LIGHT ENERGY

SOLAR CELL BASED ON ARTIFICIAL PHOTOSYNTHESIS

15TH MAY 2008

- TASK 2 -

NICOSIA CYPRUS

TABLE OF CONTENTS

1. GENERAL DIRECTIONS

- Write your names and your personal data in the frame of the first page of the two answer sheets.
- You have 4 hours to finish the test. Manage your time wisely.
- There are 24 pages in task 2, 13pages in answer sheet 1 and 2 pages in answer sheet 2.
- Write answers and calculations within the designated box.
- No additional chemicals will be provided (except distilled water). Additional glassware will be provided.
- No additional explanations will be provided.
- Volume measurements using a burette should be with precision of ±0.05 mL.
- The use of correction fluid and programmable calculators is prohibited.
- Use only black or blue pen.
- You may go to the restroom with permission.
- After finishing the test, place all sheets (Test and Answer Sheets) in the envelope provided and seal.
- Remain seated until instructed to leave the room.

2. RULES TO BE FOLLOWED IN LABORATORIES

- **Wear safety goggles, protective gloves and lab coat, during the entire duration of your stay in the laboratory.**
- **For filling a pipette, use the pipette filler bulb provided.**
- **Follow safety and risk phrases.**
- **Do not sniff reagents.**
- **Dispose used chemicals in the plastic bottle labeled "Waste basket".**
- **Discard used test tubes and broken glasses in the "Glass disposable".**
- **It is not permitted to eat or drink in the laboratory.**
- **Do not move from your place and do not borrow any chemicals or instruments from the other competitors. If you need any kind of help do not hesitate to ask the invigilator.**
- **Penalty points will be applied for the violation of safety rules or for any damaged glassware or broken instruments.**
- **Always follow the lab invigilator's directions.**

3. LIST OF CHEMICALS

Reagent	**Quantity**	**Placed in**	**Labeled**
Titanium Dioxide suspension(to be used in common)	5mL	Capped bottle	TiO_2 Suspension
Pomegranate juice +10% distilled water	40mL	Amber glass bottle	Pomegranate juice
Iodide electrolyte	15mL	Plastic dropper bottle	KI / Iodine electrolyte WARNING: contains Ethylene glycol
Sodium thiosulphate	60mL	Amber glass bottle	$Na_2S_2O_3$ 0.0780M
Iodine/potassium iodide solution in ethylene glycol	45 mL	Amber glass bottle	KI_3 $(CH_2OH)_2$ C_x
Ethanol	300 mL	Plastic wash bottle	ETHANOL
Isopropanol	100 mL	Plastic wash bottle	ISOPRORANOL
Deionized water	500mL	Plastic wash bottle	DEIONIZED WATER
Starch solution	10mL	Dropper bottle	Starch indicator
Hydrochloric acid	20mL	Dropper bottle	HCl 1M
Ammonia solution	20mL	Dropper bottle	NH_3 0.5%
Aluminium chloride	3g	Glass vial	$AlCl_3$

4. APPARATUS AND SUPPLIES

Item	Quantity
Safety goggles	1
Protective gloves	1
Digital multimeters	2
500 Ω potentiometer	1
Hot air gun with stand	1
Glass cylinder adapted to hot air gun	1
Halogen lamp	1
Scotch (3M) adhesive tape	1
Conductive glass plates	2
Binder clips	4
Graphite pencil	1
Glass rod	1
Test tubes with their stand	4
Tongs	1
Petri dish	2
Petri dish covers	2
10 mL glass pipette	1
50 mL Burette with stand	1
Erlenmeyer flask	1
100mL Glass cylinder	1
10mL glass cylinder	1
Graduated plastic Pasteur pipette	2
Glass beaker	1
Pipette filler bulb	1

Tweezers	1
Pair of scissors	1
Small spatula	1
Cotton sticks (bulbs)	5
Soft paper tissues(box)	1
Ruler	1
White sheet paper	1

5. Safety regulations, S-phrases, R-phrases

Titanium dioxide	R-none S:22-25-36/37
Ethanol	R:11 S:7-16
Isopropanol	R:11 S:7-16
Glycol	R:10-20/21/22 S:53-45
Sodium thiosulphate	R-none S-none
Iodine	R20/21 S:23-25
Starch	R-none S-none
Ethylene glycol	R: 22-26-10-20/21/22 S: 53-45
Aluminium chloride	R34 S7/8-28-45

Risk phrases (R)
R 10 Flammable
R 11 Highly flammable
R 22 Harmful if swallowed
R 26 Very toxic by inhalation
R34 Causes burns.

Combination of risk phrases(R)
R20/21 Harmful by inhalation and in contact with skin
R20/ 21/22 Harmful by inhalation and in contact with skin and if swallowed

Safety phrases (S)
S 7 Keep container tightly closed.
S 16 Keep away from sources of ignition - No smoking.
S 22 Do not breathe dust.
S 23 Do not breathe gas/fumes/vapor/spray (appropriate wording to be specified by the manufacturer).
S 25 Avoid contact with eyes
S28 After contact with skin, wash immediately with plenty of water.
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)
S53 Avoid exposure-obtain special instructions before use.

