

## Solar Cell in a Drinking Straw

**Teachers' Notes:** Make a

photoelectrochemical cell in a straw using drinking draws and raspberries! A 45-60 minute activity.

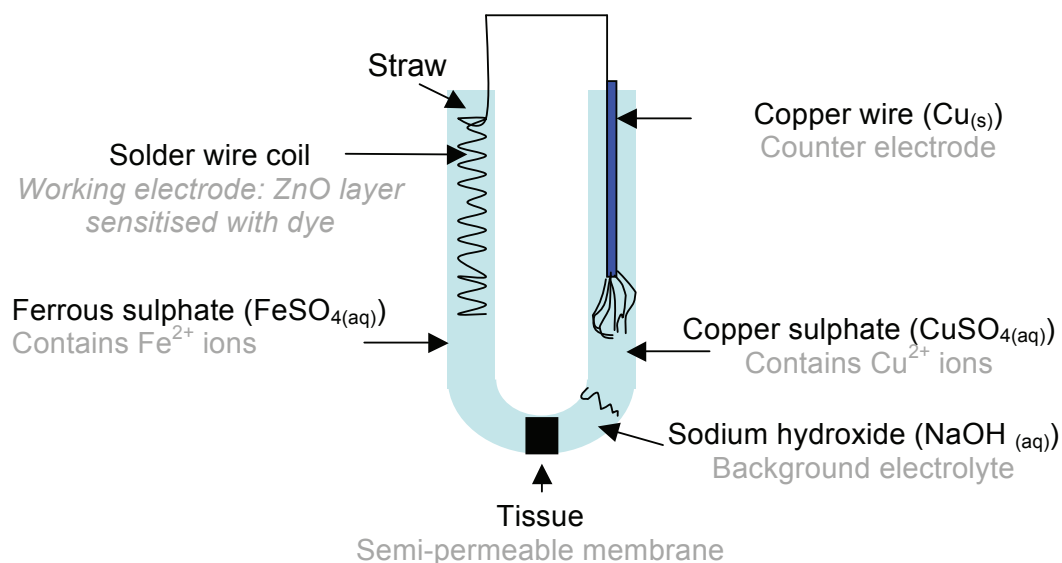
# Solar Cells in Drinking Straws Teacher's Notes

The solar cell in a drinking straw is a great way of allowing students to make their own solar cells out of cheap and readily accessible materials in their own school lab. The mechanism behind the solar cell is similar to that used in a Dye-Sensitised Solar Cell (DSSC) but uses different electrolyte and electrode materials to demonstrate the concept. Below is outlined the chemistry behind the experiment. For information on constructing the cells or sourcing the equipment, please see the Instructions and Technician's Notes documents respectively.

## Background Chemistry

### The Straw Cell

Below is a diagram of the solar cell in a straw set-up and the relative purposes of the components.

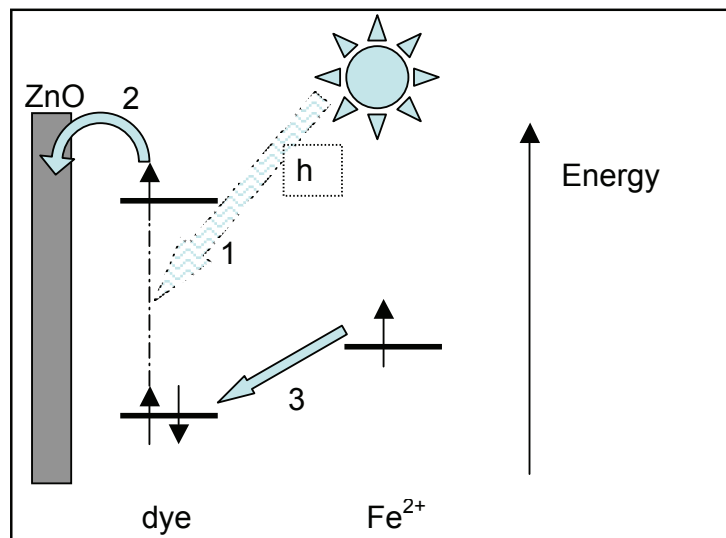


### Half equations in the cell

Half equation reaction	Electrode Potential
$\text{Cu}^{2+}_{(\text{aq})} + 2\text{e}^{-} \leftrightarrow \text{Cu}_{(\text{s})}$	<b>+0.34 V</b>
$\text{Fe}^{3+}_{(\text{aq})} + \text{e}^{-} \leftrightarrow \text{Fe}^{2+}_{(\text{aq})}$	<b>+0.77V</b>

The initial cell set-up contains  $\text{Fe}^{2+}$  and  $\text{Cu}^{2+}$  ions which, due to their relative electrode potentials, will not react with each other.

