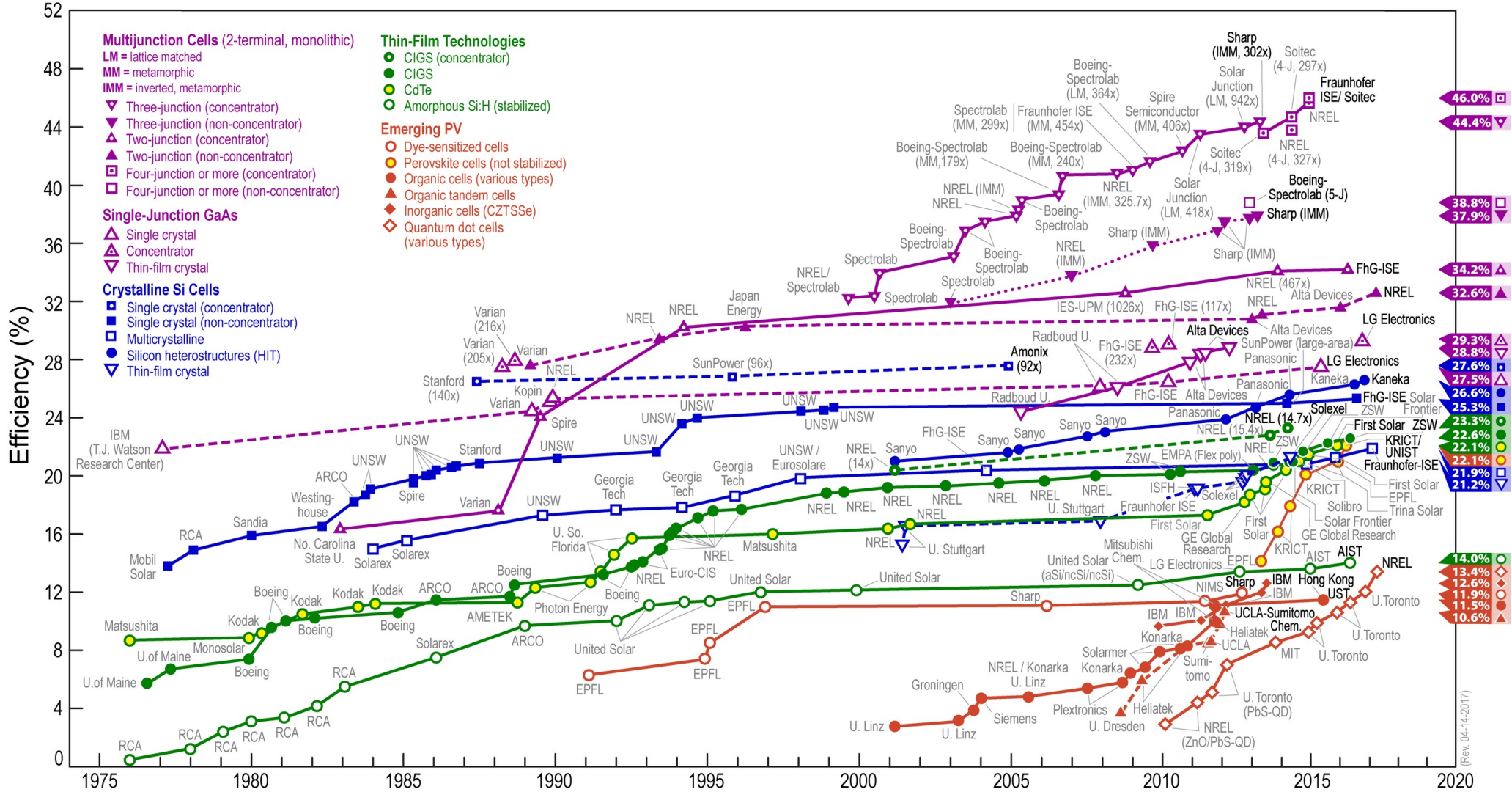


# Best Research-Cell Efficiencies

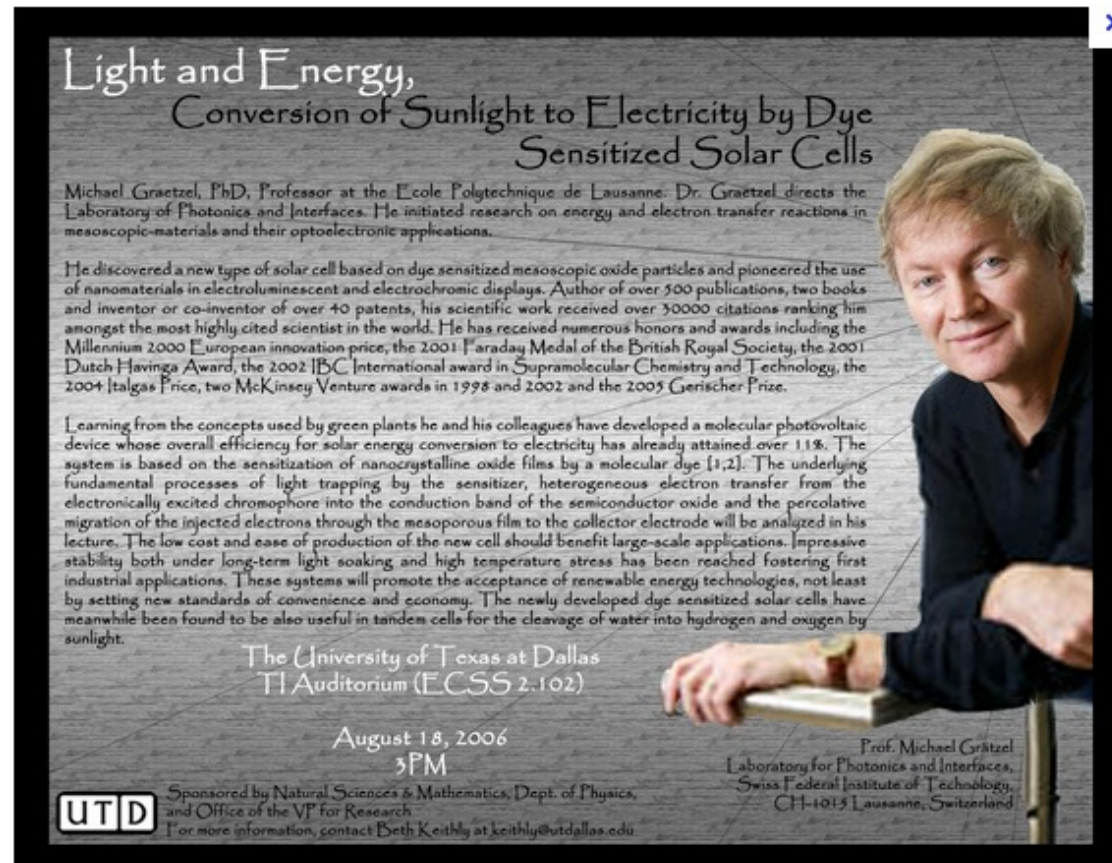


(Rev. 04-14-2017)

## Michael Grätzel, YouTube EPFL

### How the cell is made

G24i



**Light and Energy,  
Conversion of Sunlight to Electricity by Dye  
Sensitized Solar Cells**

Michael Grätzel, PhD, Professor at the Ecole Polytechnique de Lausanne. Dr. Grätzel directs the Laboratory of Photonics and Interfaces. He initiated research on energy and electron transfer reactions in mesoscopic materials and their optoelectronic applications.

He discovered a new type of solar cell based on dye sensitized mesoscopic oxide particles and pioneered the use of nanomaterials in electroluminescent and electrochromic displays. Author of over 500 publications, two books and inventor or co-inventor of over 40 patents, his scientific work received over 30000 citations ranking him amongst the most highly cited scientist in the world. He has received numerous honors and awards including the Millennium 2000 European innovation prize, the 2001 Faraday Medal of the British Royal Society, the 2001 Dutch Havinga Award, the 2002 IBC International award in Supramolecular Chemistry and Technology, the 2004 Italgas Prize, two McKinsey Venture awards in 1998 and 2002 and the 2005 Cerescher Prize.

Learning from the concepts used by green plants he and his colleagues have developed a molecular photovoltaic device whose overall efficiency for solar energy conversion to electricity has already attained over 11%. The system is based on the sensitization of nanocrystalline oxide films by a molecular dye [1,2]. The underlying fundamental processes of light trapping by the sensitizer, heterogeneous electron transfer from the electronically excited chromophore into the conduction band of the semiconductor oxide and the percolative migration of the injected electrons through the mesoporous film to the collector electrode will be analyzed in his lecture. The low cost and ease of production of the new cell should benefit large-scale applications. Impressive stability both under long-term light soaking and high temperature stress has been reached fostering first industrial applications. These systems will promote the acceptance of renewable energy technologies, not least by setting new standards of convenience and economy. The newly developed dye sensitized solar cells have meanwhile been found to be also useful in tandem cells for the cleavage of water into hydrogen and oxygen by sunlight.

The University of Texas at Dallas  
TI Auditorium (ECSS 2.102)

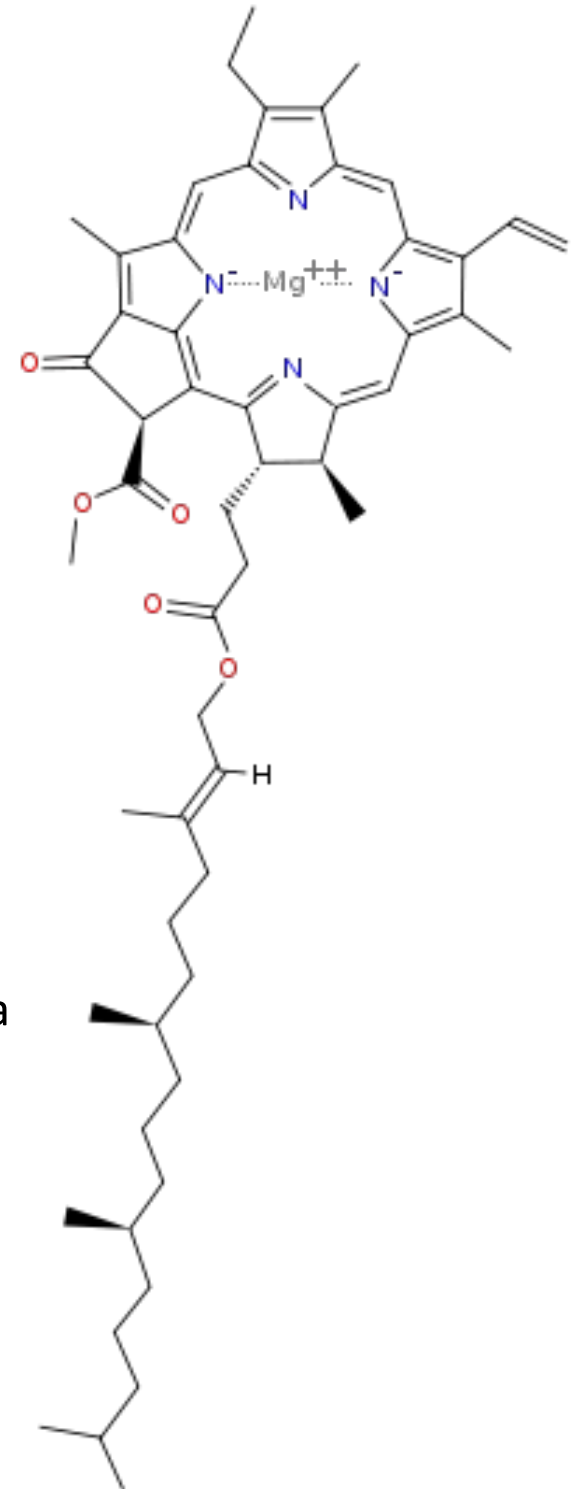
August 18, 2006  
3PM

UTD Sponsored by Natural Sciences & Mathematics, Dept. of Physics,  
and Office of the VP for Research  
For more information, contact Beth Keithly at keithly@utdallas.edu

Prof. Michael Grätzel  
Laboratory for Photonics and Interfaces,  
Swiss Federal Institute of Technology,  
CH-1015 Lausanne, Switzerland

# Why not make an artificial leaf?

Porphyrin Ring



Chlorophyll a

(Why Green  
And not Black?)

