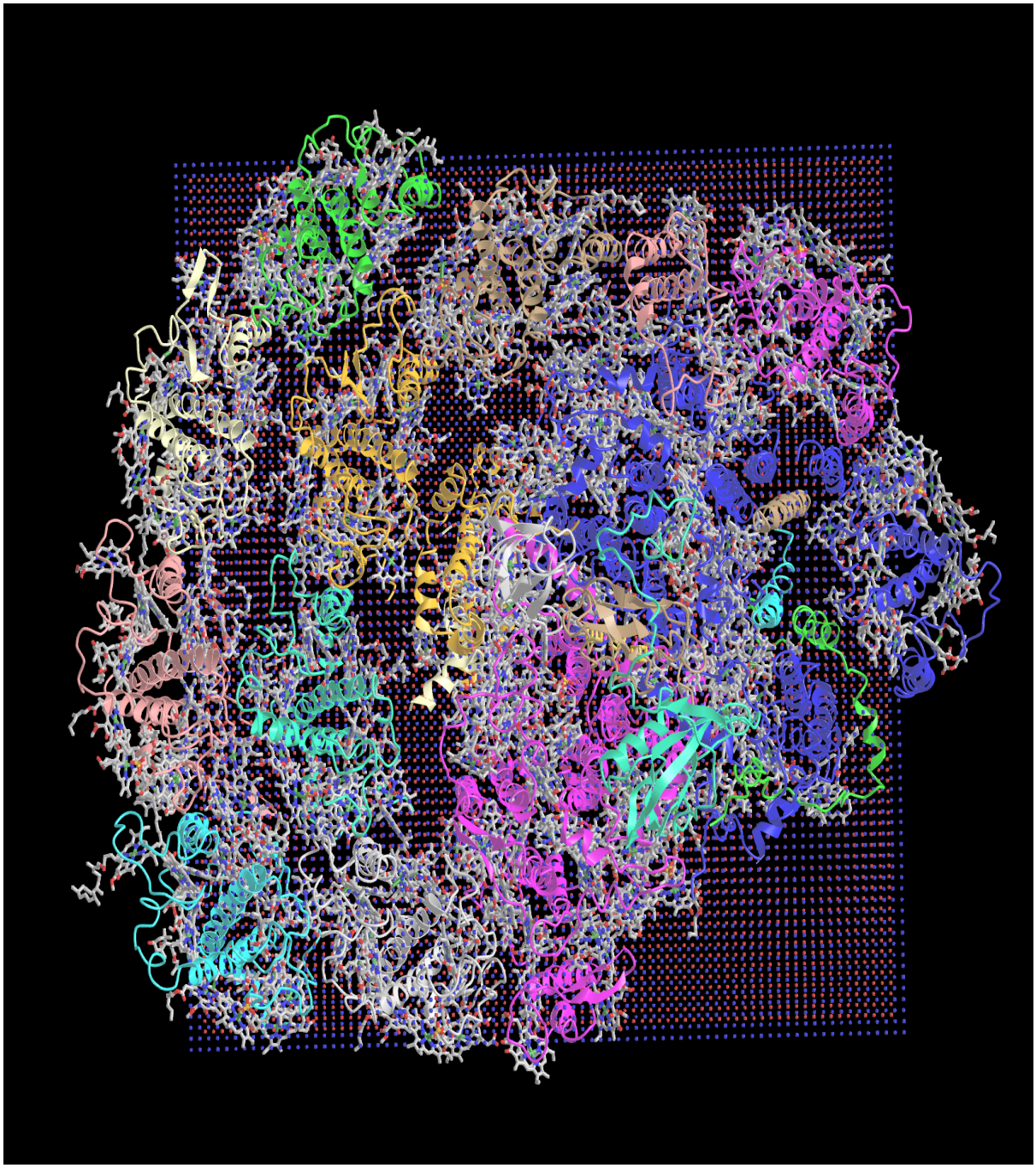


*Figure 138: Structure of Light Harvesting Complex (Basil)(Courtesy: ncbi)*

Below is the list of Subunits present in LHCs where the colour palate must be matched with the above figure.