## At the Working Electrode



The process starts at the working electrode when the sensitising dye (i.e. the raspberry juice bound to the ZnO layer on the solder wire working electrode) absorbs sunlight (Arrow 1). The energy from the light allows the raspberry dye to excite an electron to a higher energy level and from there the electron is injected into the ZnO semiconductor (Arrow 2) and travels around the circuit to the copper wire where it combines with  $\text{Cu}^{2+}$  ions to make Cu metal.

Meanwhile, the oxidised raspberry dye is reduced again by the  $\text{Fe}^{2+}$  ions in solution to form  $\text{Fe}^{3+}$  ions (Arrow 3). Now we have  $\text{Fe}^{3+}$  ions in the cell which can react with Cu metal due to favourable electrode potentials. This reaction now regenerates  $\text{Fe}^{2+}$  and  $\text{Cu}^{2+}$  ions and the process is ready to start again when more sunlight is absorbed.

The sodium hydroxide solution acts as a background electrolyte in order to increase the conductivity of the electrolyte within the cell.

### **During the experimental**

#### Plating the working electrode

The solder wire is initially left for 10 minutes in a test tube containing methylated spirit (the solvent), zinc sulphate ( $\text{ZnSO}_4$ ), aluminium foil, ammonium solution ( $\text{NH}_4\text{OH}$ ) and a small piece of solder wire.

An alcoholic solvent is used as it gives a produces a better semi-conductor crystalline structure and smaller crystal size than if water was used as the solvent.

The ammonia solution helps to make Zn (from  $\text{ZnSO}_4$ ) and Sn (from the solder wire) more soluble in the methylated spirit.  $\text{ZnSO}_4$  also reacts with ammonium hydroxide to make  $\text{Zn}(\text{OH})_2$ . This all causes the solder wire coil to be plated with a film of zinc. The presence of the aluminium foil helps to introduce Al as an impurity, see later.

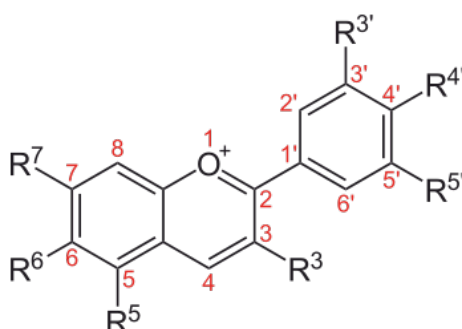
## Making the ZnO semiconductor

The solder wire is then transferred to a test tube containing methylated spirit (the solvent), ZnSO<sub>4</sub> and sodium hydroxide (NaOH). Afterwards it is heated in aluminium foil over a candle flame.

The ZnSO<sub>4</sub> reacts with the NaOH to make Na<sub>2</sub>SO<sub>4</sub> and Zn(OH)<sub>2</sub>. When heated over the flame, the Zn(OH)<sub>2</sub> converts to ZnO. Aluminium from the foil is also incorporated into the film as an impurity which increases the n-type character of the ZnO film. This is because aluminium forms Al<sup>3+</sup> ions compared to the Zn<sup>2+</sup> ions in ZnO and therefore attracts a more negative charge once in the matrix (n-type).

## Sensitising the ZnO

The coil is now put into a test tube containing mashed raspberries and raspberry juice. Here, the raspberry dye molecules bind to the ZnO surface.



The raspberry dye molecules belong to a group called anthocyanin molecules which have the basic structure shown above. The R groups are typically hydrogens, alcohol groups or ester groups. These last two help the dye bind to a semiconductor. The aromatic rings in the structure are responsible for the strong colour of the dye.