S7/8 Keep container tightly closed and dry.

Combination of safety phrases (S)

S 36/37 Wear suitable protective clothing, gloves and eye/face protection.

EXPERIMENT 1:

NANOCRYSTALLINE DYE SENSITIZED SOLAR CELL CONSTRUCTION PROCEDURE

A. INTRODUCTION

B. DEPOSITION OF TiO_2 FILM

D. TiO_2 SINTERING

E. TiO_2 STAINING WITH ANTHOCYANIN & CARBON COATING GLASS PLATE

F. SOLAR CELL ASSEMBLY

A. INTRODUCTION

The sun provides our planet with a staggering amount of energy. Green plants convert solar energy through photosynthesis to biomass with a typical yearly average efficiency of less than 0.3%.

Today solar electricity is a steadily growing energy technology and solar cells have found markets in a variety of applications ranging from consumer electronics and small scale distributed power systems to centralized megawatt scale power plants.

Despite the abundance and versatility of solar energy, we use very little of it to directly power human activities. Solar electricity accounts for a minuscule 0.015% of world electricity production, and solar heat for 0.3% of global heating of space and water.

Direct utilization of solar radiation to produce electricity is close to an ideal way of utilizing nature's renewable energy flow. With photovoltaic cells, power can be produced near the end user of the electricity, thus avoiding transmission losses and costs. The solar panels themselves operate without noise, toxic and greenhouse gas emissions and require very little maintenance. Furthermore, the huge theoretical potential and the very high practical potential of solar electricity make it attractive for large-scale utilization.

Despite significant developments over the past decades the high cost of solar cells has remained a limiting factor for the utilization of solar electricity at a large scale. The standard silicon solar cell technology has matured to a stage where cost reductions are mostly foreseen only by the economies of scale. Cost calculations of thin film photovoltaic technologies on the other hand place them more or less at the same level with standard silicon technology. There is therefore a prevailing need for the development of new materials and concepts for photovoltaic conversion, to lower the price of solar cells.

The general trend of nanotechnology has recently emerged also in the field of photovoltaic energy conversion. Development of material engineering in the nanometer scale has generated new photovoltaic materials and systems that could potentially lead to realization of low-cost solar cells in the future. These materials include for example different types of synthetic organic materials and inorganic nanoparticles and nanoparticle systems. The solar cells based on these materials are called organic solar cells or molecular solar cells. In the process, chemistry has emerged as a new key science alongside with physics in the development of new photovoltaic devices.

The best known and studied unconventional photovoltaic system is the dye sensitized nanostructure solar cell (DSSC) developed by Professor Grätzel (Lausanne, Switzerland) in 1991. At the moment this unique photo electrochemical solar cell based on a TiO_2 nanoparticle photo electrode sensitized with a light-harvesting organic dye, is on the verge of commercialization offering an interesting alternative for the existing silicon based solar cells as well as for the thin film solar cells. At the same time research activity as well as industrial interest around this technology is growing fast.

Operation principle of the dye sensitized solar cell (DSSC)

Dye sensitized solar cells are novel solar cells that scientists are developing. These cells have a lot of potential because they can be made with low-cost materials and manufactured at a low cost. Dye sensitized cells can work effectively in low lighting conditions, such as cloudy skies, where traditional cells lose some of their energy. Also, traditional models lose energy to heat. Dye sensitized solar cells are less susceptible to losing energy to heat.

A dye sensitized solar cell consists of two conducting glass electrodes in a sandwich arrangement, (see Figure 6). Each layer has a specific function in the cell. The glass electrodes are transparent which allows the light to pass through the cell. The tin dioxide coating is a transparent, conductive layer. The titanium dioxide serves as a holding place for the dye. The dye molecules (artificial or natural) collect light and produce excited electrons, which cause a current in the cell. The iodide electrolyte layer acts as a source for electron replacement. The bottom conductive layer is coated with a graphite carbon layer which serves as a catalyst.

