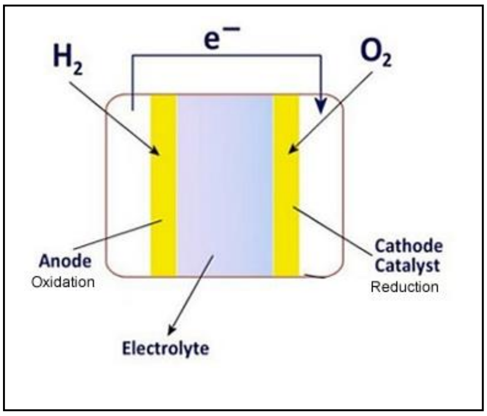
Redox reactions – fuel cells

Lesson 6



1) Fuel cells convert the chemical energy of fuels into electrical energy. Since chemical energy is directly converted into electrical energy, fuel cells are more efficient than power stations, however, they are limited in their capacity to generate large amounts of energy to rival the output of thermal power stations.
The diagram on the right shows a simplified diagram of a fuel cell. It is composed of three compartments, two containing the reactants and the middle one containing the electrolyte. These compartments are separated by porous electrodes that act as catalysts. Porous electrodes allow for the passage of ions through them to react with ions in the electrolyte and also allow for the conduction of electrons. An electrolyte serves to move ions from one electrode to the other.
The type of fuels used can differ markedly, however, the fuels always react at the anode(-) and the oxidant always at the cathode(+).
Although a fuel cell is a form of galvanic cell there are some key differences. Unlike a primary cell(disposable battery) or secondary cell(rechargeable battery) a fuel cell has its reactants continuously supplied and products continuously removed. Because of this primary and secondary cells have a limited life whereas fuel cells can operate indefinitely.
Since reactants are constantly supplied the voltage remains constant in a fuel cell as opposed to a primary or secondary cell where the voltage drops as the battery is drained.
Hydrogen gas is considered to be a zero emission fuel as the only product of its combustion in a fuel cell is water, electricity and heat. This is not entirely true, however, as almost 95% of the hydrogen used in fuel cells comes from fossil fuel via a process known as steam reformation. During this process high temperature steam in the presence of a Ni catalyst reacts with a fossil fuel, such as methane to produce hydrogen gas and carbon monoxide.

$$CH_4(g) + H_2O(g) \rightarrow 3H_2(g) + CO(g)$$

The carbon monoxide is the further treated with high temperature steam in the presence of an iron or copper catalyst.

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$$

Since CO_2 is a product of the formation of hydrogen , hydrogen fuel cells can not be considered a zero emissions technology.

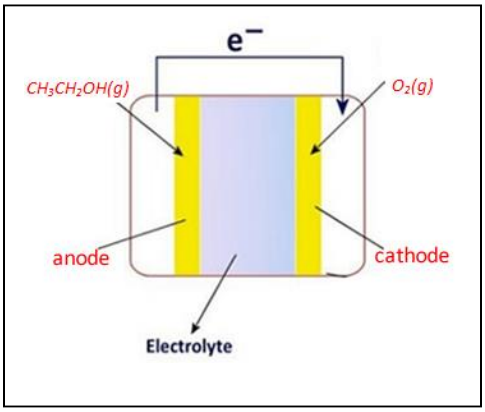
1) A fuel cell uses an acidic electrolyte to run the reaction below to generate an electric current.

$CH_3CH_2OH(g) + O_2(g) \rightarrow CH_3COOH(aq) + H_2O(l)$

a) write the banced half equation that occurs at the

- anode $H_2O(l) + CH_3CH_2OH(g) \rightarrow CH_3COOH + 4H^+(aq) + 4e$

- cathode $4e + 4H^+ + O_2(g) \rightarrow 2H_2O(l)$



b) Label the diagram on the right with the following

- anode
- cathode
- CH_3CH_2OH
- O_2

c) As the cell is discharging indicate in which direction cations move.

From anode to cathode through the electrolyte

2) A fuel cell reacts liquid methanol with oxygen gas to produce carbon dioxide, liquid water and an electric current. This fuel cell uses an acidic electrolyte and operates at around 100°C.

a) Write the balanced equation for the overall reaction.