## The Assembled cell

Once the cell is constructed, the mechanism explained above can occur. Typical values for the open-circuit voltage (when the current is zero) are 0.5-0.7 V and for the short-circuit current (when the voltage is zero) are 0.5-2.5 mA cm<sup>-2</sup>.

When the cell is under a bright light, the current increases but the voltage stays the same. This is because the voltage is determined by the energy levels of the chemicals within the cell, not by the energy absorbed. Taking away bright light should therefore bring the current back down again, however, there is often a little bit of a time lag as the cell responds slowly with the change in light.

Connecting more than one cell in a series circuit increases the voltage available and 2 cells is enough to power a small LCD calculator.

The cells can also be sealed with waterproof glue at both ends of the straw arms and should be functional for a week after construction.

## Extensions

Several investigations and projects could be devised from this experiment. A few ideas are below.

- Change the colour of the straw. Different coloured drinking straws have shown differing voltage and current values because they are not absorbing as much of the solar spectrum.
- Change the dye. Many types of fruits and vegetables contain suitable dye molecules (anthocyanins).
- Vary the light intensity shining on the cell.
- Vary the surface area of the counter electrode/working electrode.
- Investigate other suitable electrolyte compounds.
- Compare the cell mechanism with standard Dye-sensitised Solar Cells.

## Links with the curriculum

- Light: light absorption, colour,
- Electricity: series and parallel circuits, current and voltage, electrochemistry, electrode potentials, reactivity
- Renewable energy: solar energy, energy storage, safety and construction considerations in designing new technologies

## Safety

Below is some general safety information for the chemicals used in this experiment. See appropriate Hazcards for more details. For information on where to obtain the materials used please refer to the equipment list.

### Copper sulphate ( $\text{CuSO}_4$ )

- Emergency Harmful if swallowed: wash mouth with plenty of water and call for medical aid. Wash off skin with plenty of water. Flush out eye with plenty of water.
- Protection Wear safety glasses and do not breathe in powder
- Disposal Dispose of with plenty of water down the sink.

### Zinc sulphate ( $\text{ZnSO}_4$ )

- Emergency Harmful if swallowed: wash mouth with plenty of water and call for medical aid. Wash off skin with plenty of water. Flush out eye with plenty of water for at least 10 minutes and seek medical aid.
- Protection Wear safety glasses.
- Disposal Harmful to the environment. Dispose of with plenty of water down the sink only in small amounts. Keep larger amounts for alternative disposal.

### Ferrous sulphate ( $\text{FeSO}_4$ )

- Emergency Harmful if swallowed: wash mouth with plenty of water and call for medical aid. Wash off skin with plenty of water. Flush out eye with plenty of water.
- Protection Wear safety glasses.
- Disposal Dispose of with plenty of water down the sink in small amounts.



### Sodium hydroxide (NaOH)

- Emergency Corrosive. Harmful if swallowed: wash mouth with plenty of water and call for medical aid. Do not induce vomiting. Wash off skin with plenty of water and remove contaminated clothing. Flush out eye with plenty of water for at least 10 minutes and seek immediate medical help.
- Protection Wear safety glasses.
- Disposal Dispose of with plenty of water down the sink in small amounts. Larger amounts should be neutralised first.

### Ammonium solution (NH<sub>4</sub>OH)

- Emergency Corrosive. Harmful if swallowed: wash mouth with plenty of water and call for medical aid. Wash off skin with plenty of water. Flush out eye with plenty of water.
- Protection Wear safety glasses. Do not allow concentrated solutions to be used in open laboratories.
- Disposal Harmful to the environment. Dispose of with plenty of water down the sink for small amounts. Large amounts should be neutralised.

### Methylated sprits (ethanol and methanol)

- Toxic, flammable
- Emergency If swallowed call for immediate medical aid. Wash off skin with plenty of water. Remove contaminated clothing. Flush out eye with plenty of water and call for medical help.
- Protection Wear safety glasses. Remove all forms of ignition or heat. Do not breathe in vapour.
- Disposal Dispose of with plenty of water down the sink in trace amounts. Otherwise collect in non-chlorinated solvent bottle.

### References

This experiment has been adapted from a journal paper. The original document can be found at:

S.J. Appleyard, Physics Education, Volume 3, Issue 3, May 2008, pages 270-279.



