Dye-sensitised solar cell kit

Dye sensitised solar cells (DSSCs) or Grätzel cells were invented in 1991 by Michael Grätzel and his research group at the Swiss Federal Institute of Technology. These cells use a dye which directly converts the energy of sunlight into electrical energy using a process which is similar, in some aspects, to photosynthesis. Various dyes can be used in DSSCs which will have different photon trapping efficiencies, and this could form the basis of interesting student investigations linking biology, chemistry and physics to the aspirations of Curriculum for Excellence at Level 4. It also lends itself to AH Chemistry projects.

Conventional solar cells are rather expensive owing to the cost of producing high-grade silicon. In contrast, DSSCs use a nanocrystalline layer of titanium dioxide. This makes them much cheaper to construct because TiO_2 is a cheap and widely available material which is already used widely in paints, inks and paper, and plastic products.

Dye-sensitised solar cells contain two transparent electrode plates, which are internally connected by an iodine/tri-iodide electrolyte.

The photo-electrode consists of a glass or plastic base which has been made conductive by adding a thin coating of tin oxide doped with fluorine. This is coated by a nanocrystalline layer of titanium dioxide which acts both as a matrix for the dye and as a wide gap semiconductor. It is essential for the photo-electrode to hold more than single layer of dye molecules and that the 'thick' layer of porous titanium dioxide has a high volume-to-surface area ratio, allowing it to hold a large concentration of dye molecules.

When the dye molecules are exposed to sunlight (photons of light) some of their electrons are lost by photo-excitation and the dye goes into its reduced state. As the titanium dioxide layer has been sintered to make the particles pack more tightly, it acts as a semiconductor. This allows any electrons which have sufficient energy, to move from the low-energy valance band to the high-energy conductance band. The result is a current in the external circuit.

Titanium dioxide has a slightly wider band gap than a conventional silicon photocell, so that although dye-sensitised cells produce photo-excited electrons more effectively, fewer of these electrons have sufficient energy to jump the band gap. Consequently the output current from a typical commercial DSSC is only 20 mA cm^{-2}, compared to the 35 mA cm^{-2} generated by a silicon photocell. However DSSCs are cheaper and will operate at much lower light intensities than silicon photocells. Indeed it has been suggested that some devices could be powered indoors by DSSCs just using normal household lighting.

After flowing through the external circuit, the electrons move through the positive counter electrode, which is coated in graphite, to interact with the electrolyte.

The electrolyte contains an iodine/tri-iodide redox couple which results from the equilibrium set up when iodine is dissolved in a solution of potassium iodide:

$$I^- + I_2 \rightleftharpoons I_3^-$$

At the graphite-covered counter electrode the tri-iodide ion (I_3-) is reduced by gaining electrons:

$$I_3^- + 2e^- \longrightarrow 3I^-$$

The iodide ions, which are formed, move through the electrolyte and two iodide ions regenerate the reduced dye molecule on the photo-electrode by donating electrons to it:

$$2I^- \longrightarrow I_2 + 2e^-$$

The remaining iodide ion shifts the iodine/tri-iodide equilibrium towards the formation of more tri-iodide ions:

$$I_2 + I^- \rightleftharpoons I_3^-$$

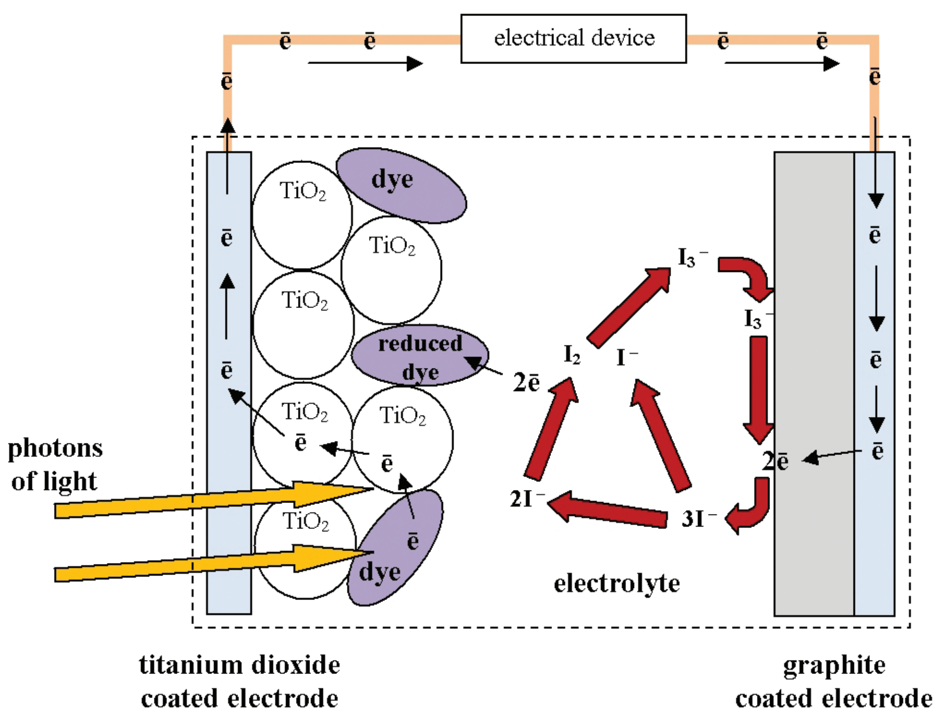

Figure 1 – Dye-sensitised solar cell

Three kits are available from the Dutch company, 'Man Solar' [1] which provide all the basic materials required for students to construct, with ease, a working dye-sensitised solar cell.

The Man Solar 2000 kit contains:

- 6 x titanium dioxide coated conductive glass electrodes
- 6 x uncoated conductive glass electrodes
- 1 x packet of dried hibiscus flowers
- 1 x dropper bottle of electrolyte
- 1 x multimeter with measurement probes
- 1 x pencil
- 10 x crocodile clip cables
- 1 x box of paperclips
- 1 x petri dish
- 1 x set of screwdrivers
- 1 x melody module
- 1 x pocket calculator
- 1 x safety glasses
- 1 x manual

This kit probably does not provide sufficient glass electrodes for a whole class activity. However additional glass electrodes, both coated and uncoated, can be purchased separately from the supplier although a minimum spend is required. It may be worthwhile considering buying only these electrodes and following the instructions given in the rest of the article in order to construct a cell.

Man Solar sell two other solar cell kits: The cheaper Man Solar 1000 kit is similar to the above description except that a titanium dioxide suspension is provided rather than the pre-coated glass electrodes.

Details of how to sinter the electrodes with a furnace or spirit burner are included in the manual. The multimeter and melody module are not included in this kit, but these should not be difficult to obtain locally.

The more expensive Man Solar 3000 kit contains all of the materials provided in the 2000 kit, and in addition contains a fuel stove to sinter the titanium dioxide suspension onto the conductive glass electrodes.

Figure 2– Man Solar Kit

Using the Man Solar DSSC kit:

a) Identifying the conducting side of the glass electrode

As both sides of the uncoated conductive glass electrodes appear to be the same, it is necessary to determine which side of the glass has the conductive coating. This can be done by touching the two ends of the glass electrode plate with the measurement probes of a multimeter, which has its function switch turned to the 200 Ω resistance position.

If the display shows a reading of 1, then this is the non-conducting side (Figure 3). Any other reading means you have the conducting side of the glass electrode (Figure 4).


Figure 3 – The multimeter indicates that this is the non-conducting side of the clear glass electrode.

b) Applying the graphite layer

When applying the graphite layer to the conductive side of the glass electrode it is best to hold the glass by the sides, keeping the surface free of fingerprints, while gently rubbing the side of the pencil lead evenly across the surface. The tip of the pencil should not be used as this can damage the conducting surface. Going over the surface a second time, rubbing the pencil in a different direction, will produce an even layer of graphite (Figure 5).