## Absorption of Light by Plant Cell Wall and the Protein Subunits

The plant cell wall is an essential structural component that surrounds plant cells and provides them with support and protection. It is composed of several different components that work together to form a complex, three-dimensional structure.

The basic components of the plant cell wall include cellulose, hemicellulose, pectin, lignin, and various proteins. Cellulose is the most abundant component and is a long chain of glucose

molecules that form microfibrils. These microfibrils provide the primary structural support for the cell wall. Hemicellulose is a complex carbohydrate that forms a matrix around the cellulose microfibrils and helps to hold them together. Pectin is a gel-like substance that helps to bind cells together and provides flexibility to the cell wall. Lignin is a complex polymer that is responsible for the rigidity and strength of the cell wall. Proteins are also present in the cell wall and provide additional structural support and enzymatic activity.

The cell wall also contains Thykaloids. Thylakoids are flattened, membrane-bound compartments within the chloroplasts of plant cells. They are the site of the light-dependent reactions of photosynthesis, where the capture of light energy is converted into chemical energy in the form of ATP and NADPH. Thylakoids are stacked on top of each other in columns known as grana and the space surrounding the grana is called the stroma.

The Light Harvesting Complexes (LHCs) are large protein complexes that are embedded in the thylakoid membrane. They are responsible for capturing light energy and transferring it to the reaction center complex, which is also located in the thylakoid membrane. The LHCs contain pigments known as chlorophylls and carotenoids, which absorb light at different wavelengths, which then leads to photosynthesis.

Photosystem I (PS I) and Photosystem II (PS II) are two of the major protein complexes involved in photosynthesis. PSII is located in the thylakoid membrane and is responsible for capturing light energy and using it to split water molecules, releasing oxygen as a byproduct. The electrons that are generated during this process are passed through a series of electron carriers, eventually leading to the production of Adenosine Tri-Phosphaate (ATP) and Nicotine Amide Adenine Dinucleotide Phosphate Hydogen (NADPH). PS I is also located in the thylakoid membrane and is responsible for using the energy captured by the LHCs to generate ATP and NADPH.

Photosystem I (PS I) is a multi-subunit protein complex that plays a critical role in the light-dependent reactions of photosynthesis. It is located in the thylakoid membrane of chloroplasts in plant cells and is responsible for converting light energy into chemical energy in the form of ATP and NADPH. Photosystem I is a large protein complex that is composed of several different subunits. The core of PSI is made up of eleven subunits, including PsaA, PsaB, PsaC,PsaD, PsaE, PsaF, PsaI, PsaJ, PsaK, PsaL, and PsaM. These subunits are organized into three domains: the PsaA-PsaB heterodimer, the PsaC-PsaD-PsaE-F subcomplex and the PsaG-PsaH-PsaI-J-K-L-M subcomplex.

The PsaA-PsaB heterodimer, also known as photosystem I reaction center subunit II (PSI-II), is a trans membrane protein complex that is composed of two subunits, PsaA and PsaB. It is located in the thylakoid membrane and acts as the core of the photosystem I (PSI) complex. The

PsaA and PsaB subunits contain several trans membrane helices and form a heterodimeric structure, which is surrounded by several peripheral subunits.

The PsaC-PsaD-PsaE-F subcomplex, also known as the peripheral antenna complex, is a protein complex that is composed of four subunits, PsaC, PsaD, PsaE, and PsaF. It is located on the stromal side of the PSI complex and functions as an antenna system that captures light energy and transfers it to the PSI-II core. The PsaC subunit is a small, soluble protein that is attached to the PSI-II core through its interaction with PsaB. The PsaD, PsaE, and PsaF subunits form a trimeric complex that binds to the PsaC subunit and helps to extend the antenna system.

The PsaG-PsaH-PsaI-J-K-L-M subcomplex, also known as the stromal subcomplex, is a protein complex that is composed of seven subunits, PsaG, PsaH, PsaI, PsaJ, PsaK, PsaL, and PsaM. It is located on the stromal side of the PSI complex and is involved in the regulation of PSI activity and electron transfer. The PsaG and PsaH subunits are small, soluble proteins that are attached to the PSI-II core through their interaction with PsaC. The PsaI, PsaJ, PsaK, PsaL, and PsaM subunits form a large, peripheral complex that is involved in the binding and transfer of electrons.

