

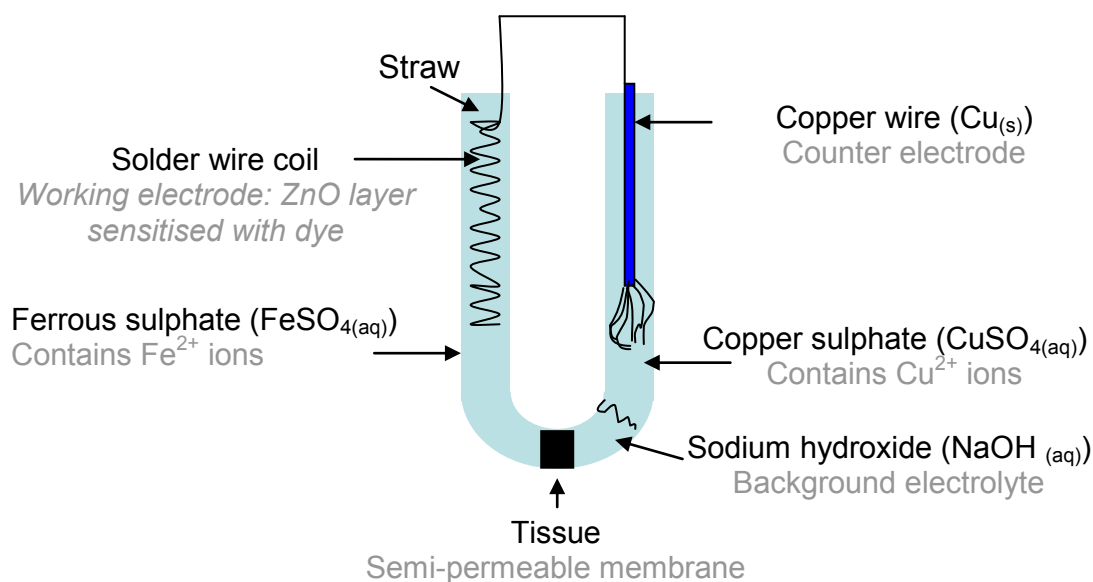
## Solar Cells in Drinking Straws Teacher's Notes

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

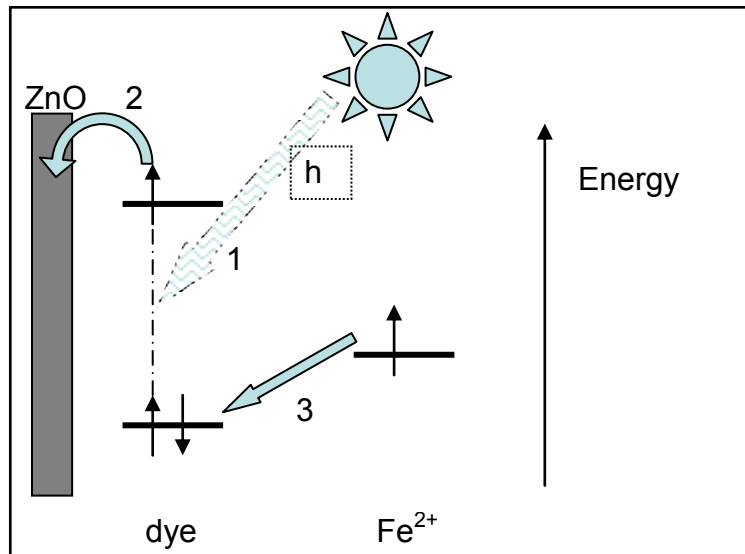
Half equation reaction	Electrode Potential
$\text{Cu}^{2+}_{(\text{aq})} + 2\text{e}^{-} \leftrightarrow \text{Cu}_{(\text{s})}$	<b>+0.34 V</b>
$\text{Fe}^{3+}_{(\text{aq})} + \text{e}^{-} \leftrightarrow \text{Fe}^{2+}_{(\text{aq})}$	<b>+0.77V</b>

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

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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

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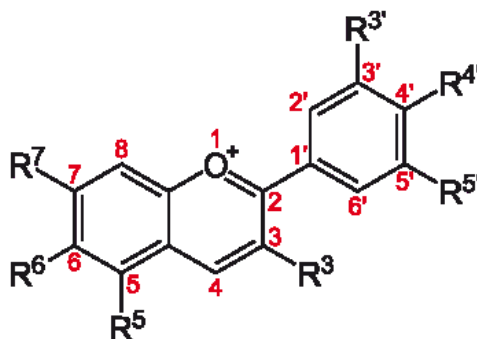
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The solder wire is then transferred to a test tube containing methylated spirit (the solvent),  $\text{ZnSO}_4$  and sodium hydroxide ( $\text{NaOH}$ ). Afterwards it is heated in aluminium foil over a candle flame.

The  $\text{ZnSO}_4$  reacts with the  $\text{NaOH}$  to make  $\text{Na}_2\text{SO}_4$  and  $\text{Zn(OH)}_2$ . When heated over the flame, the  $\text{Zn(OH)}_2$  converts to  $\text{ZnO}$ . Aluminium from the foil is also incorporated into the film as an impurity which increases the n-type character of the  $\text{ZnO}$  film. This is because aluminium forms  $\text{Al}^{3+}$  ions compared to the  $\text{Zn}^{2+}$  ions in  $\text{ZnO}$  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  $\text{ZnO}$  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  $\text{mA cm}^{-2}$ .

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**

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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 ( $\text{NaOH}$ )

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- 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.