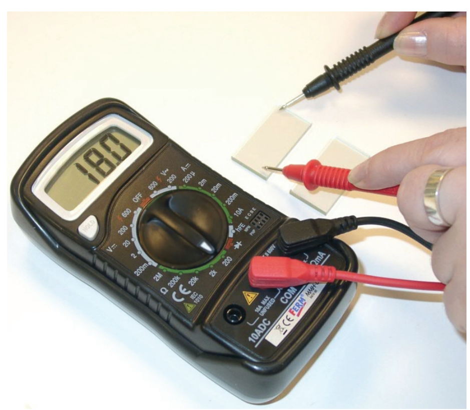
Figure 4 – The low resistance reading on the multimeter shows that this is the conductive side of the clear glass electrode.

Dye-sensitised solar cell kit

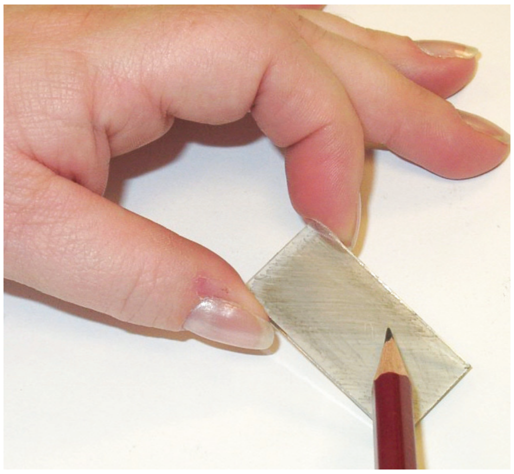

Figure 5 – Using the pencil to apply a graphite layer to the conductive side of the glass electrode.

Figure 6 – Dried Hibiscus 'flowers'.

c) Preparing the dye

The dried Hibiscus 'flowers', which are supplied in the kit (Figure 6), produce a deep red dye when 2 g is added to 50 cm^3 of boiling water in a small beaker. These flowers are actually the dried calyces (sepal bits) of the Roselle plant (*Hibiscus sabdariffa*), which is sold as Hibiscus tea or Flor de Jamaica in many health food stores. [2]

The characteristic deep red colour comes from the flavonoid glycosides, such as cyanidin and delphinidin.

d) Dyeing the titanium dioxide coated electrode

The titanium dioxide coated electrode is dyed by placing it face up in a Petri dish, and immersing it in the solution from the cooled dye-bath. The dyeing process only takes about 10 minutes (Figure 7).

After removing the dyed electrode from the dye-bath, being careful not to touch the titanium dioxide surface, it should be gently rinsed by dipping it into distilled water. The dyed electrode can then be dried by either using a hair-drier on the 'cold' setting, or carefully waving it in the air. The surface of the dyed electrode should not be dried by wiping it with paper or a tissue, as this can damage the titanium dioxide layer.

As the electrode dries its titanium dioxide surface changes colour, so that it is easy to know when it is ready for the next stage.

e) Assembling the solar cell

The solar cell is assembled by placing the dye-coated electrode, face up, on a flat surface, adding 2 drops of iodine/ tri-iodide electrolyte (Harmful), and then placing the graphite coated electrode on top, face down. The two electrodes need to be offset by about 5 mm so that crocodile clips can be attached. We suggest that the completed solar cell is held together by 19 mm bulldog clips, which are more reliable than the paperclips supplied in the kit (Figure 8).

f) Measuring the output current

The output current of the solar cell can be measured by attaching a crocodile clip cable to each end of the solar cell, and connecting these to the measurement probes of a multimeter with its function switch turned to the 2 mA position to measure current.