$3O_2(g) + 2CH_3OH(g) \rightarrow 2CO_2(g) + 4H_2O(l)$

b) Write the balanced half equations that occur at the:

- anode $H_2O + CH_3OH(g) \rightarrow CO_2(g) + 6H^+(aq) + 6e$

- cathode $4e + 4H^+ + O_2(g) \rightarrow 2H_2O(l)$

c) The electrolyte is now changed and alkaline electrolyte is used instead of an acidic electrolyte.

Write the balanced half equations that occur now at the:

- anode $6OH^-(aq) + CH_3OH(g) \rightarrow CO_2(g) + 5H_2O(aq) + 6e$

- cathode $4e + 2H_2O(l) + O_2(g) \rightarrow 4OH^-(aq)$

Follow the link for more reading in writing half equation in an alkaline solution.

www.dynamicscience.com.au/tester/solutions1/chemistry/redox/buildinghalfreactions.htm

d) The manufacturer of a methanol fuel cell using an acidic electrolyte quotes a consumption rate of 800.0 mL per kWh (1 kWh = 3600 kJ of electrical energy)

i. The combustion reaction is the same reaction that occurs in the fuel cell. Write the balanced chemical equation for the combustion of methanol with oxygen.

$3O_2(g) + 2CH_3OH(g) \rightarrow 2CO_2(g) + 4H_2O(l)$

ii. Calculate the electrical energy in kJ delivered per gram of methanol (density of methanol (0.79 g/mL).

The cell uses 800.0 mL to deliver 3600 kJ of electrical energy.

The mass of methanol in 800.0 mL is 632 g (mass = density X volume)

=> 3600 / 632 = 5.7 kJ/g

iii. Calculate the theoretical thermal energy delivered by gram of methanol.

Data sheet quotes a heat of combustion of 22.7 kJ/g

iv. What is the percentage efficiency. (electrical energy / Total heat energy)

Thermal energy in 632 g of methanol is

=> 632 X 22.7 kJ = 1435 kJ

The electrical energy produced by an equivalent amount of methanol is 3600 kJ

Percentage efficiency = (3600 /14346) X 100 = 25.1%

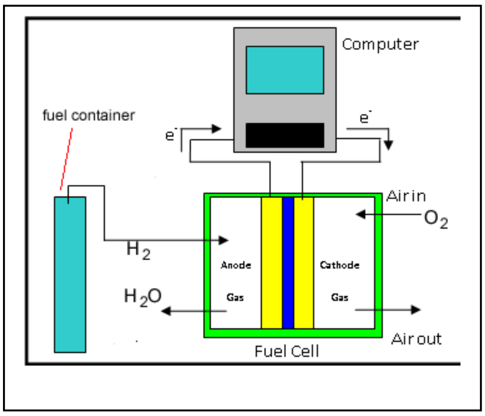
3) Fuel cells are proving promising alternatives to portable energy solutions. One type of fuel cell, is the solid oxide fuel cell (SOFC) which reacts hydrogen or carbon monoxide fuels with oxygen to produce electricity, as shown in the diagram below.

The half equations are given

Anode: $2\ H_2 + 2\ O^{-2} \rightarrow 2\ H_2O + 4\ e^-$

Cathode $O_2 + 4\ e^- \rightarrow 2\ O^{-2}$

Overall: $2\ H_2 + O_2 \rightarrow 2\ H_2O$



In one such setup a 50.0 litre storage cylinder of hydrogen gas at 13789 kPa and 25.0 °C is used to fuel an SOFC. This SOFC is 60.00% efficient in converting the combustion energy into electrical energy.

a) What ions pass through the membrane separating the two chambers?

O^{-2}

b) Calculate the number of mol of H_2 gas in the cylinder

PV = nRT

=> n = PV/RT

=> n = (13789 X 50.0) / (8.31 X 298) = 278

c) What is the total combustion energy available?

Heat of combustion of hydrogen is 282 kJ/mol

=> 278 X 282 kJ = 7.84 X 10^4 kJ

d) What is the total amount of electrical energy available to the computer?

Since it is only 60% efficient

=> 78,400 kJ X 0.600 = 4.70 X 10^4 kJ

e) If the energy consumption of the computer is 4.5012 kJ per minute how long can the computer operate for in hours. Give the answer to the right number of significant figures.

4.70 X 10^4 / 4.5012 = minutes of operation

=> 10441 minutes => 174 hours

f) Calculate the total amount of energy lost as heat to the environment.

=> 3.14×10^4 kJ is lost as heat.