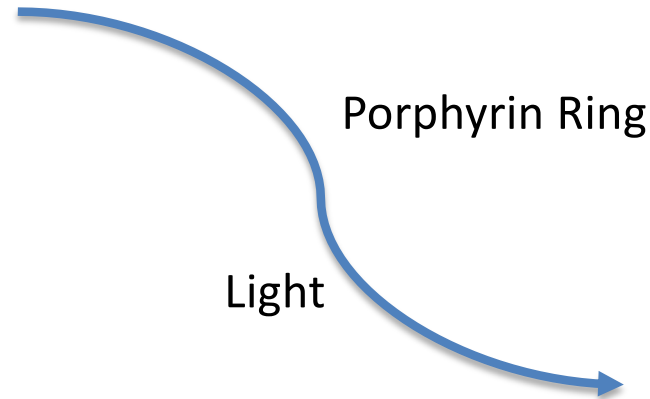
# Why not make an artificial leaf?

Incident light excites electrons in porphyrin ring.

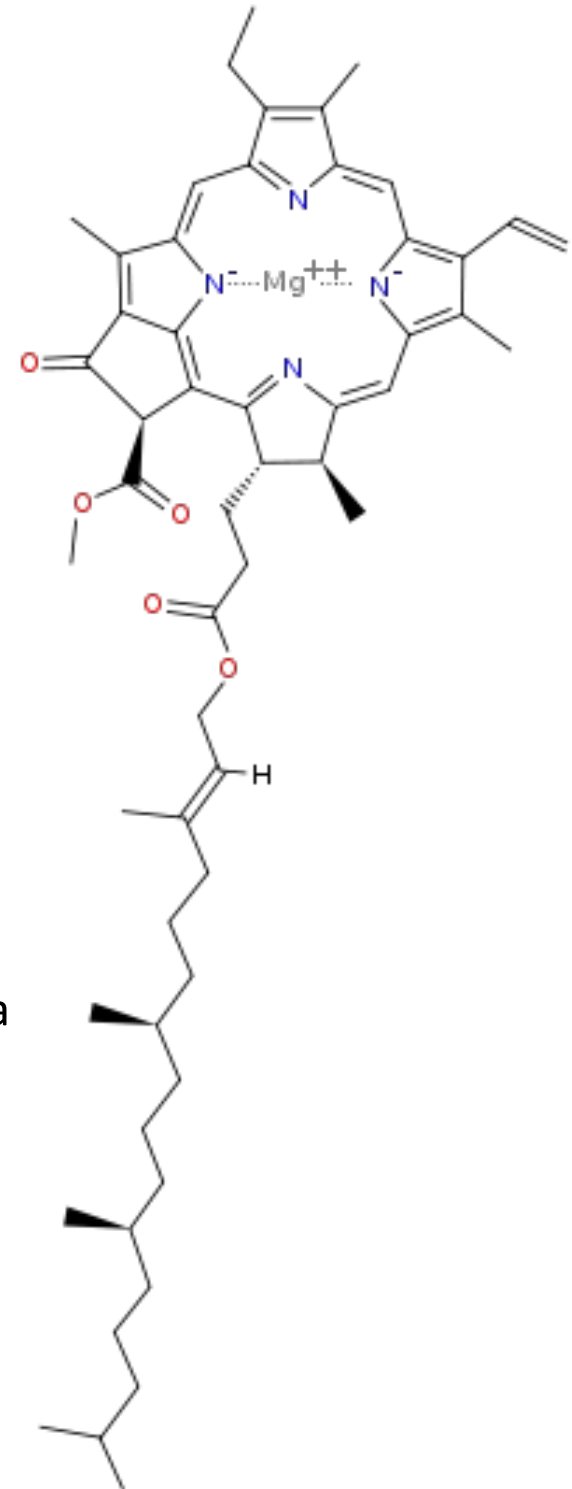
Chlorophyll is in a protein complex that separates charge.

Charged chlorophyll is reduced by oxidation of water. 2 Waters are oxidized releasing  $O_2$  and protons,  $4H^+$ .

The released electrons power the transport of protons further interact with ATP for cell energy eventually reducing  $CO_2$  to sugars.



Chlorophyll a



# Why not make an artificial leaf?

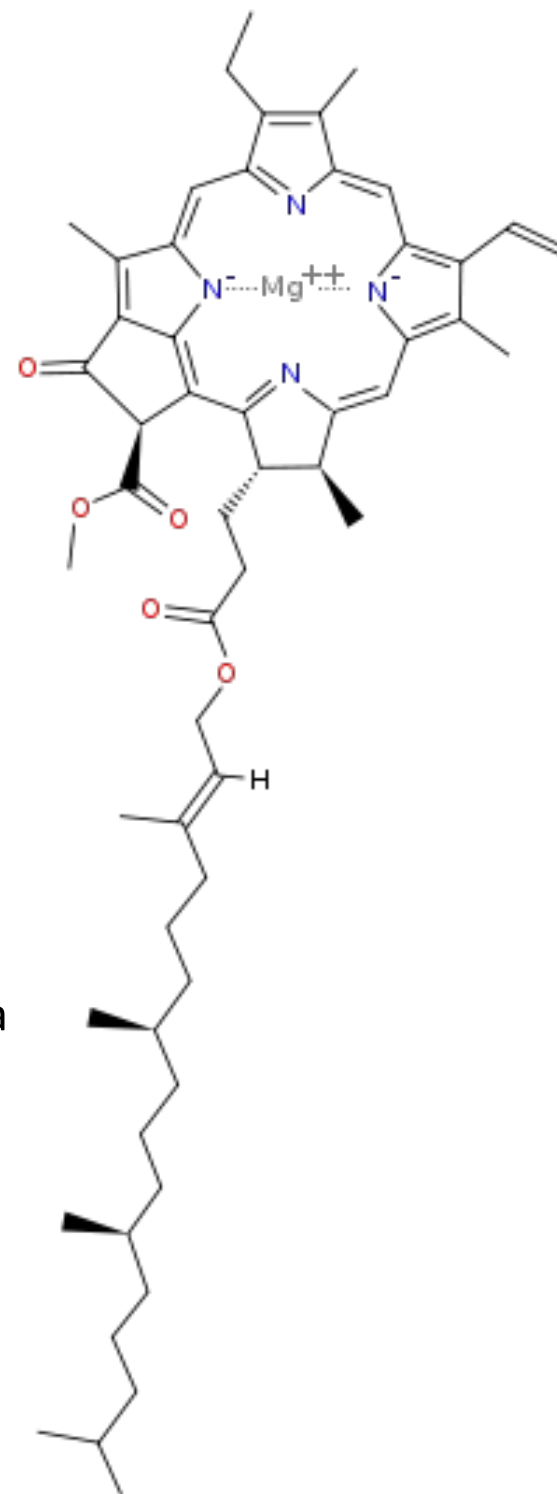
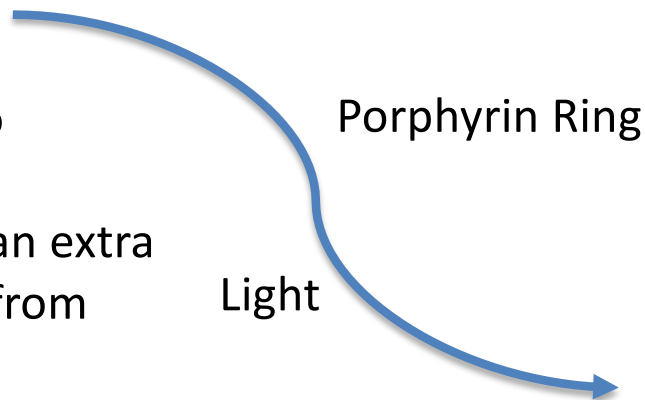
1970 Helmut Tributsch and Melvin Calvin wanted to study the electrochemical properties of chlorophyll in an extra cellular environment (away from the protein).

They found they could achieve charge separation using large band gap semiconductors ZnO or CdS in contact with an electrolyte.

Chlorophyll injects electrons from excited levels into the conduction band giving an anodic photocurrent.

Charge separation is irreversible.

The electrolyte is oxidized at the chlorophyll molecule and is reduced at the cathode to complete the circuit.