The absorption peaks of the photosystem I (PSI) complexes are determined by the pigments they contain, mainly chlorophylls and carotenoids. The absorption peaks of the different complexes can vary depending on the specific composition of pigments, but here are some general ranges for the absorption peaks:

The PSI-II core (PsaA-PsaB heterodimer) has a main absorption peak around 700 nm, which corresponds to chlorophyll a molecules in the reaction center.

The peripheral antenna complex (PsaC-PsaD-PsaE-F subcomplex) has absorption peaks in the range of 680-710 nm, which correspond to chlorophyll a and chlorophyll b molecules in the antenna pigments.

The stromal subcomplex (PsaG-PsaH-PsaI-J-K-L-M subcomplex) has absorption peaks in the range of 650-680 nm, which correspond to chlorophyll a and carotenoid molecules in the peripheral subunits.

It's important to note that the absorption spectrum of the PSI complex as a whole is broader than that of the individual subcomplexes, as the pigments in the different subunits interact and transfer energy between each other. The overall absorption spectrum of PSI typically extends from around 600 nm to 800 nm, with a peak around 700 nm.

So in conclusion, pigments of PSI are responsible for capturing light energy and transferring it to the reaction center, where it is used to generate ATP and NADPH. The primary pigments in PSI are chlorophyll a molecule, which are organized into four clusters known as P700, P680, P650, and P600. The P700 cluster is the primary electron acceptor in PSI and absorbs light at a

wavelength of 700 nm. The P680 cluster is found in Photosystem II (PSII) and absorbs light at a wavelength of 680 nm. The P650 and P600 clusters are accessory pigments that help to capture light energy and transfer it to the reaction center.

### ELECTRON TRANSFER PATHWAYS OF PSI:

The electron transfer pathways of PSI are complex and involve several different protein subunits and cofactors. The process begins when a photon of light is absorbed by a pigment molecule in the LHCs, which transfer the energy to the reaction center of PSI. The energy is then transferred to the P700 cluster, where it excites an electron to a higher energy state. This electron is then passed through a series of electron carriers, including the iron-sulfur clusters, phylloquinones, and a bound plastoquinone molecule, before being transferred to ferredoxin.

From ferredoxin, the electron is passed to the enzyme ferredoxin-NADP+ reductase (FNR), which catalyzes the transfer of electrons to NADP+ to form NADPH. This reaction is coupled to the transfer of protons across the thylakoid membrane, which generates a proton gradient that is used to generate ATP through the process of chemiosmosis.

Photosystem II (PSII) is a multi-subunit membrane protein complex located in the thylakoid membrane of chloroplasts. It plays a key role in the light-dependent reactions of photosynthesis by capturing light energy and using it to oxidize water molecules to produce oxygen, protons, and electrons.

The structure of PSII has been extensively studied using a combination of X-ray crystallography, electron microscopy, and biochemical techniques. PSII is composed of more than 20 subunits, which are organized into four main domains: the core complex, the antenna complex, the oxygen-evolving complex, and the extrinsic subunits.

**CORE COMPLEX:** The core complex is the central part of PSII and is made up of several subunits, including D1, D2, CP43, and CP47. The D1 and D2 subunits form the reaction center, where the initial steps of photosynthesis occur. The CP43 and CP47 subunits form the core antenna complex, which is responsible for capturing light energy and transferring it to the reaction center.The absorption spectrum of PSII has been extensively studied, and the peak absorption wavelengths of the core complex pigments are known.

The main pigments in the core complex are chlorophyll a (Chl a), chlorophyll b (Chl b), and carotenoids. The peak absorption wavelengths of these pigments in the core complex are:

Chl a: The primary electron donor in PSII, Chl a has an absorption peak at around 680 nm.

Chl b: An accessory pigment that transfers energy to Chl a, Chl b has an absorption peak at around 640 nm.