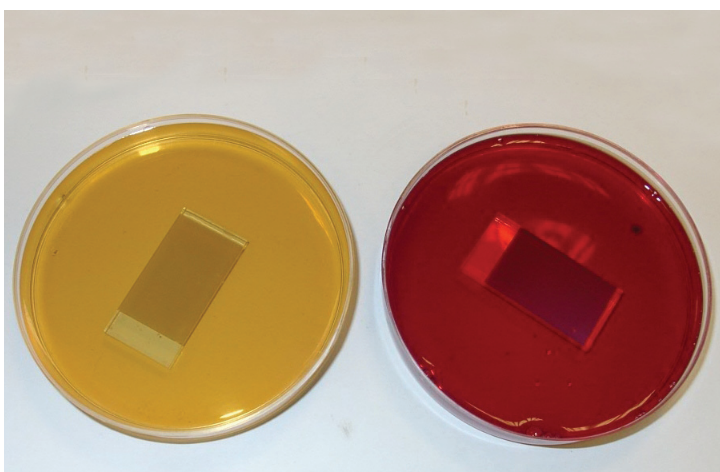

Figure 7 – Dyeing the titanium dioxide coated glass electrodes.

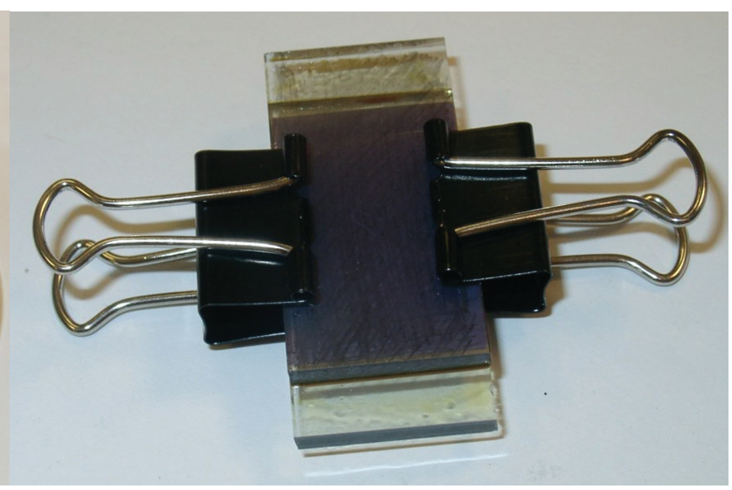

Figure 8 – A completed solar cell, showing the offset electrodes being held together by bulldog clips.

When the solar cell is illuminated by either natural or artificial light,an output current is produced. If a hand is passed over the solar cell, blocking out part of the light, the display reading decreases, proving that the solar cell is transforming light into electrical energy.

Turning the solar cell upside down will result in a different output current. The higher output current is obtained when the titanium dioxide side of the solar cell is illuminated (i.e. the side where the graphite pencil marks are **not** visible).

A constant degree of illumination is required if solar cells containing different dye pigments are to be compared. One way of doing this is by positioning an angle-poise table lamp directly above the solar cell at a distance of approximately 20 cm.

g) Connecting solar cells in series to produce a higher voltage

Several solar cells can be joined in series (like in a battery) by connecting the positive (graphite coated) electrode of one solar cell to the negative (titanium dioxide coated) electrode of the next solar cell, using a crocodile clip cable. When solar cells are connected in series, their voltages are added together (Table 1).

Arranging the solar cells in series makes it possible to produce a high enough voltage to operate a melody module or a calculator.

The melody module will function when six hibiscus-dyed solar cells are arranged in series, with the terminal graphite electrode connected to the positive (red) wire of the melody module, and the terminal titanium dioxide electrode connected to the negative wire.

By unscrewing the back of a cheap pocket calculator, the wires leading to the battery holder can be detached, and the calculator can be reassemble with the power wires exposed from either side (Figure 11).