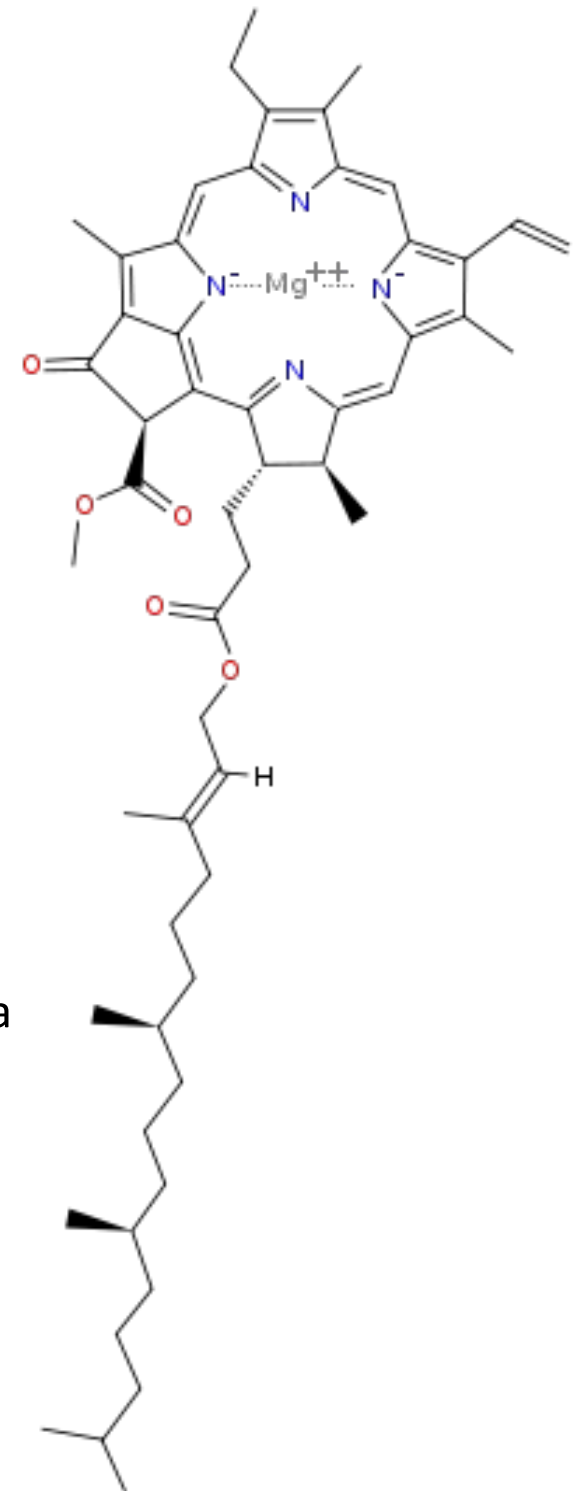
# Why not make an artificial leaf?

1970 Helmut Tributsch  
and Melvin Calvin used this  
process to measure the absorption  
Spectrum of various chlorophylls  
And other natural organic dyes.

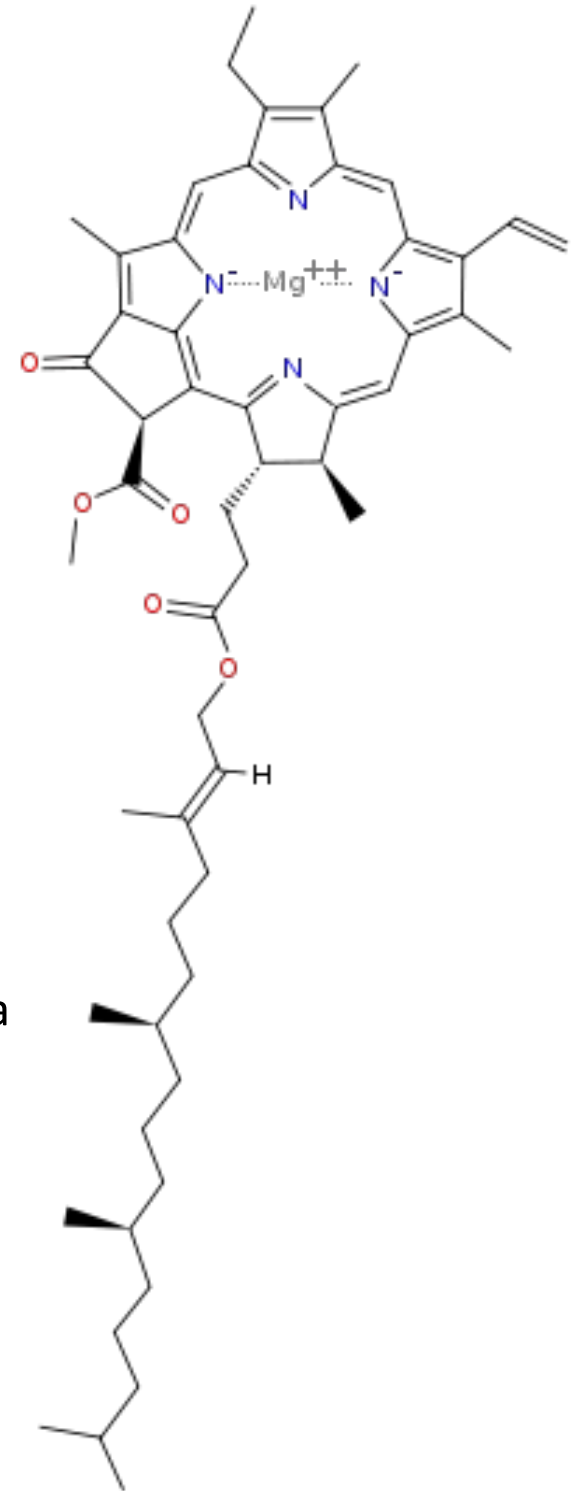
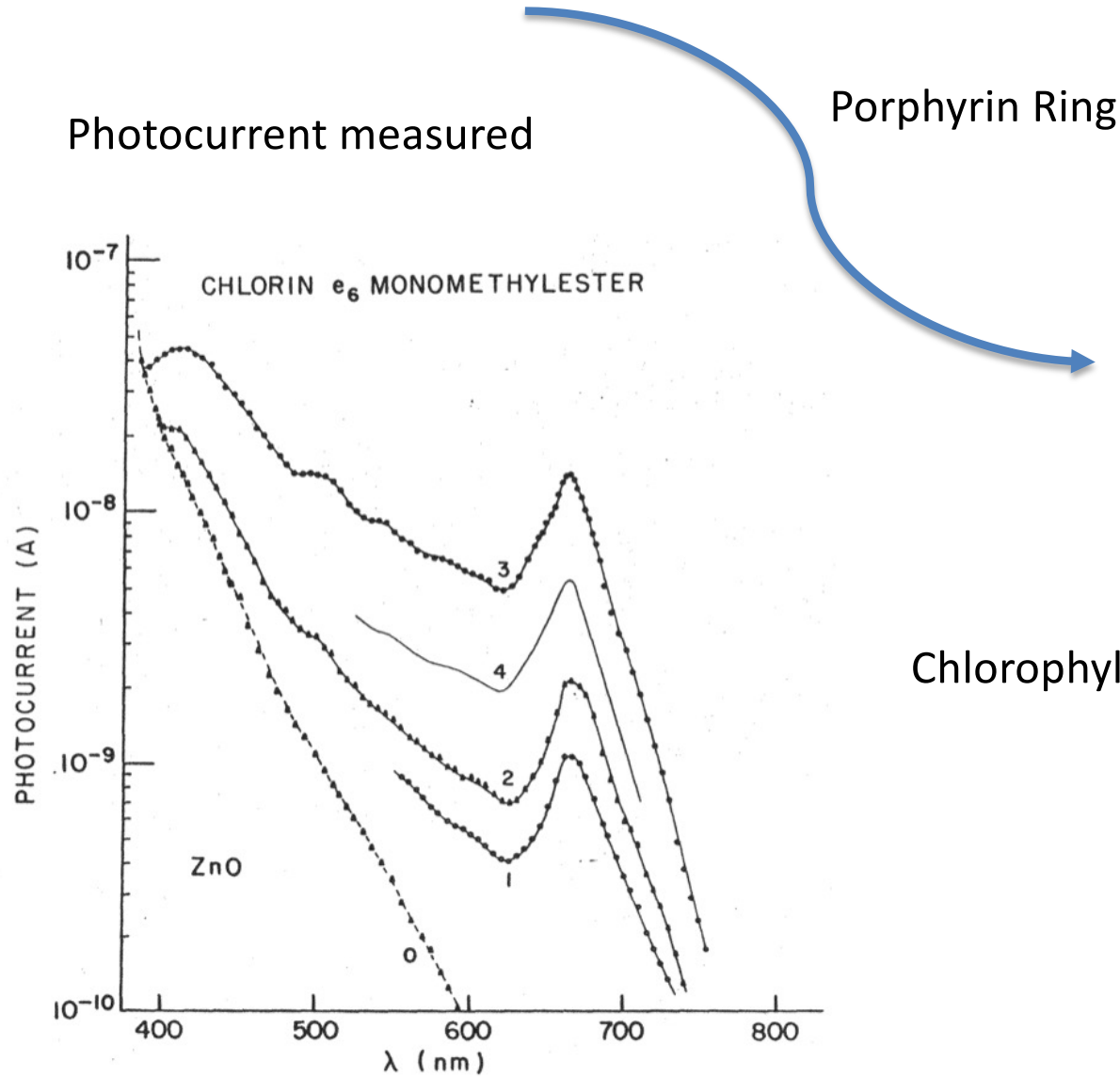
In the absence of an energy gap  
the charged chlorophyll molecule is  
quenched since both holes and electrons  
can be conducted in metals.

They used ZnO semiconductor anode  
Platinum cathode in KCl electrolyte solution.

Porphyrin Ring  
Light



# Why not make an artificial leaf?



## SENSITIZATION OF CHARGE INJECTION INTO SEMICONDUCTORS WITH LARGE BAND GAP\*

H. GERISCHER, M. E. MICHEL-BEYERLE,

F. REBENTROST and H. TRIBUTSCH

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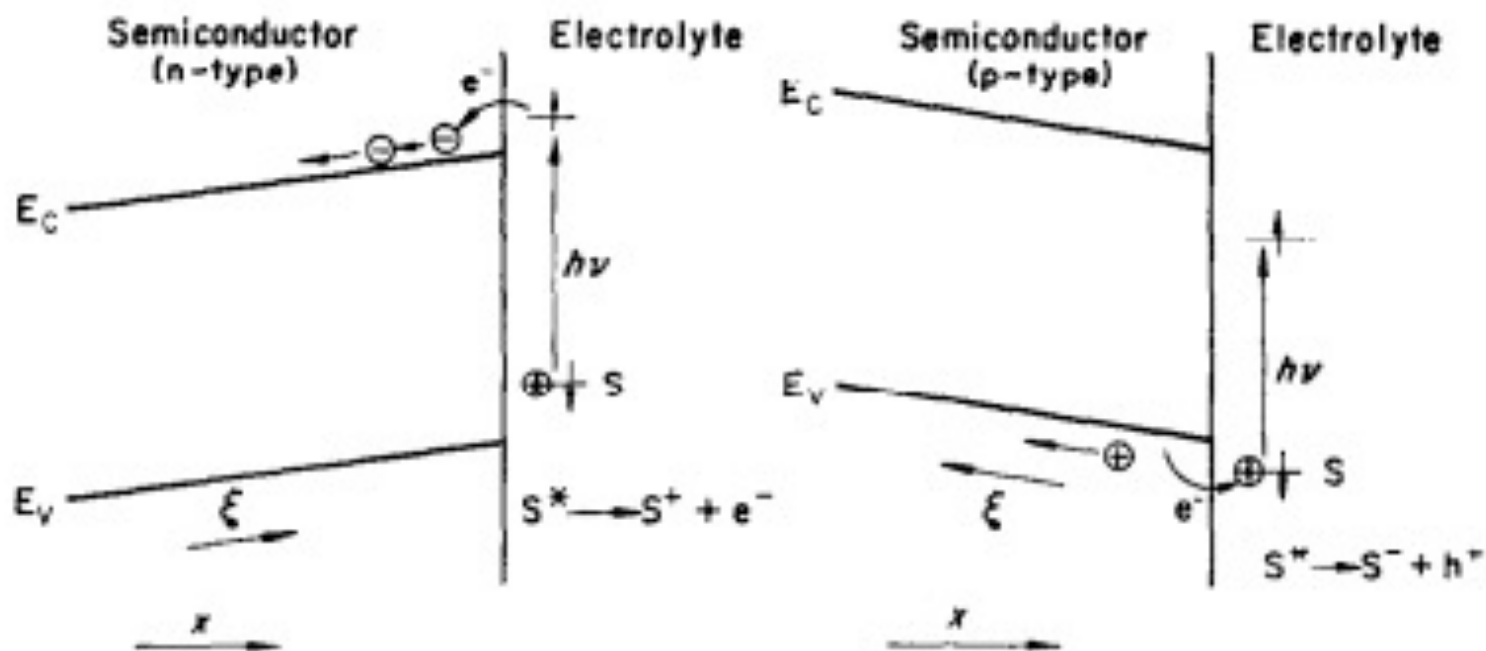


FIG. 8. Sensitized charge transfer at semiconductor electrodes.