**CAROTENOIDS:** These pigments act as photoprotective agents by dissipating excess energy and have multiple absorption peaks between 400 and 550 nm.

It's worth noting that the absorption spectrum of PSII is broad and complex, with multiple absorption peaks and shoulders. This reflects the fact that PSII contains a large number of pigments that work together to efficiently capture and transfer light energy.

**ANTENNA COMPLEX:** The antenna complex consists of several subunits, including Lhcb1, Lhcb2, Lhcb3, and Lhcb6. These subunits contain chlorophyll and carotenoid pigments that absorb light energy and transfer it to the reaction center of the core complex.

The absorption spectrum of the antenna complex is broad and complex, with multiple peaks and shoulders in the visible range of the electromagnetic spectrum. The precise absorption peaks of the antenna complex pigments can vary depending on their specific chemical structure and the local environment within the complex. However, some general features of the absorption spectrum of the antenna complex include:

The main absorption peak of the antenna complex is in the range of 600-700 nm, which corresponds to the red to far-red wavelengths of light.

The absorption spectrum of the antenna complex has several smaller peaks in the range of 400-550 nm, which corresponds to the blue and green wavelengths of light. These peaks are due to the presence of carotenoid pigments in the antenna complex.

The relative intensities of the absorption peaks in the antenna complex can vary depending on the specific composition of the pigments and the organization of the complex.

**OXYGEN-EVOLVING COMPLEX:** The oxygen-evolving complex (OEC) is responsible for the oxidation of water molecules to produce oxygen, protons, and electrons. It consists of four manganese ions and a calcium ion, as well as several subunits, including PsbO, PsbP, and PsbQ.

OEC in Photosystem II (PSII) is a cluster of four manganese atoms and one calcium atom, along with associated protein and water molecules that is responsible for the light-driven oxidation of water to molecular oxygen. The OEC undergoes a series of oxidation state changes during the water-splitting cycle, and each of these oxidation states is associated with characteristic absorption peaks in the visible and near-UV regions of the electromagnetic spectrum.

The absorption peaks of the OEC in PSII depend on the oxidation state of the cluster, which can be probed using various spectroscopic techniques. Here are some of the absorption peaks associated with different oxidation states of the OEC in PSII:

**$S_0$ state:** The $S_0$ state is the resting state of the OEC, in which all four manganese atoms are in the +2 oxidation state. The $S_0$ state is associated with a broad absorption peak centered around 320 nm.

**$S_1$ state:** The S1 state is the first intermediate in the water-splitting cycle, in which one of the manganese atoms is oxidized to the +3 oxidation state. The $S_1$ state is associated with a broad absorption peak centered around 330 nm.

**$S_2$ state:** The S2 state is the second intermediate in the water-splitting cycle, in which a second manganese atom is oxidized to the +4 oxidation state. The S2 state is associated with two absorption peaks: one at around 350 nm and another at around 490 nm.

**$S_3$ state:** The S3 state is the third intermediate in the water-splitting cycle, in which a third manganese atom is oxidized to the +4 oxidation state. The S3 state is associated with an absorption peak at around 365 nm.

**$S_4$ state:** The S4 state is the final intermediate in the water-splitting cycle, in which the remaining manganese atom is oxidized to the +4 oxidation state, and molecular oxygen is released. The S4 state is associated with an absorption peak at around 420 nm.

**EXTRINSIC SUBUNITS:** The extrinsic subunits of PSII are located on the lumen side of the thylakoid membrane. These subunits are involved in stabilizing the PSII complex and in regulating the flow of electrons through the photosynthetic electron transport chain.

The precise arrangement of these subunits within PSII is still a subject of active research, but it is clear that their coordinated interactions are critical for the efficient capture and transfer of light energy, as well as for the efficient oxidation of water molecules.

The extrinsic subunits of Photosystem II (PSII) are proteins that are not part of the core reaction center complex, but are bound to the luminal surface of the PSII membrane and play important roles in the function and regulation of the water-splitting reaction. These extrinsic subunits are also known as PsbO, PsbP, PsbQ, and PsbR.

