Ongoing revision 2 Unit 3 – Fuels, enthalpy, electrolysis

1. Electrolysis of water is used to produce H_2 gas which is pumped into a 300 litre vessel at 24.0 ^oC. This vessel is connected to a proton exchange membrane fuel cell (PEMFC) to generate electrical energy.

   a. The pressure needed for the efficient production of electrical energy is 180 kPa short.

      i. What mass, in kg, of hydrogen gas is needed to get to the correct operating pressure ?

      Step 1 Find the mol of hydrogen gas necessary to create 180 kPa pressure under the conditions stated in the question.
      => $n = PV/RT = 180 \times 300 /(8.31 \times 297) = 21.88$
      Step 2 Find the mass of H_2 gas.
      => $21.98 \times$ molar mass (H_2) = $21.98 \times 2.00 = 43.8$ g = 0.0438 kg.

      ii. The electrolytic cell used to generate the hydrogen gas has an operating current of 2.24 amps. Calculate the time, in hours, taken to produce the required amount of hydrogen gas in order to achieve the operating gas pressure.

      Step 1 Write the half equation for the production of H_2 gas at the cathode. Use the E^o table found in the Data Booklet.
      => $2H_2O(l) + 2e \rightarrow H_2(g) + 2OH^-(aq)$
      Step 2 Find the mol of electrons needed to produce the amount of hydrogen asked for in question i. above.
      => $2 \times 21.88 \times 96500 = 4.222 \times 10^6$ C.
      Step 3 Find the time necessary using Faraday law. ($Q = It$)
      => $4.222 \times 10^6 = 2.24\ t$
      => $4.222 \times 10^6 / 2.24 = 1.885 \times 10^6$ seconds = 524 hours.

   b. The hydrogen gas produced from the electrolysis of water is labelled "Green Hydrogen". This hydrogen, however, is turned into ammonia via the reaction, shown below, known as the "Haber-Bosch process".

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

   This reaction occurs at a temperature around 500^oC.

   i. Discuss with reference to intermolecular bonding why it is more economically viable to transport hydrogen in the form of liquid ammonia than as pure liquid hydrogen.

   Intermolecular bonding in H_2 is pure dispersion forces.
   Intermolecular bonding in NH_3 is composed of dispersion forces and hydrogen bonding.
   Stronger intermolecular forces found in ammonia as compared to hydrogen cause it to be easily liquefied and stored at much higher temperatures and lower pressures than hydrogen which requires very high pressure and extremely low temperatures to be liquefied. The ease

of NH_3 to be liquefied makes it cheaper to transport and store as very high pressure and cold temperatures and expensive to maintain. View the [video on dispersion forces]

ii. Argue against the use of the term "Green Hydrogen"

The production of hydrogen at 500°C, on an industrial scale, requires a great deal of energy consumption which ultimately comes from fossil fuels. So this fact alone make the term Green Hydrogen, highly dubious.

iii. Given that hydrogen and ammonia gases are kept in separate sealed 300 L vessels, under the same conditions of temperature and pressure, suggest a reason why more hydrogen can be transported in the form of ammonia rather than in pure hydrogen. Use a calculation to justify your reasoning.

Since both gases are in exactly the same conditions the amount of each gas is also the same.
=> $n_{hydrogen} = PV/RT = n_{ammonia}$
=> one mol of ammonia has a mass of 17.0 grams, three grams of which is composed of hydrogen.
=> one mol of hydrogen on the other hand has 2 grams of hydrogen.
Ammonia has a greater percentage of hydrogen
=> (mass of hydrogen in one mol of ammonia / mass of one mol of hydrogen) X 100 = 150%
=> ammonia has 50%, by mass, more hydrogen.
Any attempt at calculating the higher mass of hydrogen present in ammonia given equal mol of hydrogen and ammonia gases was awarded the marks.

2. Another electrolytic cell, shown in diagram 1, consumes a charge of 8.00×10^4 C in 8.00 minutes.

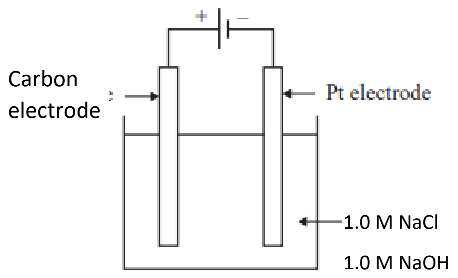


Diagram 1

i. Calculate the mol of electrons consumed.