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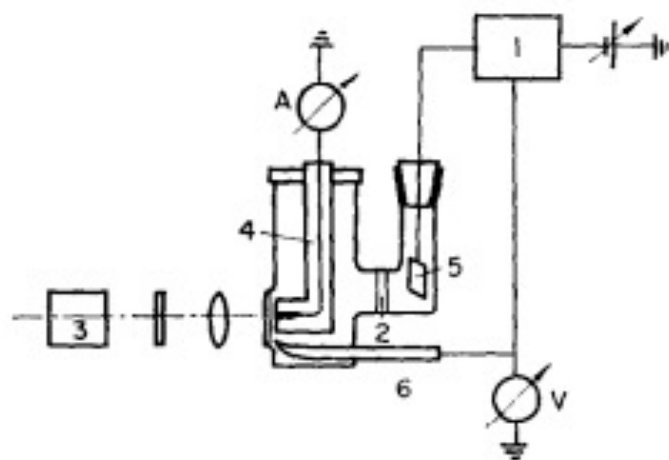


FIG. 1. Circuit for steady-state measurements with ZnO single-crystal electrode. 1, potentiostat; 2, diaphragm; 3, light source; 4, specimen holder; 5, inert electrode; 6, luggin capillary.

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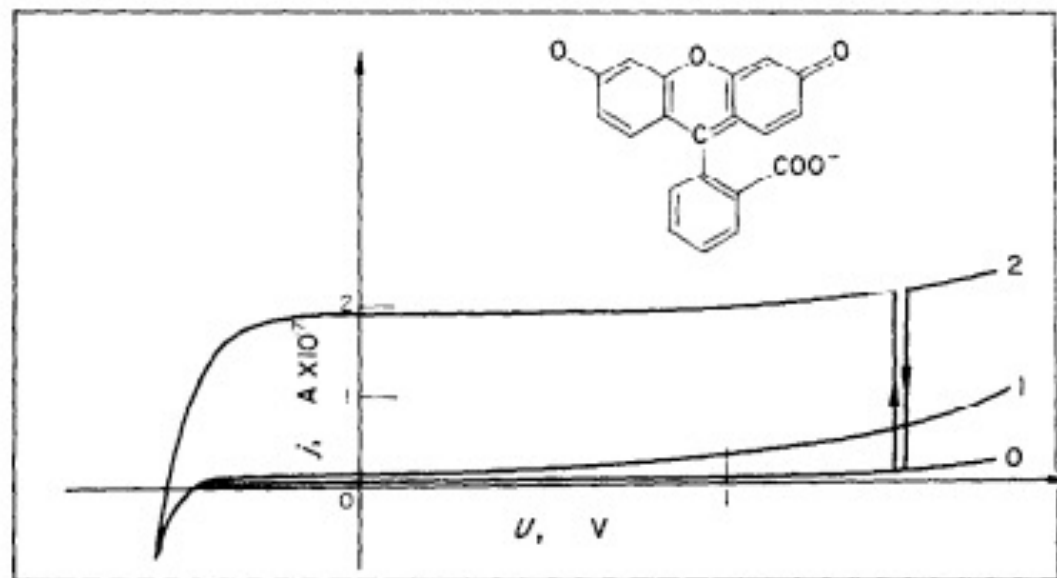


FIG. 2. Current/voltage characteristic for zinc-oxide single-crystal electrode-  
0, without illumination and without dye; 1, with illumination and without dye;  
2, with illumination and with dye.  
Effect of switching off the light is indicated by the arrows.

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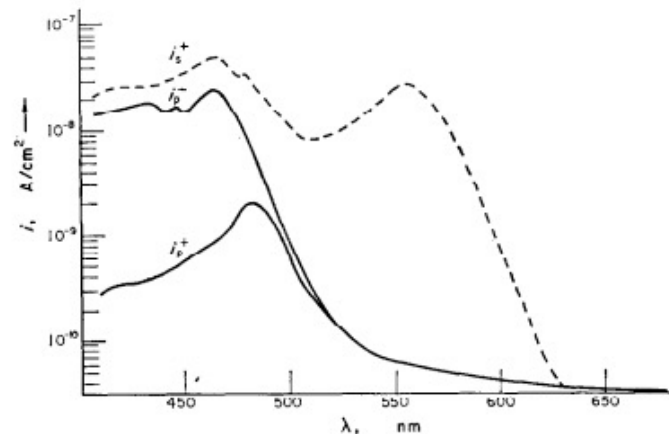


FIG. 6. Spectral dependence of the photocurrent  $i_p$  and the photosensitized current  $i_s$  at perylene single-crystal electrodes.

$i^-$  refers to currents with electrode A (see Fig. 5) negative,  $i^+$  to currents with electrode A positive. The subscript p indicates the photocurrent due to absorption of light by the perylene crystal; the subscript s means the limiting current due to absorption of light by the dye adsorbed at the perylene/solution interface; the first peak corresponds to the absorption edge of the crystal, the second to the absorption maximum of the dye. The dye was rhodamine B ( $ca 10^{-5}$  M).

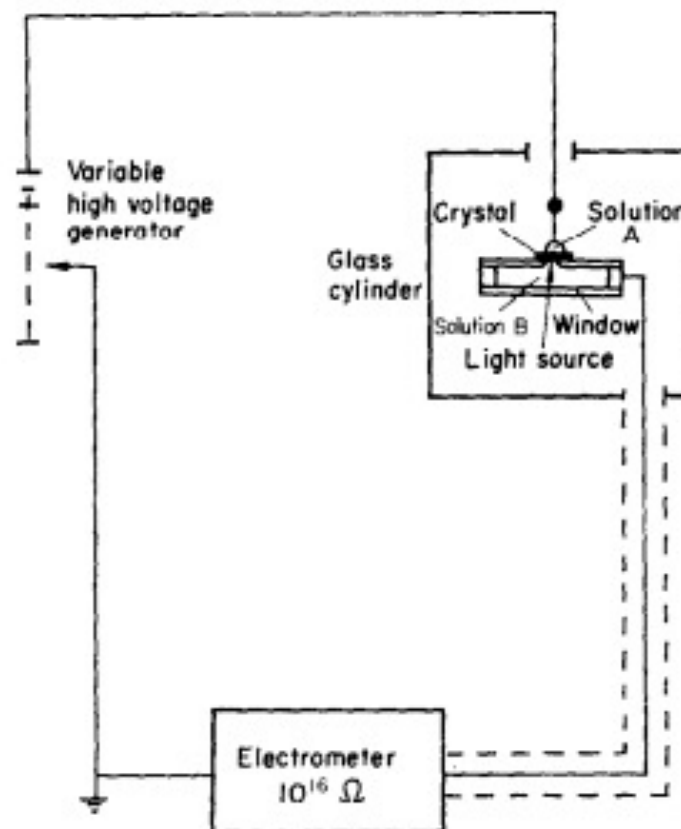


FIG. 5. Circuit for steady-state measurements of dye sensitized photocurrents.

# **Dye Sensitization and Surface Structures of Semiconductor Electrodes**

**Michio Matsumura, Shigeyuki Matsudaira, and Hiroshi Tsubomura\***

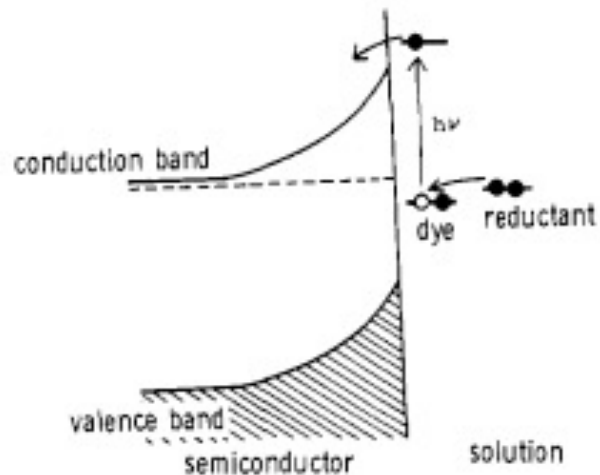
*Department of Chemistry, Faculty of Engineering Science, Osaka University, Toyonaka, Osaka, 560, Japan*

**Masasuke Takata and Hiroaki Yanagida**

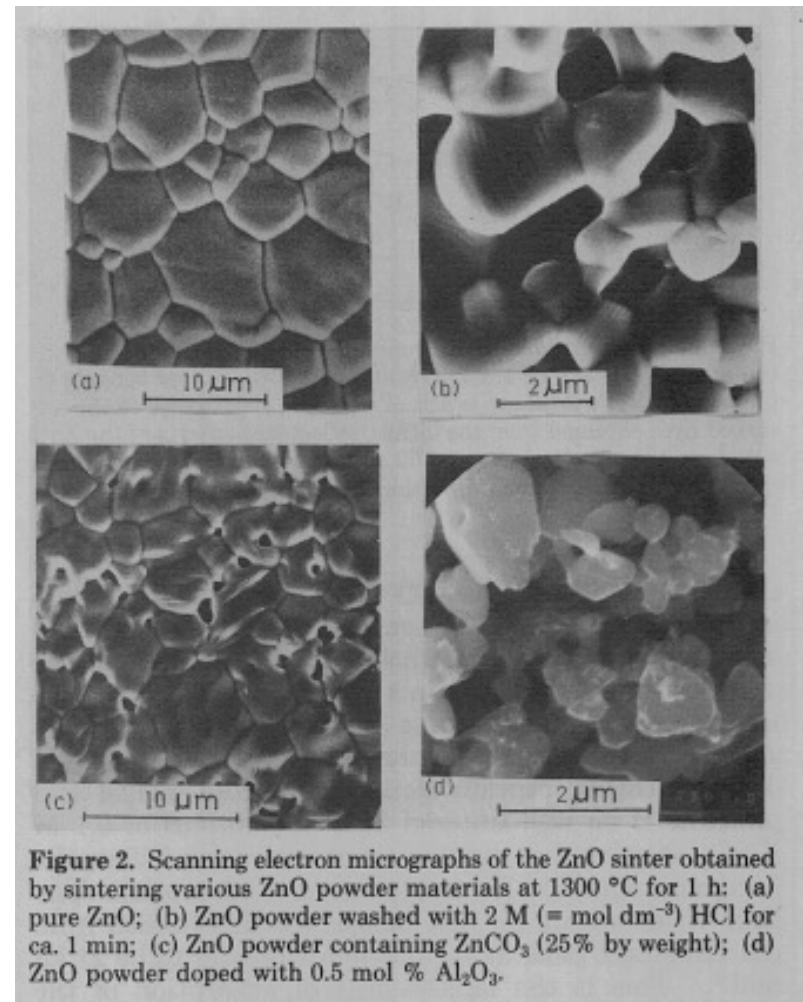
*Department of Chemistry, Faculty of Engineering, University of Tokyo, Tokyo, 113, Japan*