The extrinsic subunits of PSII have characteristic absorption peaks in the visible and UV regions of the electromagnetic spectrum, which can be used to monitor changes in their conformation and function. Here are some of the absorption peaks associated with the extrinsic subunits of PSII:

**PSBO:** PsbO is a small extrinsic protein that is involved in the stabilization and regulation of the OEC. It has absorption peaks at around 280 nm and 320 nm.

**PSBP:** PsbP is another extrinsic protein that is involved in the stabilization of the OEC and the regulation of PSII activity. It has absorption peaks at around 280 nm and 340 nm.

**PSBQ:** PsbQ is a small extrinsic protein that is involved in the regulation of PSII activity and the protection of PSII against photodamage. It has absorption peaks at around 280 nm and 330 nm.
**PSBR:** PsbR is a larger extrinsic protein that is involved in the assembly and stability of PSII. It has absorption peaks at around 280 nm and 320 nm.
It is important to note that the exact absorption peaks of the extrinsic subunits can vary depending on their conformation, binding environment, and other factors, and may also overlap with the absorption peaks of other PSII components. Therefore, the interpretation of spectroscopic data must be done with caution and in conjunction with other biochemical and biophysical techniques.
It is worth noting, PSI and PSII are not themselves light-harvesting complexes, but they are integral components of the photosynthetic machinery that harvests light.
The light-harvesting complexes (LHCs) are pigment-protein complexes that are located in the thylakoid membranes of chloroplasts in plants, algae, and cyanobacteria. LHCs contain various pigments, including chlorophylls, carotenoids, and phycobilins, which absorb light energy and transfer it to the reaction centers of PSI and PSII.
PSI and PSII are the two main photosystems that are responsible for the conversion of light energy into chemical energy during photosynthesis. Each photosystem contains a reaction center surrounded by several light-harvesting complexes. When a photon of light is absorbed by a pigment molecule in a light-harvesting complex, the energy is transferred from molecule to molecule until it reaches the reaction center, where it is used to drive the primary photochemical reaction of photosynthesis.
Photosystems and light-harvesting complexes (LHCs) are both integral components of the photosynthetic machinery that harvests light, but they differ in their structure and function.
Light-harvesting complexes are pigment-protein complexes that are responsible for capturing light energy and transferring it to the photosystems. LHCs are composed of various pigments, including chlorophylls, carotenoids, and phycobilins, which absorb light energy over a range of wavelengths. The absorbed energy is then transferred from one pigment molecule to another until it reaches the reaction center of the photosystem.

In contrast, photosystems are large, multi-protein complexes that contain a reaction center surrounded by several light-harvesting complexes. There are two main photosystems, PSI and PSII, which are responsible for the primary photochemical reactions of photosynthesis. PSI absorbs light primarily at a wavelength of 700 nm, while PSII absorbs light primarily at 680 nm. Each photosystem contains a reaction center composed of chlorophyll a molecule that are

responsible for the primary photochemical reaction, as well as accessory pigments that help to funnel light energy into the reaction center.

## ELECTRON TRANSPORT CHAIN IN GREEN PLANTS

The electron transport chain (ETC) is a series of redox reactions that occur in the inner mitochondrial membrane of eukaryotic cells and the plasma membrane of prokaryotic cells. It is responsible for generating the majority of the ATP (adenosine triphosphate) produced during cellular respiration, which is the process by which cells convert glucose and other organic molecules into usable energy. In this section, a detailed explanation of the electron transport chain, including each step and reaction has been provided.

The electron transport chain reactions which occur in the inner mitochondrial membrane are mediated by a series of protein complexes and electron carriers. They form a chain that passes electrons from one molecule to the next. Each step in the chain is coupled with the pumping of protons ($H^+$) across the inner mitochondrial membrane, creating an electrochemical gradient that is used to drive the synthesis of ATP by the enzyme ATP synthase.