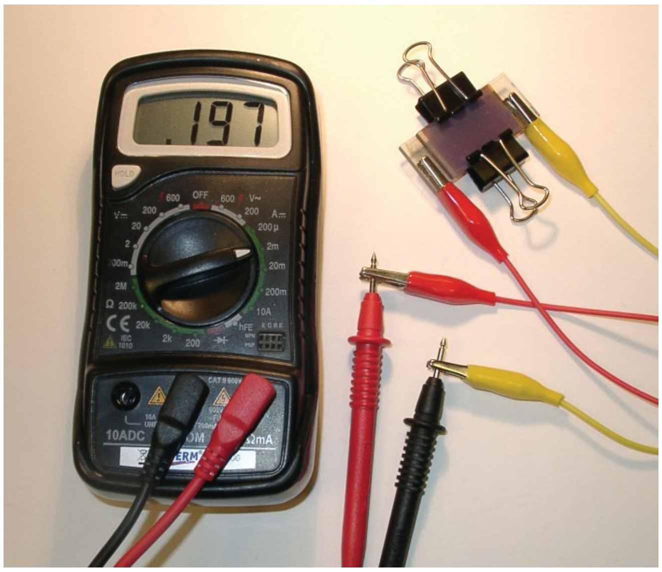

Figure 9 *– Measuring the output current from a dye-sensitised solar cell using a multimeter.*

Figure 10 *– Solar Cells in series*

Number of solar cells in series	Voltage of combined solar cells (V)
1	0.348
2	0.651
3	0.970
4	1.182
5	1.406
6	1.633

Table 1: *The effect of increasing the number of solar cells arranged in series.*
(Note: The solar cells are not identical in their photon capturing efficiencies so each will have a unique current and voltage.)

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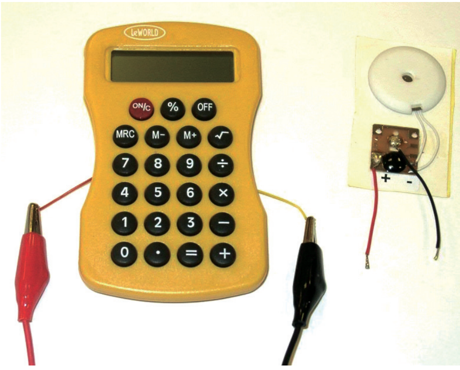

Figure 11 – *Both the melody module and the calculator will function using solar cells.*

Once again, if the terminal graphite electrode is connected to the positive (red) wire of the calculator, and the terminal titanium dioxide electrode connected to the negative wire, the calculator will function when connected to six hibiscus-dyed solar cells arranged in series and switched on.

A package of teaching and learning materials is now available as a SSERC workshop where delegates extract dyes from plants, test them for their suitability; and then try them in Gratzel cells.

For workshop booking details contact sts@sserc.org.uk

Chemicals & procedures	Main Hazard	Control Measures
Iodine/tri-iodide electrolyte	Harmful indirect vent goggles.	Wear nitrile gloves and
Glass electrodes (assembling solar cell)	May have sharp edges and may break if pressed too hard.	Hold glass electrodes carefully and add bulldog clips gently.
Boiling water for dye-bath	Scalding	Don't touch or move beaker containing the boiling hot dye-bath.

Table 2 – *Hazard and Control Measures*

Sources of materials:

[1] MAN SOLAR B.V., Westerduinweg 3, 1755 LE Petten, The Netherlands
E-mail: mansolar@ecn.nl.
Internet: http://www.mansolar.com

[2] Hibiscus 'flowers', 'Hibiscus tea' or 'Flor de Jamaica' can be purchased in many health food stores. Alternatively dried Hibiscus flowers can be purchased on the internet for about £2 per 100g (e.g. www.Mexgrocer.co.uk) or MexGrocer.co.uk, 1 Tennyson Rd, Stockport, SK5 6JJ.
Tel : 0800 849 9042 (Information Line Only)

Dry Ice Maker

We have recently had a query about one of these not working. It transpired that the problem could well have been with the type of gas cylinder and not the attachment. Dry ice making attachments will only work with a particular type of CO_2 cylinder. The cylinder must be fitted with a dip tube (this is often referred to as a 'siphon type' cylinder). This allows liquid CO_2 to be siphoned from the bottom of the cylinder.

Therefore, if you are considering purchasing a dry ice maker check if your cylinder is fitted with a siphon tube.[1]

For example, suitable cylinders from B.O.C. are black with two white stripes, diametrically opposite, indicating that it has a siphon tube and is suitable for making dry ice.

Reference

[1] http7//www.practicalphysics.org/go/Guidance_24.html
This site gives further information on types of CO_2 cylinders and links to suppliers of dry ice making attachments, with the catalogue numbers etc.