The dye-sensitization effects on the ZnO, CdS, and TiO<sub>2</sub> electrodes in electrochemical photocells were investigated for anionic, cationic, and zwitterionic dyes. The most efficient dye-sensitized photocell was achieved by using an aluminum-doped porous ZnO sinter electrode dyed with rose bengal (an anionic dye), the energy conversion efficiency being 2.5% for incident light of 562 nm. The effect of aluminum doping was attributed to the increase of the porosity (or surface area) of the sinter and the decrease of the electrical resistance. The effect of pH and the added salts in the solution as well as the effect of crystal face were extensively investigated. It turned out that these effects mainly influence the adsorptivity of the electrode surfaces for the sensitizing dyes, not the intrinsic current quantum efficiency. From these results, the structures of the dyes on the semiconductor surfaces were discussed in relation with the mechanism of photoinjection of electrons. The merits of dye-sensitized photoelectrodes as a photoenergy converter were discussed.

Use a Porous electrode to improve efficiency  
Lifetime still a problem



**Figure 1.** A model for the electron injection from an excited dye into an n-type semiconductor.



**Figure 2.** Scanning electron micrographs of the ZnO sinter obtained by sintering various ZnO powder materials at 1300 °C for 1 h: (a) pure ZnO; (b) ZnO powder washed with 2 M (= mol dm<sup>-3</sup>) HCl for ca. 1 min; (c) ZnO powder containing ZnCO<sub>3</sub> (25% by weight); (d) ZnO powder doped with 0.5 mol % Al<sub>2</sub>O<sub>3</sub>.

Optimum porous electrode is pyrolytic titania made in a spray flame as a Pigment in white paint, paper etc.



Optimum porous electrode is pyrolytic titania made in a spray flame as a Pigment in white paint, paper etc.

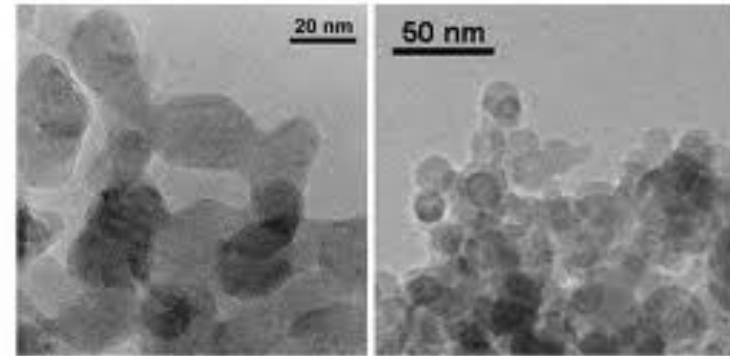
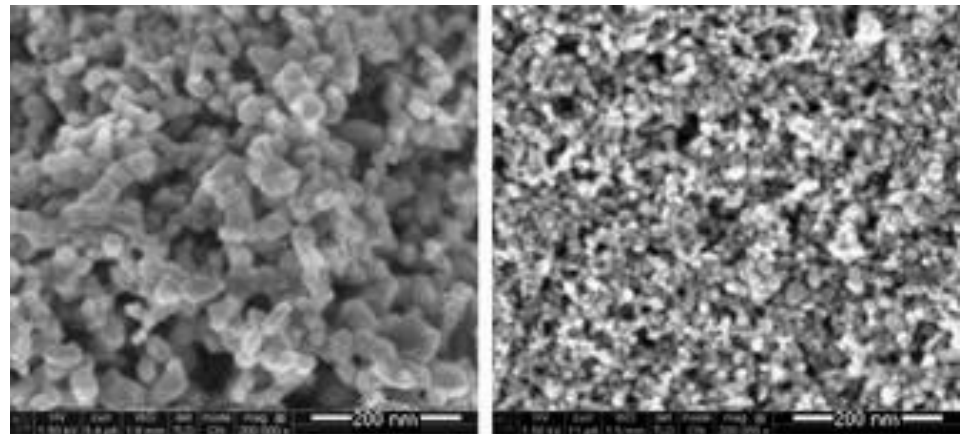


Fig. 1: Transmission electron micrograph of flame-made amorphous calcium carbonate (left) and calcium phosphate (right) nanoparticles. The morphology resembles the structure of fumed silica.

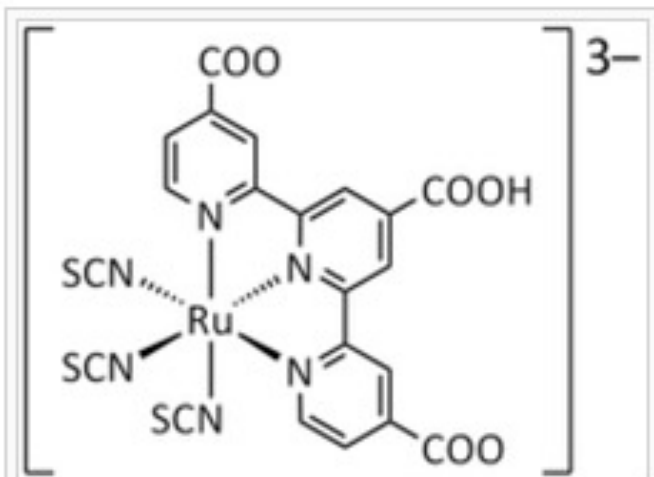


Compared to a silicon solar cell the Grätzel cell separates duties that are done by the pn-junction.

Electron-hole pairs are generated in the dye molecule (depletion zone in Si). Charge separation occurs at the dye/semiconductor interface due to the band gap in the semiconductor and an ionization energy level difference between the dye and semiconductor conduction band (for electrons) or valence band (for holes). This is done also by the pn junction in silicon.

Charge transport is done by the semiconductor and the anode. At the cathode the electrolyte is reduced and an electron is carried to the dye molecule to complete the circuit. This is all done by the silicon in a pn-junction cell.

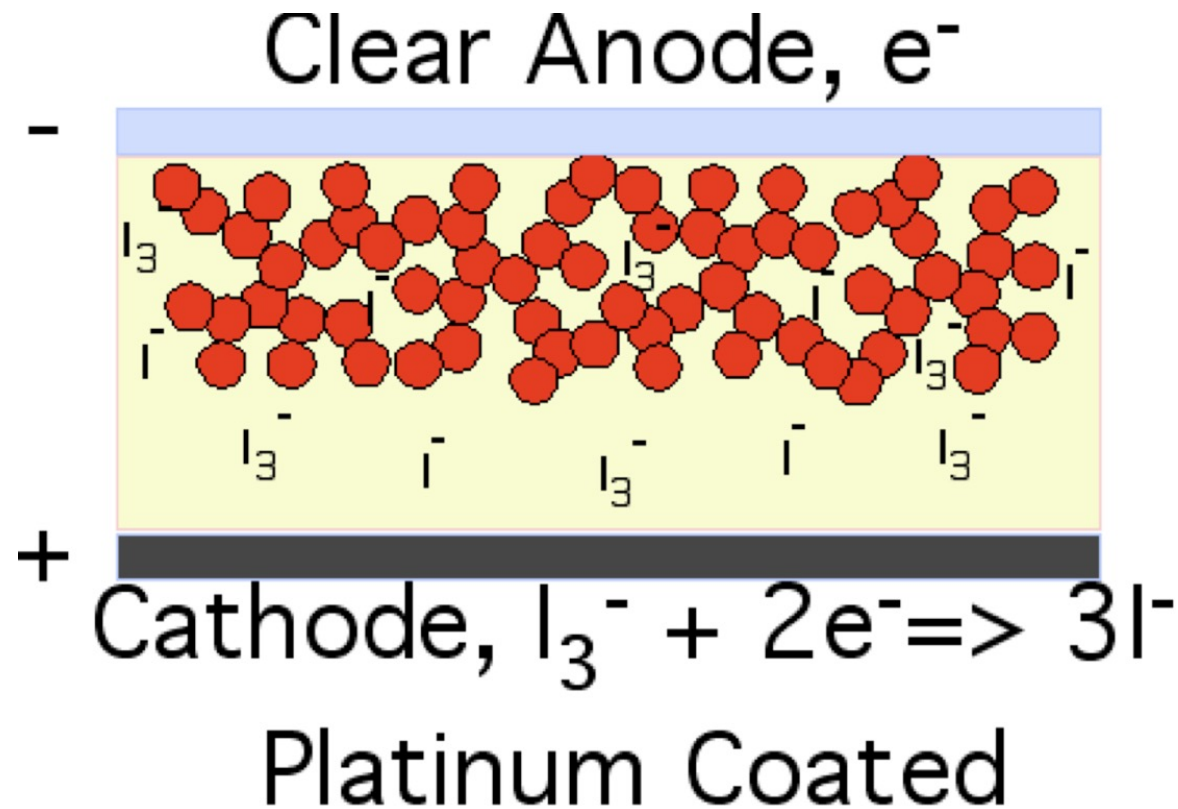




"Black Dye", an anionic Ru-terpyridine [complex](#)