# The Reaction Chain

## Complex I

### (Nicotinamide Adenine Dinucleotide + Hydrogen) NADH dehydrogenase

The first complex in the electron transport chain is NADH dehydrogenase (also known as complex I), which accepts electrons from NADH and passes them to coenzyme Q ($C_oQ$). The reaction is as follows:

$$NADH + H^+ + C_oQ \rightarrow NAD^+ + C_oQH_2$$

In this reaction, NADH is oxidized to $NAD^+$ while $C_oQ$ is reduced to $C_oQH_2$. As electrons are passed from NADH to $C_oQ$, protons are pumped across the inner mitochondrial membrane, contributing to the electrochemical gradient.

## Complex II (Succinate dehydrogenase)

The next step in the electron transport chain is the transfer of electrons from succinate to $C_oQ$ via succinate dehydrogenase (also known as complex II). In this reaction, succinate is oxidized to fumarate, and FAD (flavin adenine dinucleotide) is reduced to $FADH_2$:

$$Succinate + FAD \rightarrow Fumarate + FADH_2$$

The electrons carried by $FADH_2$ are then passed on to CoQ, contributing to the electrochemical gradient.

## Complex III (cytochrome bc1 complex)

The third complex in the electron transport chain is the cytochrome bc1 complex (also known as complex III), which accepts electrons from $CoQH_2$ and passes them to cytochrome c. The reaction is as follows:

$$C_oQH_2 + 2 \text{ cytochrome c } (Fe^{3+}) \rightarrow CoQ + 2 \text{ cytochrome c } (Fe^{2+}) + 2\ H^+$$

As electrons are passed from $C_oQH_2$ to cytochrome c, protons are pumped across the inner mitochondrial membrane, contributing to the electrochemical gradient.

### Complex IV (cytochrome c oxidase)

The final complex in the electron transport chain is cytochrome c oxidase (also known as complex IV), which accepts electrons from cytochrome c and passes them to molecular oxygen ($O_2$) to form water ($H_2O$). The reaction is as follows:

$$\text{cytochrome c } (Fe^{2+}) + O_2 + 8\ H^+ \rightarrow 4 \text{ cytochrome c } (Fe^{3+}) + 2\ H_2O$$

As electrons are passed from cytochrome c to oxygen, protons are pumped across the inner mitochondrial membrane, contributing to the electrochemical gradient. The final product of this reaction is water, which is essential for the survival of the cell.

### ATP synthase

The electrochemical gradient created by the pumping of protons across the inner mitochondrial membrane is used to power the ATP synthase enzyme, which synthesizes ATP from ADP (adenosine diphosphate) and inorganic phosphate (Pi). The ATP synthase enzyme is a large complex that spans the inner mitochondrial membrane and consists of two main components: the $F_0$ component, which is embedded in the membrane and pumps protons across it, and the $F_1$ component, which protrudes into the mitochondrial matrix and synthesizes ATP.

As protons flow back into the mitochondrial matrix through the $F_0$ component of ATP synthase, the energy released is used to drive the synthesis of ATP by the $F_1$ component. This process is known as oxidative phosphorylation and is responsible for the majority of the ATP produced during cellular respiration.

### Regulation of the electron transport chain

The electron transport chain is tightly regulated to ensure that ATP production is balanced with cellular energy demand. One important regulatory mechanism is the control of electron flow between the various complexes in the chain. For example, if the demand for ATP is high, electrons may be diverted away from complex I and instead be passed directly to complex III via a process known as bypass or alternative pathways. This bypass allows for a faster flow of electrons, leading to increased ATP production.

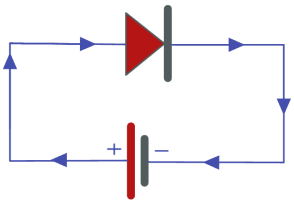
Another regulatory mechanism is the control of proton flow across the inner mitochondrial membrane. This is achieved through the action of uncoupling proteins (UCPs), which allow

protons to flow back into the mitochondrial matrix without passing through ATP synthase. This process is known as uncoupling and serves to dissipate the electrochemical gradient, reducing ATP production. Uncoupling is important in situations where excess energy needs to be dissipated, such as during cold exposure or in brown adipose tissue.