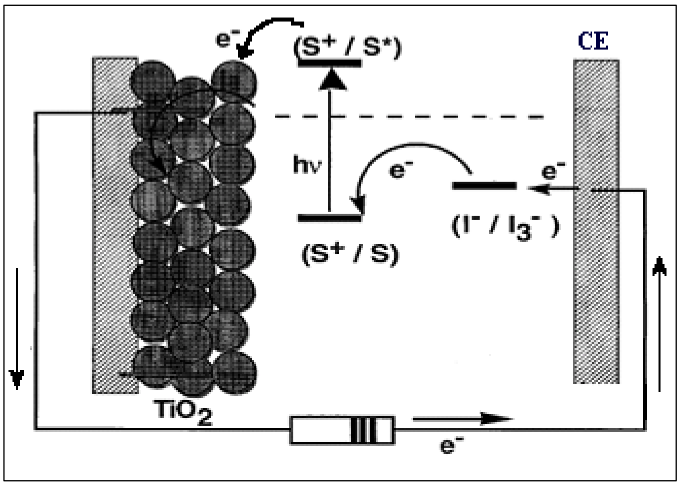

Figure 1

Dye sensitized solar cells produce electricity through electron transfer. Sunlight passes through the conductive glass electrode (see Diagram below). The dye absorbs the photons of light and one of the electrons in the dye goes from the ground state to an excited state. This is referred to as photo excitation. The excited electron jumps to the titanium dioxide (TiO_2) layer and diffuses across the film. The electron then reaches the conductive electrode, travels through the wire, and reaches the counter electrode. The dye molecule, having lost an electron to the titanium dioxide, is now oxidized, which means it has one less electron than before. The dye wants to recover its initial state so it seeks to obtain an electron. It obtains this electron from the iodide electrolyte (I^-) and the dye goes back to the ground state. This causes the iodide to become oxidized. When the original lost electron reaches the counter electrode, it gives the electron back to the electrolyte (I_3^-) (see Figure 1).

$$S + \text{light} \rightarrow S^*$$

$$S^* + TiO_2 \rightarrow e^- (TiO_2) + S^+$$

$$e^- (TiO_2) + C.E. \rightarrow TiO_2 + e^- (CE) + \text{electrical energy}$$

$$S^+ + 3/2\ I^- \rightarrow S + 1/2\ I_3^-$$

$$1/2\ I_3^- + e^- (C.E) \rightarrow 3/2\ I^- + CE$$

S: dye molecule

S^*: excited dye

S^+: oxidized dye

CE: counter electrode

B. DEPOSITION OF TiO_2 FILM

1. Obtain and clean two conductive glass plates (2.5cm x 2.5cm) by rinsing them in ethanol and then drying with soft tissue—use tissue technique as with cleaning a pair of eyeglasses. **Once you have cleaned the glass plates, do not touch the faces of the plates, as the oils on your hand will contaminate these surfaces.**

2. **Hint: During the experiment handle glass plates using tongs or pick them up at the edges.**

3. Use a digital multimeter, set to ohms, in order to check which side of the glass is conductive; the reading should be between 10 to 30 ohms.

4. Orient one glass plate with the conductive side up. This plate will be coated with the TiO_2 suspension. Turn over another glass plate, so that the conductive side is face down. Place it adjacent to the glass slide that is to be coated. When the assembly is completed, one glass plate will be conductive side up and the other with its conductive side down (keep track of the plate that is conductive side up). At this stage, the second piece of glass merely aids in the coating process.

5. Apply two pieces of Scotch (3M) adhesive tape (6-7 cm in length) to the top faces of the glass plates, in order to mask a strip NO MORE than 1 mm wide on the two longer edges. (See Figure 2).

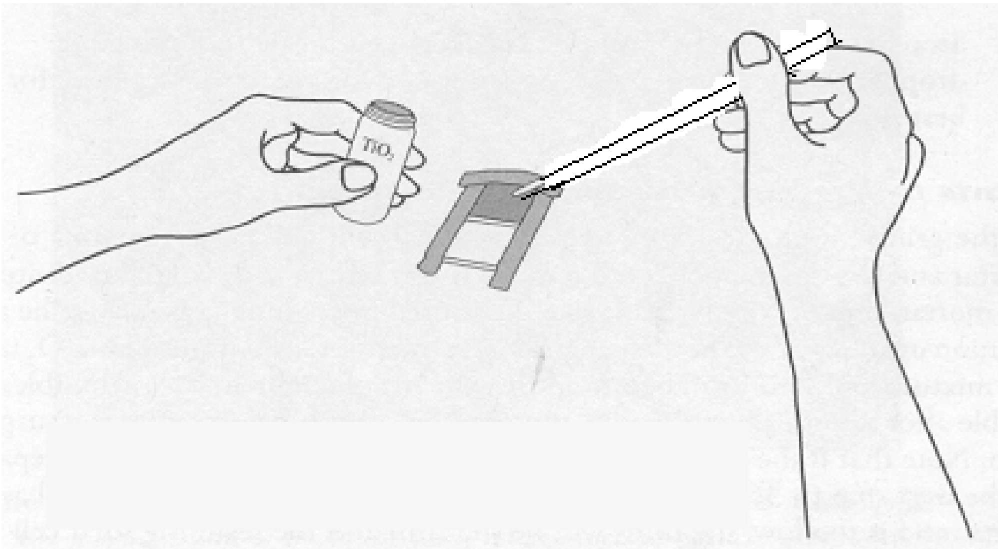

Figure 2: Orientation of conductive glass plates, masking of plates and application of Titanium dioxide to the surface of the conductive plate

6. Apply another piece of adhesive tape along the top of the glass to be coated so as to mask a 4 to 5 mm strip. The three pieces of tape should extend from the edge of the glass to the table in order to secure the plates to the table.