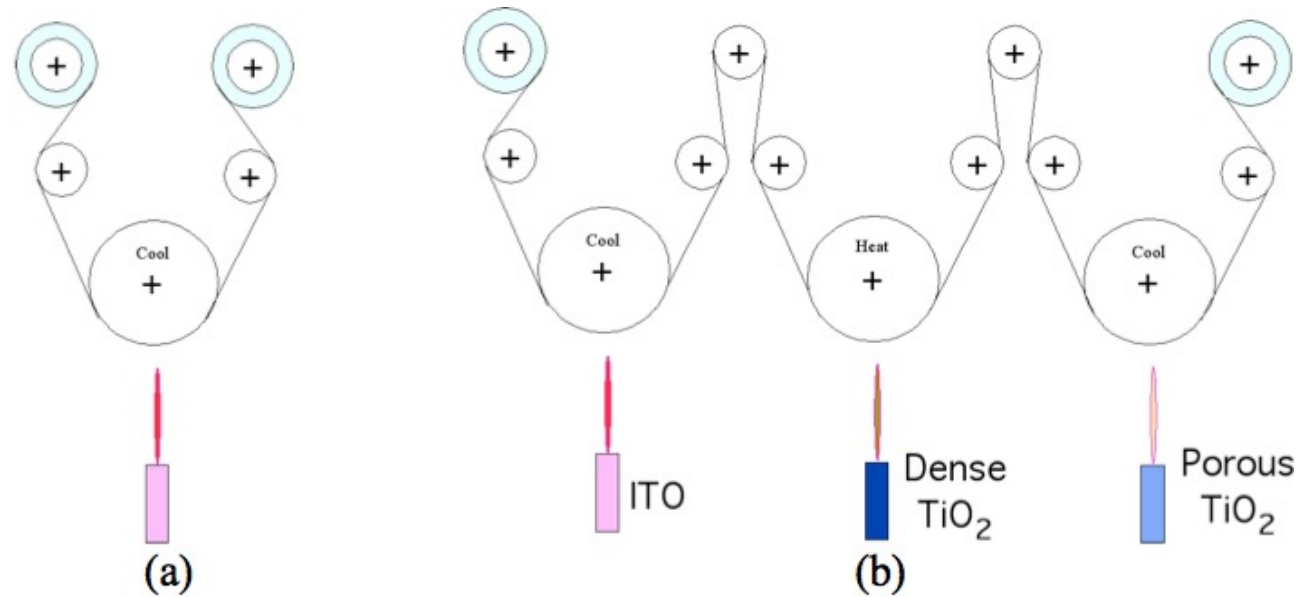
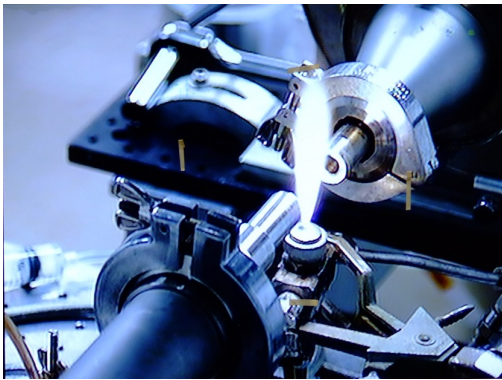
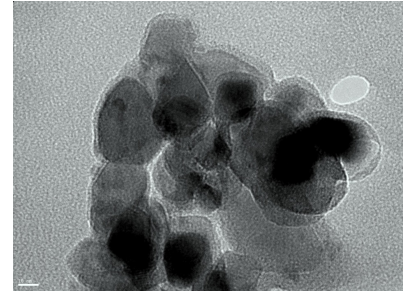
# One type of simple photovoltaic device that could be produced in Africa



*Schematic of a Graetzel Cell. Red circles are titania aggregates coated with a dye. Pink background is an iodide electrolyte gel. Platinum coated cathode is at the bottom and a clear plastic sheet coated with fluorine doped tin oxide anode is at the top.*

# Grätzel Cell Production by Spray Flame

- Dye/titania development for inexpensive single step synthesis
  - Use carbon coated titania to enhance interaction
  - Use in situ synthesized CdS nano particles supported on titania
- A single reel-to-reel, flame-based process for coating of plastic substrates in a continuous process for flexible solar cell sheets.



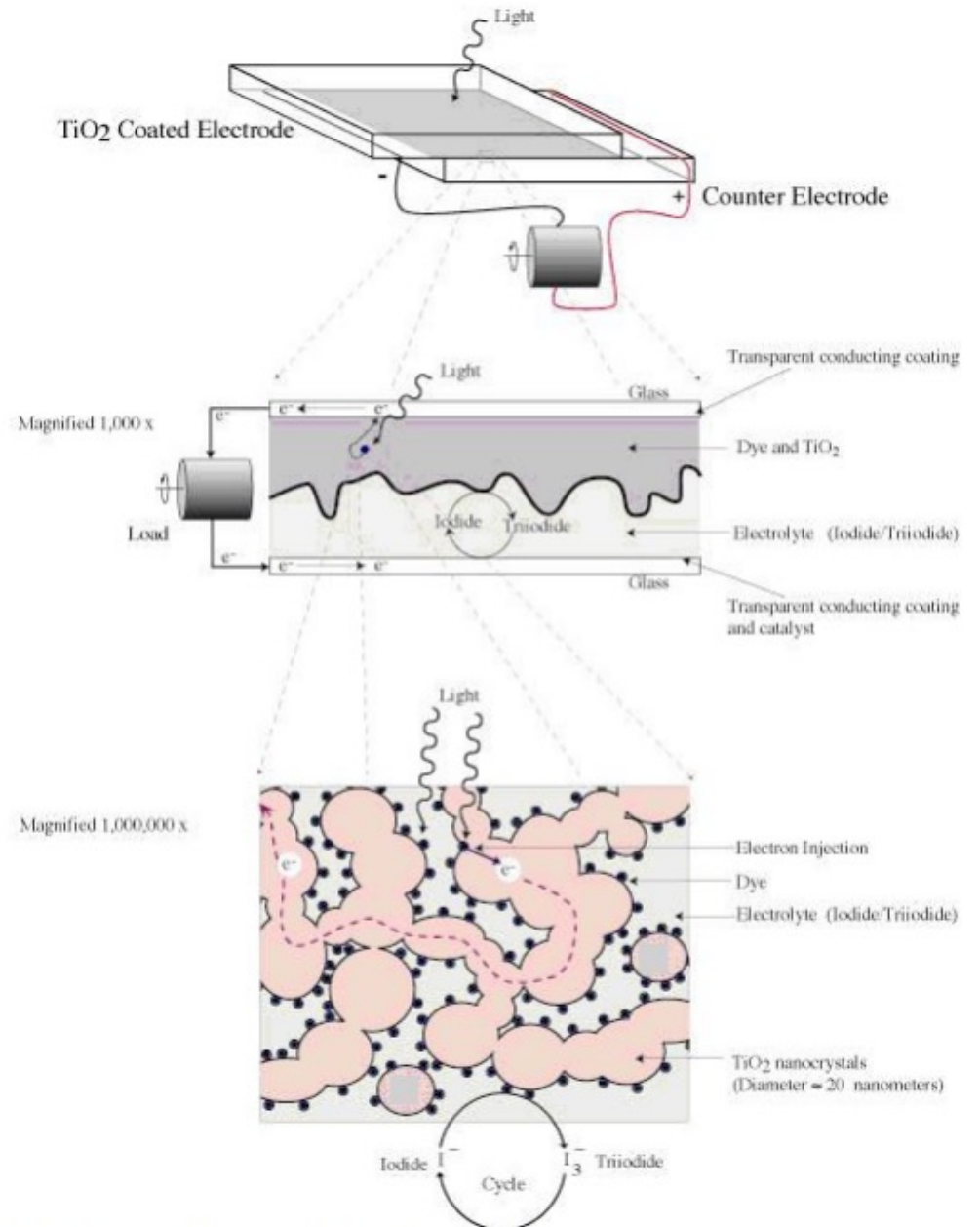
# Grätzel Cell or Dye Sensitized Solar Cell

[Web link to Grätzel Cell Fabrication](#)

[College/High School Lab to Make a DSSC](#)

# Grätzel Cell or Dye Sensitized Solar Cell

Lab UTexas



<http://www.solideas.com/solrcell/howworks.html>

# Grätzel Cell or Dye Sensitized Solar Cell

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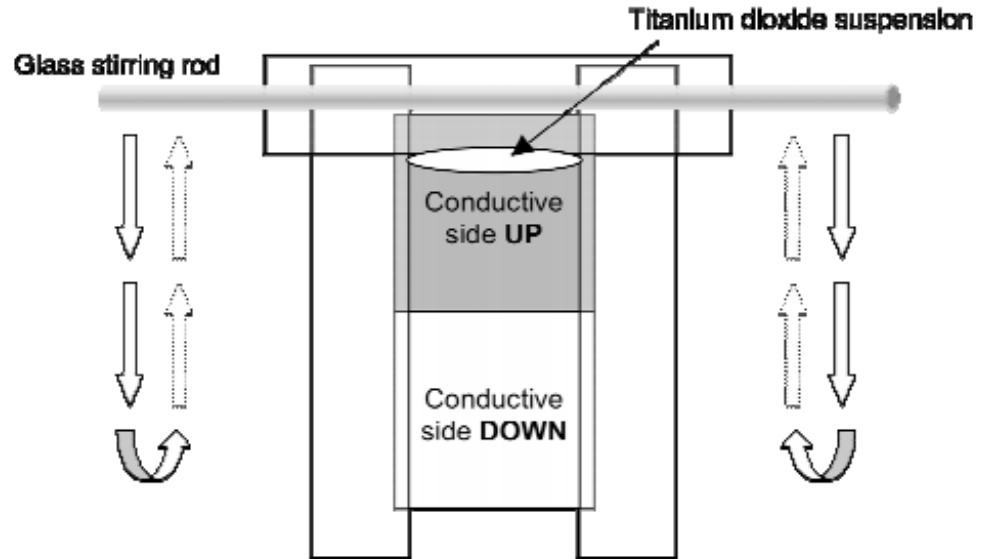


Figure 2 Diagram of how to make a thin layer of  $\text{TiO}_2$  on the glass slide.