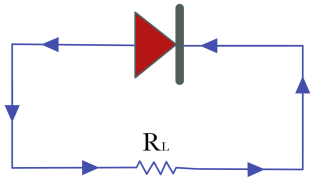
In conclusion, the electron transport chain is a complex series of redox reactions that occur in the inner mitochondrial membrane. It is responsible for generating the majority of the ATP produced during cellular respiration and is tightly regulated to ensure that ATP production is balanced with cellular energy demand. Each step in the chain is coupled with the pumping of protons across the inner mitochondrial membrane, creating an electrochemical gradient that is used to drive the synthesis of ATP by the enzyme ATP synthase. Understanding the electron transport chain is essential for understanding the mechanisms of cellular respiration and the regulation of energy metabolism.

## IV Characteristics of Solar cells

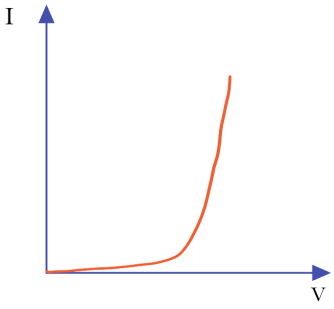
A solar cell is a simple PN junction diode where light is incident on the junction, thereby creating electron hole pair. The electrons move towards the p type of the devise and move through the external circuit. When PN junction diode is connected in forward bias it is found that on applying voltage electrons move towards the n-type of diode and move through the external circuit. This direction of the current is opposite to the direction of current observed in solar cells. Also, while measuring the IV characteristics of the solar cell, potential is applied to the devise which serves as the external load. Hence, in the characteristics of solar cells, for the positive values of voltage, current obtained is considered to be negative.



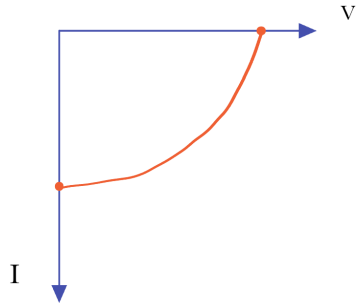

Forward bias of PN Junction




PN Junction serving as solar cells and generation of current opposite to forward bias




IV Characteristics of Forward bias Diode




IV Characteristics of Solar cells

## List of Publications

1. Study Of Optical Properties Of Hydrothermally Synthesized Cu/Cu2O/CuO Nanocrystals (AIP Conf. Proc. 1536, 245(2013))
2. Thermal analysis of microwave assisted synthesized poly(acrylic)acid/alumina composites (AIP Conf. Proc. 1536, 897 (2013))
3. Comparative study of PAA/alumina composites with PAA/alumina nano composites and thermal analysis of PAA/alumina nano composites with doping of metals (Solid State Phenomena Vol. 209 (2014) pp 121-124)
4. Effect of Preparation method on Optical and Structural properties of TiO2/ZrO2 Nanocomposite. (J. Nano. Adv. Mat. 2, No. 1, 27-33 (2014))
5. Investigation of Optical Properties of TiO2/CdS/PbSMultilayered Thin Film (Indian Streams Research Journal)
6. Synthesis and Characterization of Nanostructured PbS Thin film (Int.J. ChemTech Res.2014, 6(3), pp 1923-1925)
7. Enhancement of Optical Properties of Hydrothermally Synthesized TiO2/ZrO2 Nanoparticles by Al, Ce Co-doping (Solid State Physics, AIP Conf. Proc. 1665, 050124-1– 050124-3, (2015))
8. Pure Single Crystallographic Form of TiO2 Nanoparticles: Preparation and Characterization (Solid State Physics AIP Conf. Proc. 1665, 050125-1–050125-3, (2015))
9. Al and Mg Doped TiO2-ZrO2 Nanocomposites for Dye Sensitized Solar Cell Application (Invertis Journal of Renewable Energy, Vol. 5, No. 4, 2015; pp. 220-224)
10. Improved Conversion Efficiency of Dye Sensitized Solar Cell Using Zn Doped TiO2-ZrO2 Nanocomposite (Solid State Physics AIP Conf. Proc. 1731, 050132-1–050132-3 (2015))
11. To study interaction of TiO2/Photosystem I complexes for hybrid solar cells