This tape controls the thickness of the TiO_2 layer, forming a 40-50µm deep channel for the TiO_2 suspension. The tape also masks a strip of the conductive glass so that an electrical contact can later be made.

7. To coat the glass, a thin line (or three drops) of the TiO_2 suspension is uniformly applied to the edge near the tape of the conductive-side-up glass using a glass rod. **Be careful, do not dip the glass rod in the TiO_2 suspension, but just touch the rod on the surface of the suspension.**

8. Within five seconds after application of the TiO_2 suspension, slide (**DO NOT ROLL**) a clean glass rod (held horizontally) over the plate to spread and distribute the material (see Figure 3). The most successful technique for achieving a uniform film is to use a rapid sweeping motion of the rod towards the bottom of the setup and then back over the film in the opposite direction. Repeat if needed without lifting the rod.

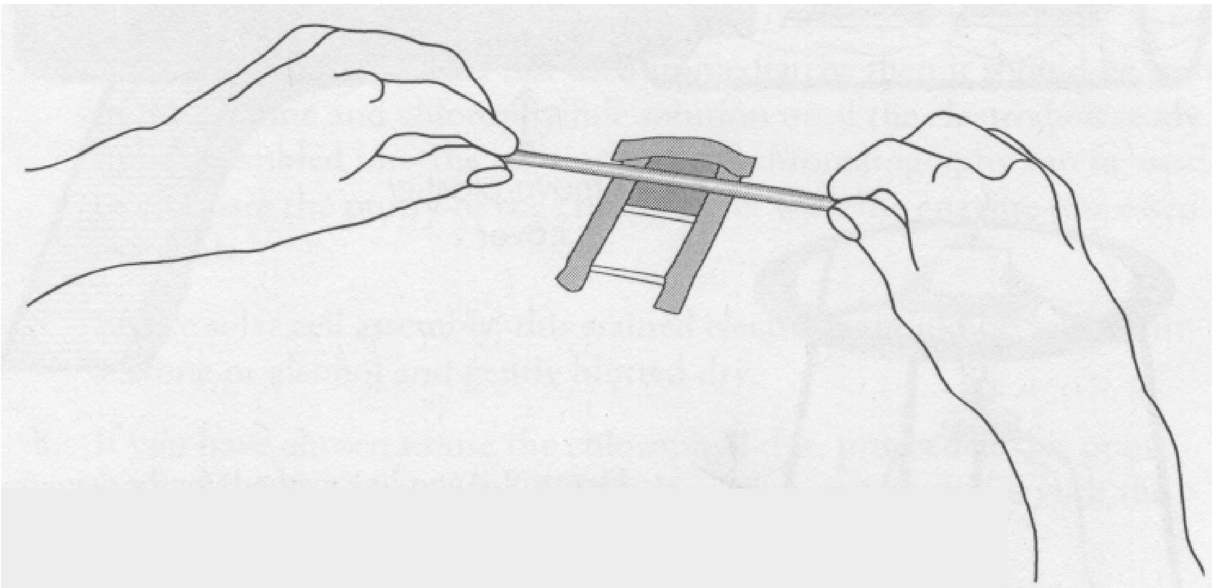

Figure 3: A rapid sweeping motion of the glass rod is used to coat titanium dioxide suspension on the masked conductive glass plate.

9. If the coating looks non-uniform, then the material can be wiped off the plate and the glass rod wiped with a dampened tissue and the deposition procedure repeated. After deposition of the TiO_2 suspension, carefully remove the tape. Place the plate in a Petri dish without touching its face and cover it. Allow the TiO_2 film to dry for one minute. Wash and dry the plate that was conductive side down and clean glass rod.

C. TiO_2 SINTERING

1. Anneal the TiO_2 film on the conductive glass plate using the hot air gun provided. The heating of the film should take place in the hood.

2. Transfer carefully the conductive glass (Titanium dioxide side up) within the horizontal glass tube (see Figure 4) and set air gun switch to stage 1 (upwards). The air temperature reaches 450^oC and the titanium dioxide film anneals and sinters by heating for 30 minutes.

3. Hint: While waiting for the sintering to be completed, carry out EXPERIMENT 2

4. After annealing is completed, allow the glass plate to slowly cool within the glass cylinder to room temperature. This will take approximately fifteen minutes.