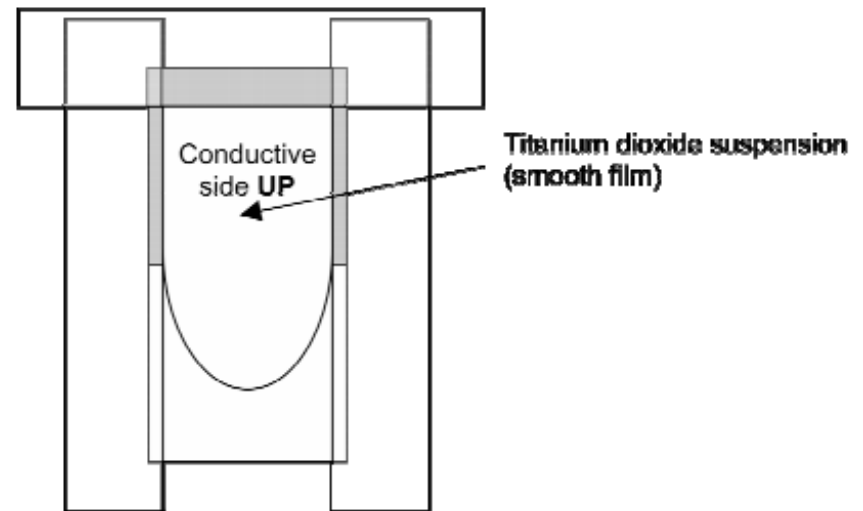
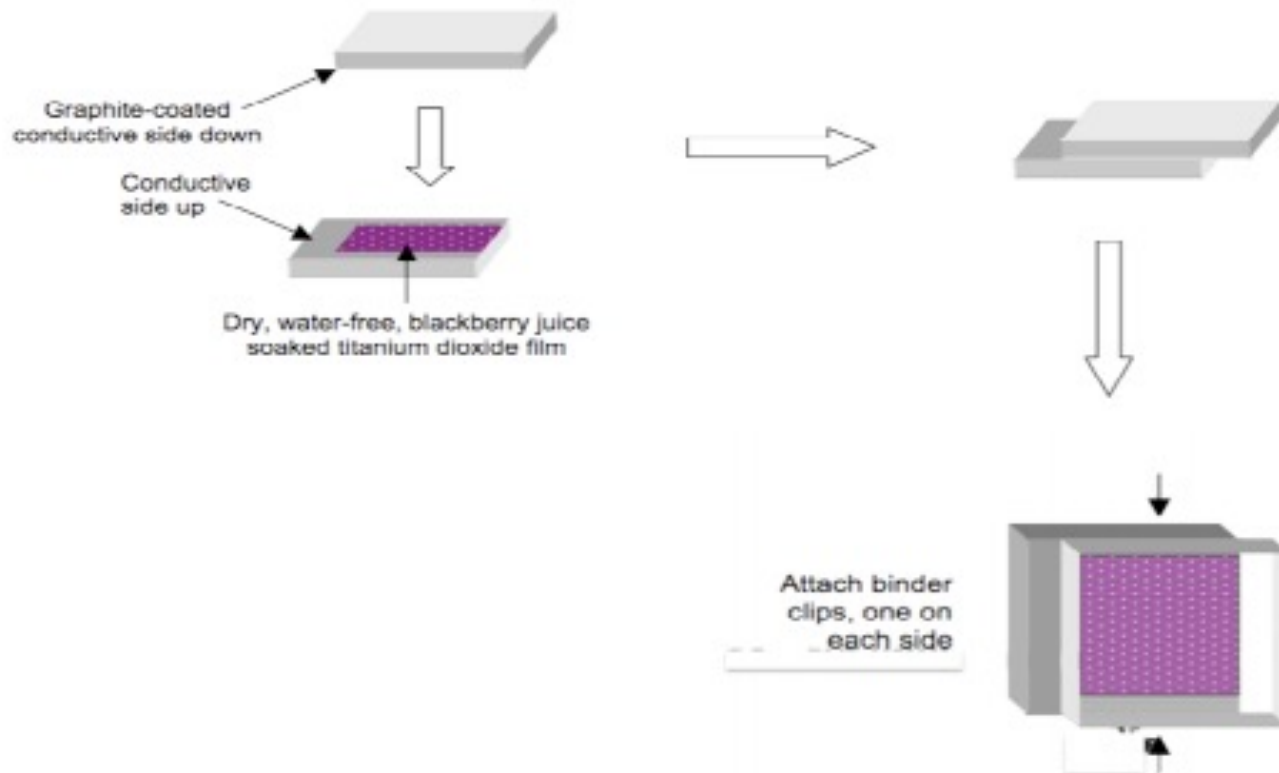


Figure 3 The  $\text{TiO}_2$  will cover all of the slide with the conductive side up.

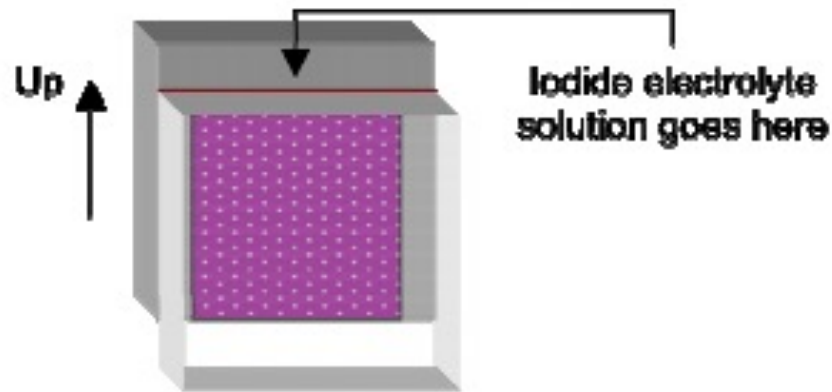
# Grätzel Cell or Dye Sensitized Solar Cell

Lab UTexas

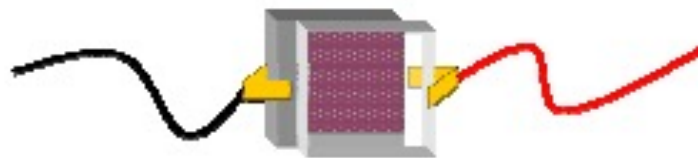


# Grätzel Cell or Dye Sensitized Solar Cell

Lab UTexas



**15.** Your solar cell is complete! Now, get a multimeter and use the alligator clip leads to attach your cell to the multimeter, in the positions shown below (make sure neither alligator clip touches both slides). Measure both the voltage and the current output of your cell in light and in darkness, and examine its behavior (ask an instructor to assist in this step).

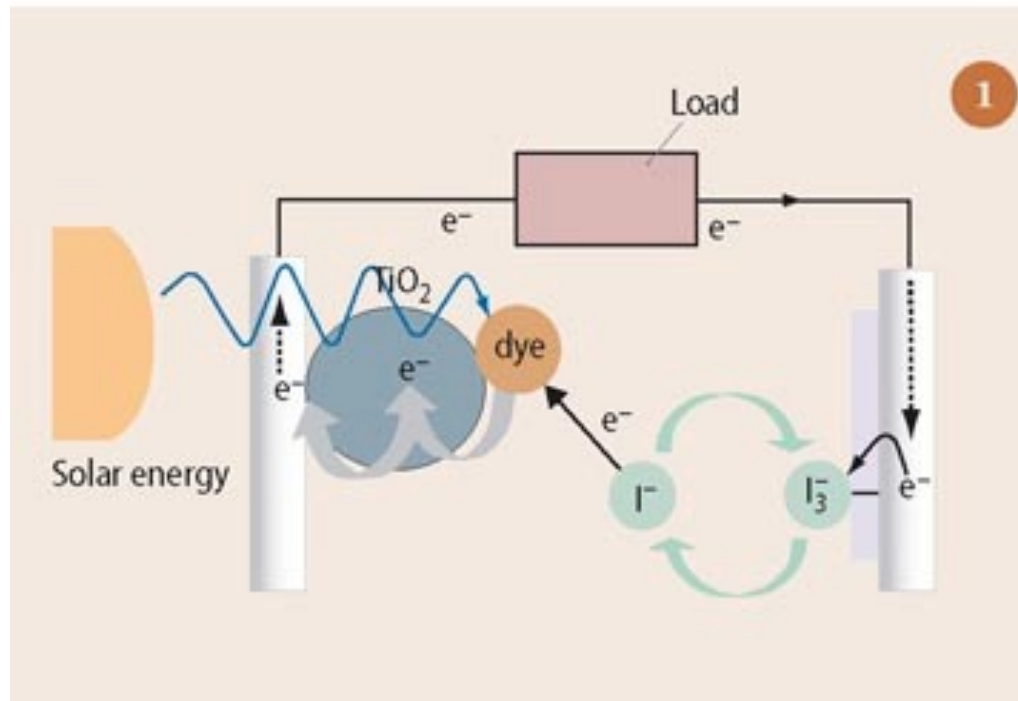




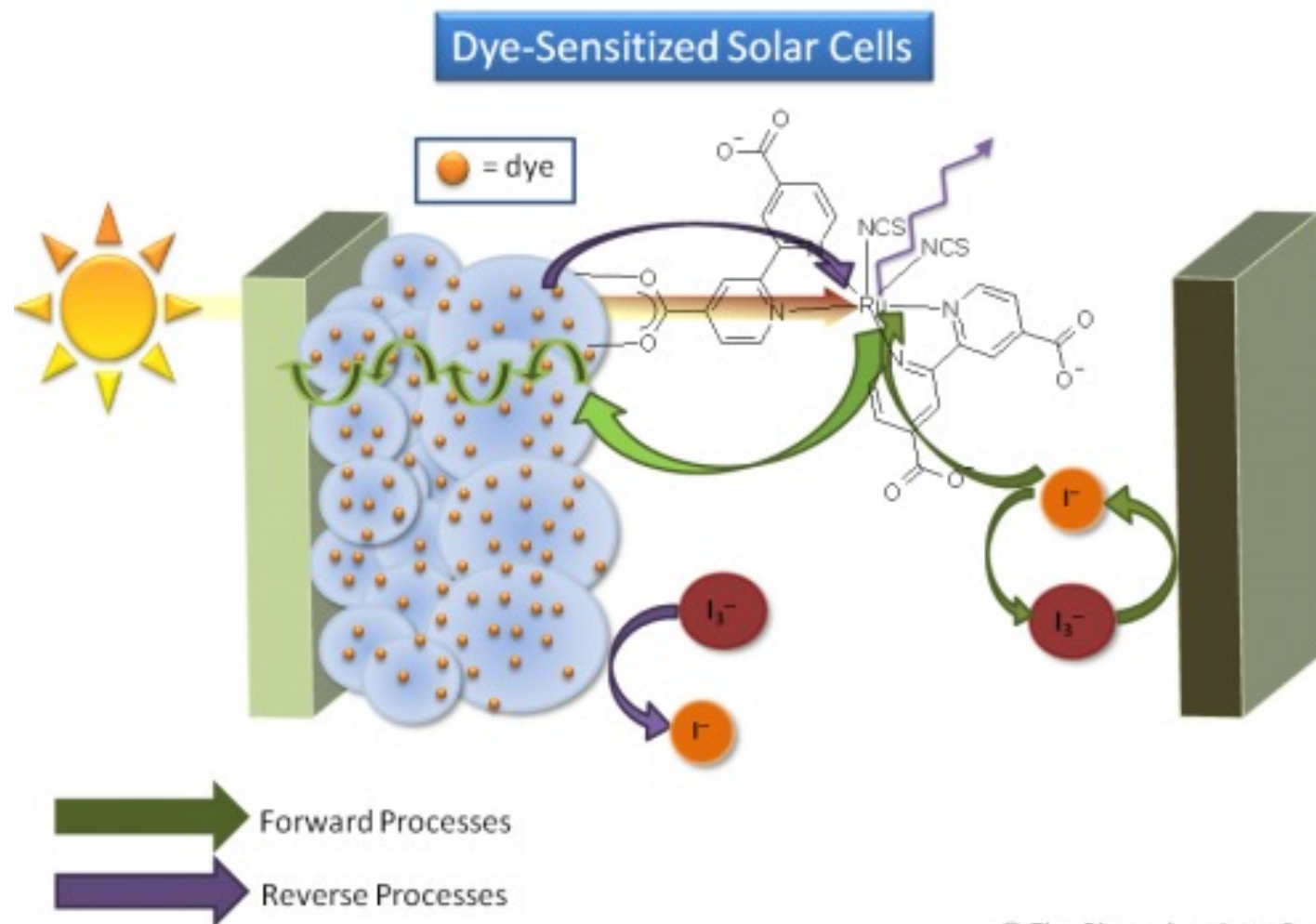
# Grätzel Cell or Dye Sensitized Solar Cell



