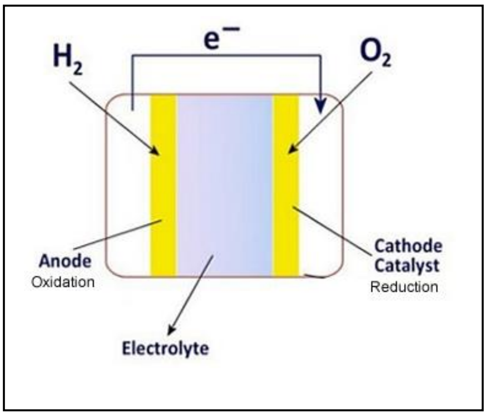
Redox reactions – fuel cells

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 with regular replacement of electrodes.
   - 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.
   - Electrodes in a fuel cell are different to other galvanic cells:
     - act as catalysts,
     - are expensive when compared to primary and secondary cells,
     - are porous, to allow gases to pass through increase surface area ,
     - are used to separate the reactants and products from the electrolyte.
   - Fuel cells can operate at very high temperatures as compared to the relatively mild temperatures that primary and secondary cells operate under.

   Hydrogen gas is considered to be a net zero emissions fuel, as the only product of its combustion in a fuel cell is water, electricity and heat. Although water is a greenhouse gas it is not as big a player in climate change as CO_2. Currently 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 then further treated with high temperature steam in the presence of an iron or copper catalyst.

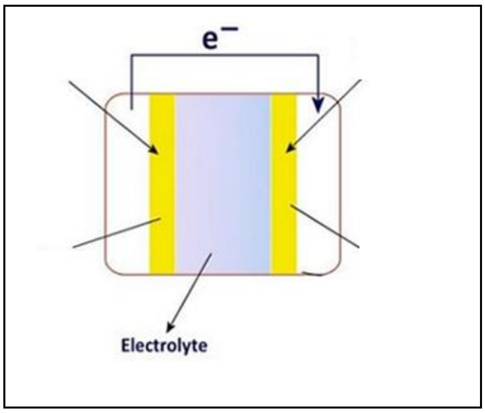
$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$$

   Since CO_2 is a product of the formation of hydrogen, hydrogen fuel cells cannot 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 balanced half equation that occurs at the
- anode ________________________________

- cathode ________________________________

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.



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.

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

- cathode

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

- cathode

d) The manufacturer of a methanol fuel cell using an acidic electrolyte quotes a consumption rate of 800 mL per kWh (1 kWh = 3600 kJ of electrical energy).

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

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

iii. What is the theoretical thermal energy delivered by a gram of methanol.

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

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.

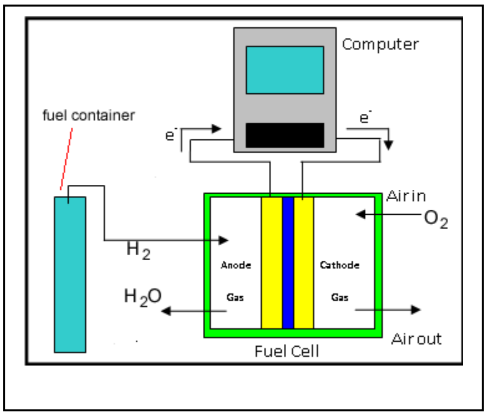
The half equations are given

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 energy from the heat of combustion into electrical energy.



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

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

c) What is the total combustion energy available?

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

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.

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