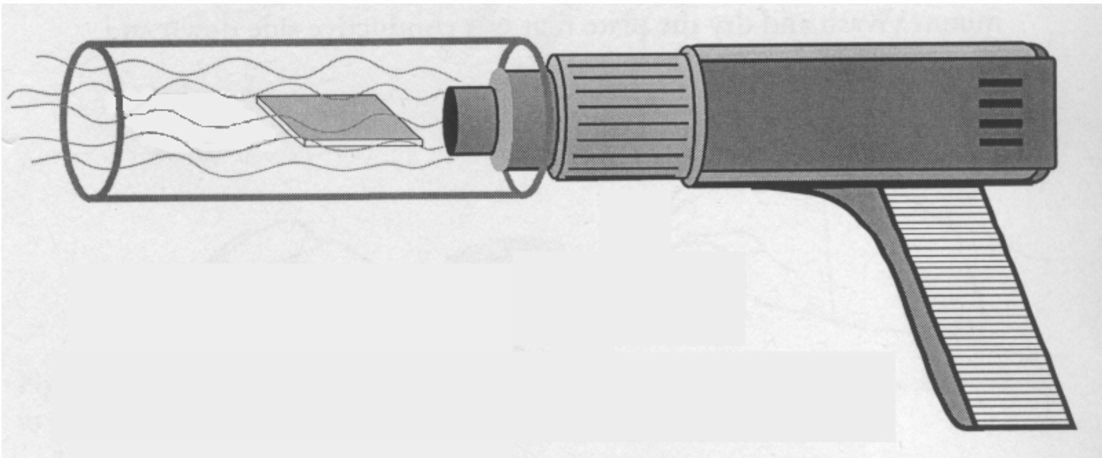

Figure 4: The film is placed inside a glass tube furnace for annealing of the titanium dioxide film on the conductive glass.

5. Store the plate in a clean Petri dish for later use and cover it.

D. TiO_2 STAINING WITH ANTHOCYANIN & CARBON COATING GLASS PLATE

1. Transfer the cooled TiO_2-coated glass plate and place it (face down) into a Petri dish containing a 30mL anthocyanin (pomegranate juice) solution. Soak the TiO_2-coated glass plate for 10 minutes in the dye. If any of the white colour of the TiO_2 can be seen upon viewing the stained film from either side of the glass plate, then the film should be placed back in the dye solution for an additional 5 minutes. Adsorption of anthocyanin to the surface of TiO_2 and complexation to Ti (IV) sites is rapid.

   Hint: While soaking the titanium coated plate in the anthocyanin solution a member of the team may carry out experiment 3

   Do not remove the glass plate from the pomegranate solution until you are ready to assemble the solar cell in the next section.

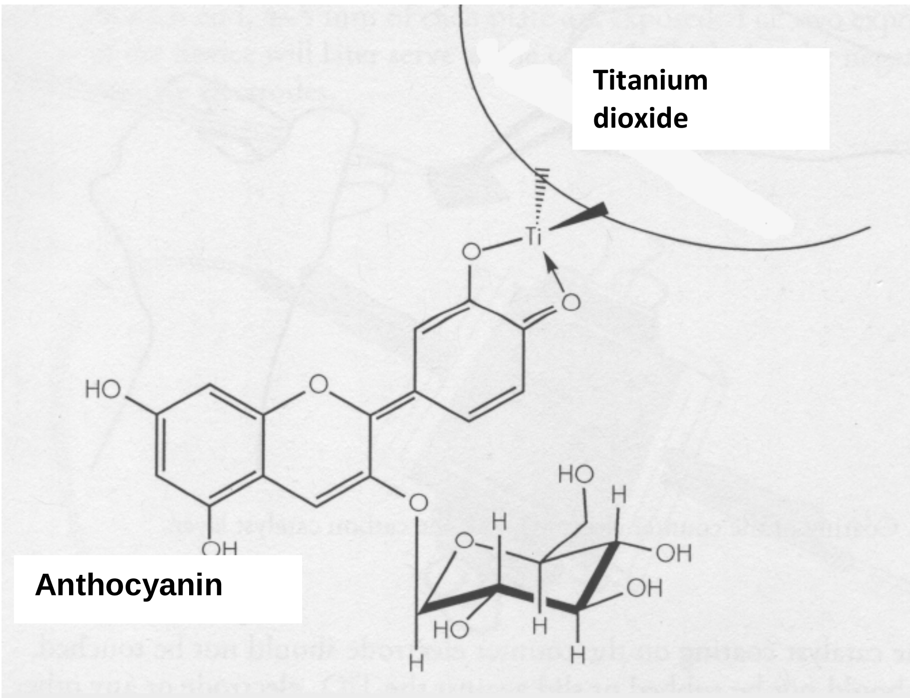

Figure 5: The dye molecule must possess carbonyl (- C=O) or hydroxyl (-OH) groups capable of complexing (chelating) to TiO_2

2. While the TiO_2 electrode is being stained in the pomegranate juice, the carbon-coated counter electrode can be made from the other conductive (2.5cm x 2.5cm) glass plate.
   Clean your second glass plate (the one that is not soaking in pomegranate juice) by rinsing it in ethanol and then drying with a soft tissue—use the same technique as with cleaning a pair of eyeglasses. Use a digital multimeter, set to ohms, in order to

check which side of the glass is conductive; the reading should be between 10 to 30 ohms.