# Equipment List

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## Equipment per person/pair/group

- Test tube rack
- 3 test tubes
- Clear drinking straw
- Multimeter with wires and crocodile clips
- Screw with about 5cm length thread, thin enough to fit into a drinking straw
- Lead-free solder wire, ~ 25cm
- Plastic coated copper wire, ~6cm. Either strip off the plastic at each end (about 1cm both ends) or provide wire-strippers/scissors that can do the job.
- Matches
- Tealight candle
- Heatproof mat
- Tweezers
- Pestle and mortar (or provide ready ground sodium hydroxide)
- Measuring cylinder (>10 ml)
- Teaspoon (or spatulas)
- Tissue
- Scissors
- Small beaker / flask for water
- 2 pipettes (>2 ml)
- Retort stand or similar support
- Food bag ties/cable ties/string
- Beaker/dish containing a few raspberries to be mashed and something to mash them up with eg spatula/glass rod.
- Bright light and electric socket
- Small LCD calculator
- Aluminium foil

## Chemicals for each person/pair/group in vials, bottles, beakers etc.

- copper sulphate (3g)
- ferrous sulphate (3g)
- zinc sulphate (8g)
- ammonia solution (5ml)
- sodium hydroxide pellets (?g) (already ground if they will not have access to a pestle and mortar)
- methylated spirit (30ml)

## Sourcing the equipment

- Methylated spirit: pharmacies, paint shops, hardware stores. (£1.92 for 500ml)
- LCD calculator: supermarkets, stationers. (60p at Sainsburys)
- Raspberries (£2.25)- bought frozen so you can only defrost amount required and keep rest for another time- , matches (59p), kitchen foil (30p) tealight candles (£1.47), straws (100 in a dispenser £2.49), food bag ties/string from supermarket
- Lead-free solder wire: Hardware stores. £11.29 for 250g (each cell requires about 2g) Resin core solder wire at Homebase was fine.
- Household ammonia: Hardware store (£1.99 from Homebase)
- Plastic coated copper wire: Hardware stores



## Solar Straws – RISK ASSESSMENT

Hazard	Likelihood and Seriousness of Injury	Control measures	Assessment of remaining risk
Use of scissors	Possible, serious injury unlikely.	Explain risk of cuts. Care needed.	Low
Lit tea light candle	Possible, serious injury unlikely.	Explain risk of burns. Ensure all flammable substances removed before lighting. Use heatproof mat. Extinguish flame when not in use.	Medium
Handling of glass equipment	Possible, serious injury unlikely.	Handle carefully. Report breakages to be cleared by staff.	Low
Use of chemicals	Possible, serious injury unlikely.	Safety glasses must be worn at all times. Careful handling. See additional risk assessment form.	Low



Title: Solar cell straws

Assessor's Name: Nina Chadwick

Signature:

Supervisor's  
Signature:

Date: 17 / 01 / 2012

Substance	Quantity	Carcinogen, teratogen, mutagen	Toxic/very toxic	Harmful/irritant	Explosive	Pyrophoric	Flammable/highly flammable	Oxidising	Corrosive	Lachrymator	Other (please specify)
Methylated spirits			X	X			X				
Copper sulfate			X	X							
Iron sulfate			X	X							
Zinc sulfate			X	X							
Sodium hydroxide pellets				X					X		
Ammonia solution			X	X					X		
Level of supervision (see Safety Handbook)	<b>A</b>	<b>B</b>			<b>C</b>			<b>D</b>			

Heating	Cryogenics	Pressure	Vacuum	Other Equipment:
Safety Glasses	Labcoat	Fume hood	Safety screen	Gloves (type):
Face mask	Dust mask	Overnight permit	Other Controls:	
Emergency procedures:	Standard procedures.			
Disposal procedures:	<b>All chemicals can be washed down the sink with plenty of water. Straws can be disposed of in standard waste.</b>			
First aid:	Standard procedures.			
Extra precautions:	<b>Care needed with scissors to prevent cuts. Ensure all methylated spirits are moved to another table before lighting tea light candles. Supervision required when lighting tea light candles. Care needed with glass equipment – any breakages to be cleared up by a volunteer or staff member.</b>			

**Scheme of Work/Procedure:**

See instruction sheet.



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