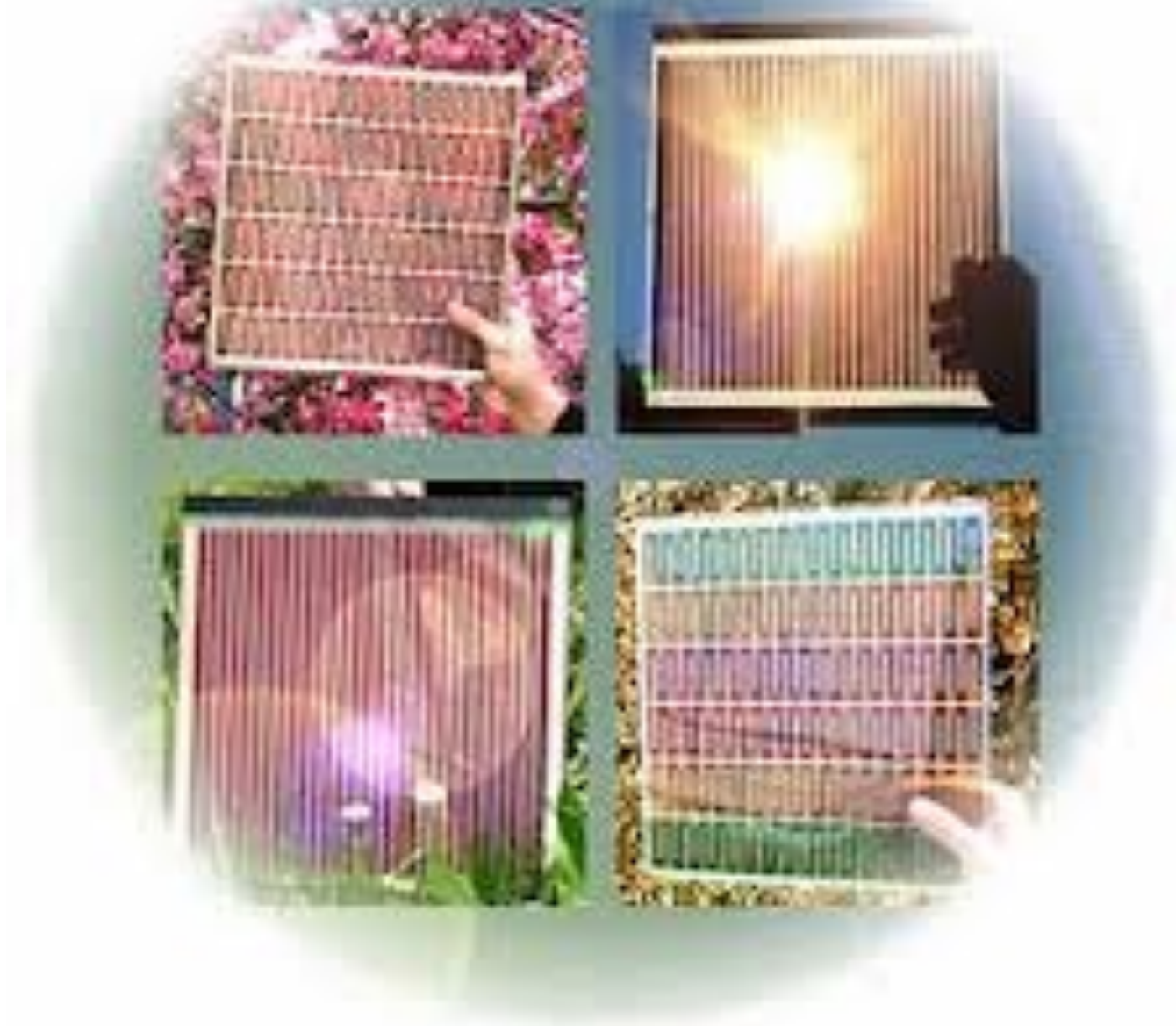
# Grätzel Cell or Dye Sensitized Solar Cell



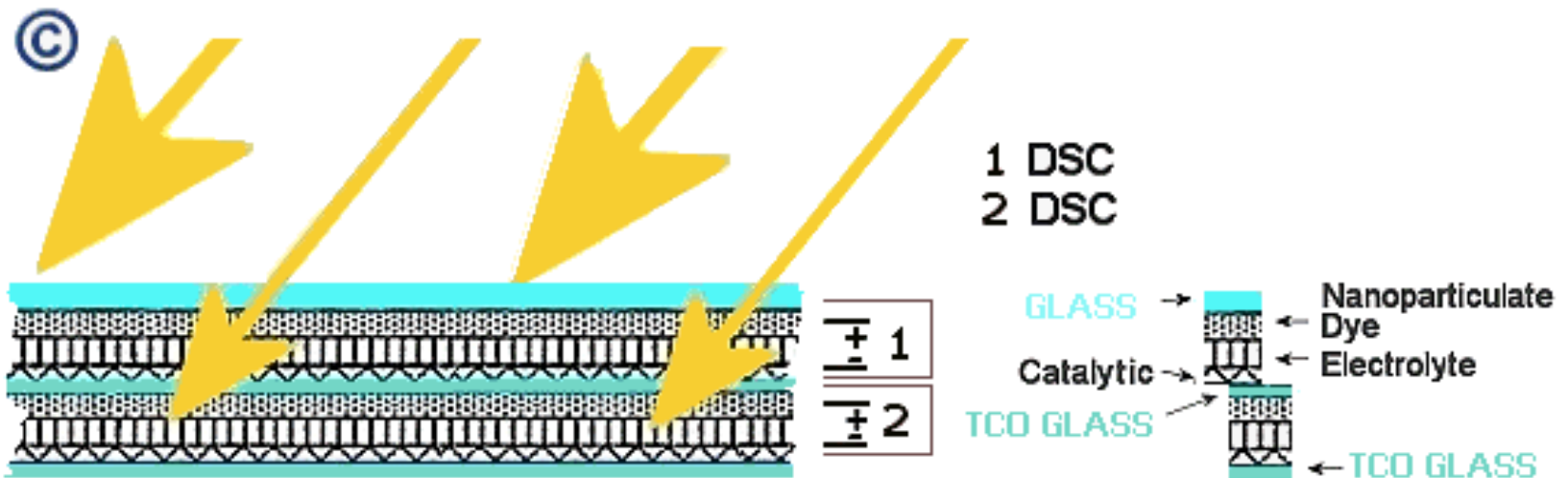
# Grätzel Cell or Dye Sensitized Solar Cell



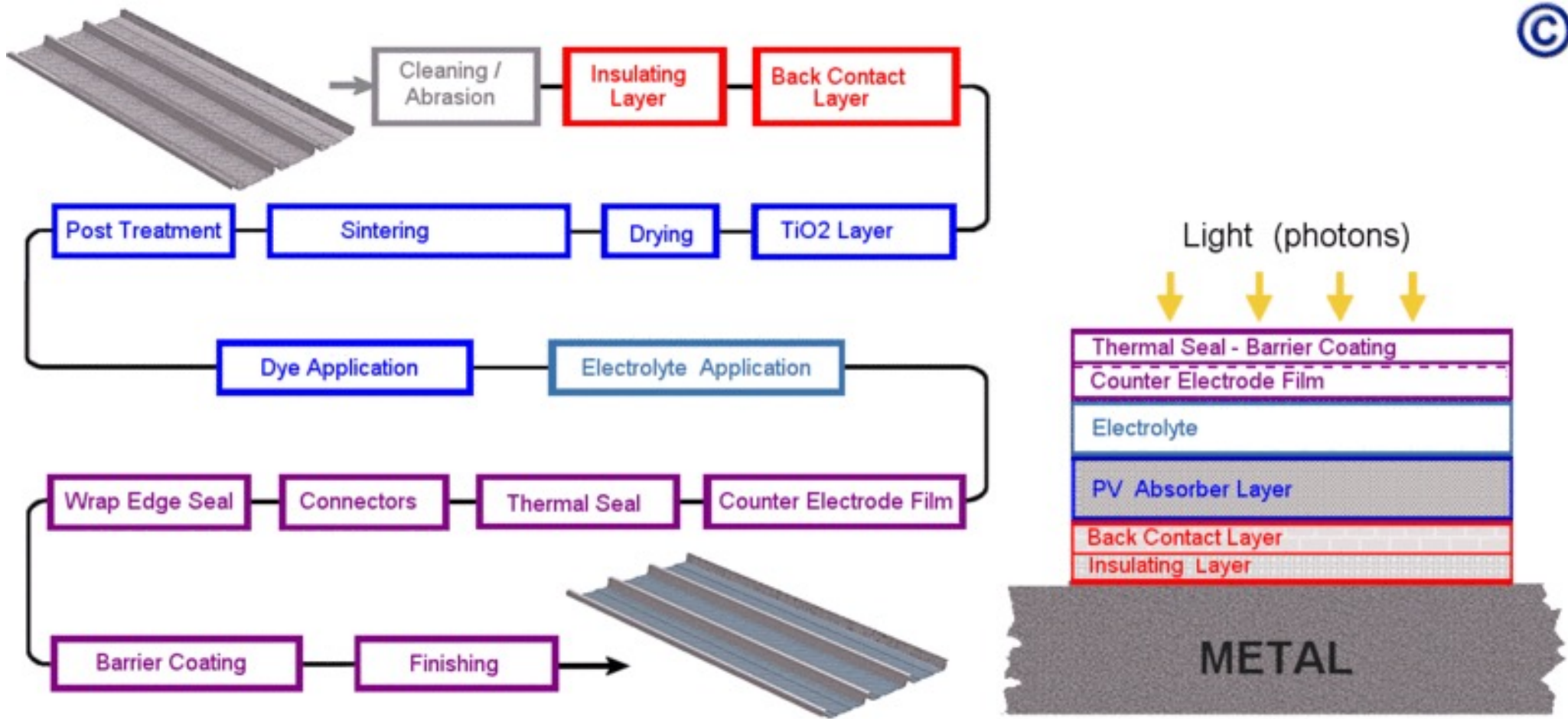
# Grätzel Cell or Dye Sensitized Solar Cell



Dyesol, Queanbeyan, New South Wales



Dyesol, Queanbeyan, New South Wales



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[Gcell \(Video in bottom left\)](#)

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Fujikura

Perovskite Solar Cell

Perovskite Improvements Park

TED Talk on Perovskite