3. Hold the conductive glass plate on the bench by the edges or with tweezers. Using a graphite (carbon) pencil provided, apply very tightly, pressing the plate, a uniform carbon film to the entire conductive side of the plate. Be careful not to miss any spots. This thin carbon layer serves as a catalyst for the electron transfer resulting in the triiodide to iodide regeneration reaction. No tape is required for this electrode, and thus the whole surface is coated with the catalyst (see Figure 6).

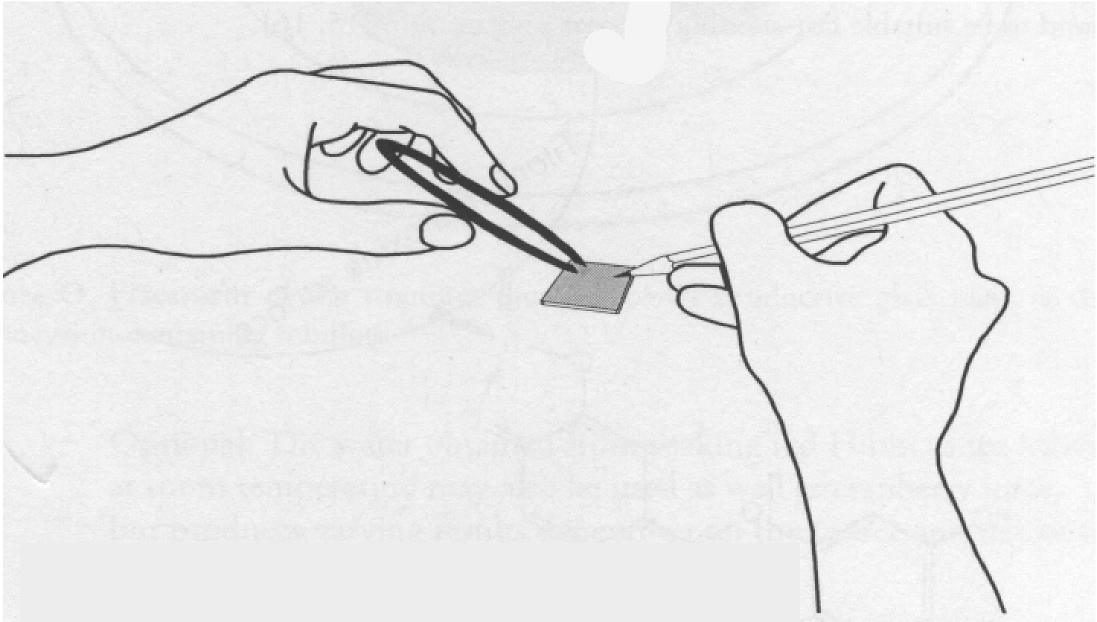

Figure 6: Coating of counter electrode with the carbon catalyst

4. The catalyst coating on the counter electrode should not be touched. It should not be rubbed or slid against the TiO_2 electrode or any other surface. The counter electrode should be picked up at the edges and carefully placed where it is desired.

E. SOLAR CELL ASSEMBLY

1. Using tongs remove glass plate (which is stained dark purple) from the pomegranate juice and rinse it with deionized(distilled) water, and then with ethanol.
2. Place the plate on a paper tissue with the film side up. Gently press the TiO_2 with another dry tissue (**repeat drying procedure using ethanol**).
3. **It is important to dry the stained glass plate and to remove the water from within the porous TiO_2** film before the iodide electrolyte solution is applied to the film. One way to ensure the TiO_2 film is dry is to repeat above procedure with isopropanol.
4. Place the dried and stained electrode on a flat surface so that the TiO_2 film is face up; the carbon-coated counter electrode is placed on top of the TiO_2 film such that the conductive side of the counter electrode faces the TiO_2 film. *To avoid excessive exposure of the stained film to air, this step should be completed within 1 minute*.
5. Gently lift the counter electrode and offset the two plates so that all of the TiO_2 is covered by the carbon-coated counter electrode, and the uncoated 4-5 mm strip of each glass plate is exposed (see figure 7).

At each end, 4-5 mm of each plate is exposed. The two exposed sides of the device will later serve as the contact points for the negative and positive electrodes.

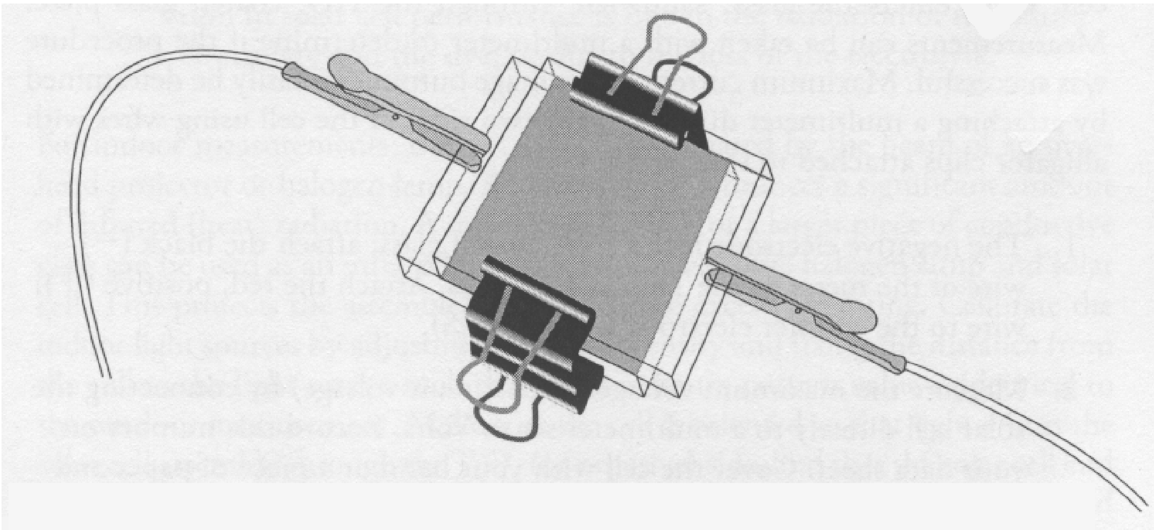

Figure 7: Assembled dye sensitized solar cell. The two glass plates are offset so that the uncoated portion of the TiO_2 plate is exposed. A portion of the catalyst coated plate will also be exposed. Light enters the assembly through the TiO_2 side of the cell.

6. Carefully pick up the assembly while it is in this orientation. Place two binder clips on the longer edges to hold the plates together.

7. The iodide electrolyte solution consists of KI mixed with I_2 in ethylene glycol. Carefully place two drops of this liquid I_3^- solution at one edge of the plates. Keeping the plates sandwiched together, alternately remove and replace each binder clip. This creates a small space between the plates into which the solution is drawn by capillary action. Continue alternating between the clips until all of the stained area is contacted by the electrolyte.

8. Wipe off the excess electrolyte from the exposed areas of the glass using cotton sticks (buds) dampened with ethanol and finally with dry tissues**. It is important that the electrolyte is completely removed from the two exposed sides of the cell.**

EXPERIMENT 2: VOLUMETRIC DETERMINATION OF IODINE IN DSSC ELECTROLYTE SOLUTION

INTRODUCTION

The dye sensitized solar cell electrolyte is an I_2/ KI (I_3^-) solution in ethylene glycol solvent. The ionic chemical equation of the reaction between sodium thiosulphate, $Na_2S_2O_3$ and I_3^- is given below.

$$I_3^- + 2\,S_2O_3^{2-} \rightarrow 3I^- + S_4O_6^{2-}$$

INSTRUCTIONS

1. Prepare and fill the burette with the standard solution of sodium thiosulphate $Na_2S_2O_3$ 0.0780M
2. Record the initial reading of your burette in the answer sheet.
3. Using a pipette, transfer an aliquot of 10mL of the solution of iodine in ethylene glycol into a clean Erlenmeyer flask.
4. Titrate, swirling the conical flask until a yellow colour appears. Add 2mL starch indicator and 10 mL deionized (distilled) water and continue titration until the blue black colour disappears and the solution becomes colourless.
5. Record the final reading of your burette in the answer sheet.
6. Repeat the titration three times.
7. Complete the table in the answer sheet.
8. Calculate the molar concentration of I_3^- in the electrolyte with an accuracy of four decimals.

EXPERIMENT 3: CHEMICAL PROPERTIES OF ANTHOCYNIN

Using a 10mL glass cylinder transfer one mL of pomegranate anthocyanin solution and 9mL of distilled water into a 100mL beaker (solution A). Using a plastic graduated Pasteur pipette transfer 1mL of the diluted solution (solution A) into each of 4 test tubes. In addition 1 drop of HCl is added to the solutions of T_2, T_3 and T_4. Five drops of ammonia solution are added to T_3. Using a small spatula add 0.5 grams of aluminium chloride to T_4. Shake all test tubes very well.

Complete the table in answer sheet 1.

EXPERIMENT 4.

THE ELECTRICAL OUTPUT CHARACTERISTICS OF THE SOLAR CELL.

A. APPARATUS

B. THEORY

C. EXPERIMENT

D. ANALYSIS

A. APPARATUS

- TiO_2 solar cell
- light source (a halogen lamp)
- 2 (digital) multimeters
- a 500 Ω potentiometer
- connecting leads
- a stand
- a clamp
- a ruler

B. THEORY

The power of a cell is the rate at which the cell supplies energy to a circuit, i.e

Power of a cell = energy supplied by the cell / unit of time.

The power (P) given by a cell to a circuit can also be found by multiplying the voltage (V) across the cell and the current (I) through the cell, i.e. P = I.V

Power is measured in watts (W), voltage is measured in volts (V) and current is measured in amperes (A).

The efficiency of an energy conversion process is defined by:

efficiency= useful energy output / total energy input

and is expressed as a fraction or as a percentage.

C. EXPERIMENT

The completed cell will be illuminated by the beam of a halogen lamp. *This cell is a kind of battery that derives its energy from the lamp.*

A set of values for the current and the voltage output will be measured. Using these values the power generated by the cell will be calculated and finally the efficiency of the cell will be determined.

Prepare the apparatus.

1. The negative electrode is the TiO_2 coated glass. Attach the black (negative) crocodile clip to the TiO_2 coated glass. Attach the red (positive) crocodile clip to the counter electrode.

2. Place the light source approximately 2 cm – 3 cm directly above the cell.

3. Make sure the cell is oriented so that light enters the cell through the TiO_2 side, and that the solar cell and the light source do not move during the next part of the experiment.

Measure the open circuit voltage and the short circuit current.

The maximum voltage output and current can be measured by attaching the multimeter directly to the two sides of the cell using the connecting leads.

In Figure 1 and Figure 2 it is shown how the voltmeter and the ammeter are connected to the cell.

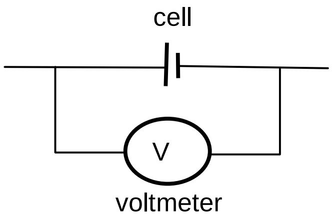

Figure 1

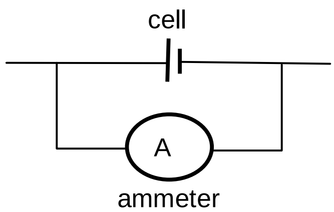

Figure 2

4. Switch on the main so the halogen lamp illuminates the cell.

DO NOT TOUCH THE HALOGEN LAMP. IT BECOMES VERY HOT!

5. Allow the cell to stabilize in the light source for five minutes before taking measurements.

6. Measure the maximum voltage (open circuit voltage) by connecting the multimeter across the solar cell. Set the multimeter to mV ($1mV = 10^{-3}$ V). Record this number on your answer sheet 1 at EXP4.1.

7. Measure the maximum current (short circuit current) by connecting the multimeter across the cell. Set the multimeter to mA (milliamperes). Record this number on your answer sheet 1 at EXP4.2.

If the maximum current you have measured is greater than 1.6 mA continue measuring the full range of values for the voltage and current.

If the maximum current you have measured is less than 1.6 mA call the invigilator and ask her/him for a new cell.

Then begin your experiment again by placing liquid I_3^- solution to the new cell (Exp1.E.7).

Repeat steps 5, 6 and 7 and record the new values of voltage and current on your answer sheet at EXP4.1.1 and EXP 4.2.1

Measure the full range of values for the voltage and current.

The full range of values for the current (I) and voltage (V) will be determined using a 500-ohm potentiometer as a variable load.

8. Draw the circuit diagram, needed to obtain the voltage and current values, on the separate answer sheet 2 provided.
9. Hand in this answer sheet to the invigilator. The invigilator will provide you with the suitable circuit diagram in order to continue with your experiment.
10. Use the circuit diagram provided and completes the circuit.
11. Test your setup by changing the resistance of the circuit (i.e. moving the knob on the potentiometer). Note if the values of current and voltage change. If they don't, check your connections.

If you need help with your circuit, call the invigilator.
You will be penalized with 4 marks.

12. Gather point-by-point current and voltage data pairs at incremental resistance values. Do not move the solar cell or light source during these measurements. Note that increments of 10 mV will suffice for most of the measurement. Record each pair of values on your answer sheet 1 at EXP4.3.
13. When you are finished taking measurements switch off the light source.

D. ANALYSIS

14. Determine the output power of the cell for each pair of values for the voltage and current. Record the power of the cell on your answer sheet 1 at EXP4.3.

15. Plot the current (I) against the voltage (V) on the graph paper given at EXP4.4. Plot also the open circuit voltage and short circuit current.

16. Obtain a smooth I-V curve.

17. Plot the power (P) against the voltage (V) on the graph paper given at EXP4.5. Obtain a smooth P – V curve.

Determine the sunlight to electrical energy conversion efficiency of the solar cell.

The incoming to earth solar intensity, is approximately 80-100 mW/cm^2. Approximately the same intensity reaches the cell from the light source when the source is placed at a distance of 2 cm – 3 cm from the cell.

At this final step of your calculations you will determine the sunlight to electrical energy conversion efficiency.

18. Determine from graph EXP4.5 the maximum power output of the cell. Record the maximum power on your answer sheet 1 at EXP4.6.

19. Use the ruler to measure the dimensions of the active (stained) area of the solar cell. Record the area on your answer sheet 1 at EXP4.7.

20. Divide the maximum value of the power by the active area of the cell (mW/cm^2), and record the result of the power per unit area on your answer sheet 1 at EXP4.8.

21. To determine the sunlight to electrical energy conversion efficiency, divide the maximum power per unit area of the cell by the incoming solar intensity (80 mW/cm^2). Record the efficiency as a percentage on your answer sheet 1 at EXP4.9.

END OF EXPERIMENTS

Some of the figures were taken from a booklet of the Institute of chemical education.