Find the mol of electrons 8.000×10^4 C represents.
=> $n_{electrons} = 8.000 \times 10^4 / 96500 = 0.829$

ii. Give the gaseous products that occur at each electrode and justify your choice by writing the half equations for the reactions occurring at the:

- Anode *oxygen gas* $4OH^-(aq) \rightarrow O_2(g) + 4e^- + 2H_2O(l)$
- Cathode *hydrogen gas* $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

iii. Discuss, the changes in pH that occur:

- at the anode. *OH^- is consumed so pH falls*
- at the cathode. *OH^- is produced so pH rises*
- in the electrolyte. *No change, as the mol of OH^- consumed at the anode is equal to the mol of OH^- produced at the cathode. Overall reaction equation is $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$*

iv. Calculate the mass of gaseous product formed at the anode. Give the answer to the right number of significant figures.

Step 1 give the balanced equation to the reaction taking place at the anode. Use the Data booklet.
=> $4OH^-(aq) \rightarrow O_2(g) + 4e^- + 2H_2O(l)$
Step 2 Using the answer to question i. above derive the mol of oxygen gas.
=> 0.829 / 4 = mol of oxygen gas.
=> 0.2073 mol of oxygen gas.
Step 3 Find the mass of O_2
=> 0.2073 X 32.0 = 6.63 grams

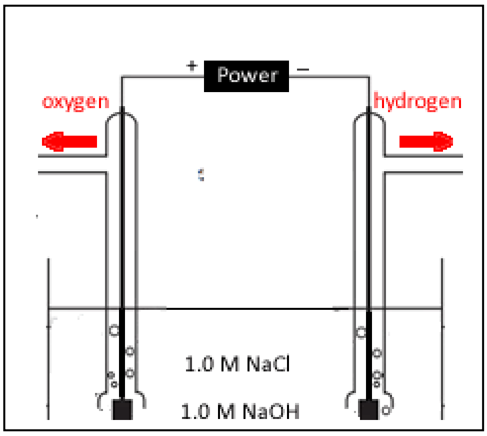
v. The efficiency of the cell in producing electrical energy is given by the expression on the right.

$$\frac{\text{Actual mass of product at the anode}}{\text{Theoretical mass of product at the anode}} \quad \text{X } 100$$

Calculate the efficiency of the cell if 5.40 grams of gas is produced at the anode.

=> (5.40 / 6.63) X 100 = 81.4%

vi. The cell's design has an inherent safety hazard. Explain what this hazard may be with reference to the products that are formed at each electrode and redesign the **electrodes** only to deal with the safety hazard identified. Use the space provided in the box on the right to draw an appropriate solution.



Hydrogen and oxygen gases are produced in the electrolytic cell. A mixture of hydrogen and oxygen gas is highly explosive.
Since we must redesign the electrodes only it is suggested that gas electrodes be used for this cell to extract the gases at the point of origin and prevent gases forming an explosive mixture.

3. Propene (C_3H_6) gas undergoes complete combustion in atmospheric oxygen at SLC.
   a. Given that 4.20 grams of propene releases enough heat energy to increase the temperature of 2.00 kg of water by 24.6 °C:
   i. find the molar heat of combustion of propene.

Step 1 Find the energy released by 4.20 grams of propene.
=> E = 4.18 X 2000 X 24.6 = 205.7kJ
Step 2 Find the mol of propene
=> 4.20 /42.0 = 0.100 mol
Step 3 Find the molar heat of combustion
=> 205.7 /0.100 = 2057 kJ mol^{-}

ii. write a balanced thermochemical equation for the complete combustion of propene.

$2C_3H_6(g) + 9O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ $\Delta H = -4114$ kJ mol^{-}

iii. calculate the minimum volume, in litres, of oxygen required to completely combust 4.20 grams of propene at SLC.

Step 1 Find the mol of O_2 needed to combust the 0.100 mol of propene.
=> 9/2 X 0.100 = 0.450 mol of oxygen gas.
Step 2 Find the volume at SLC of oxygen gas.
=> 0.450 X 24.8 = 11.2 litres.

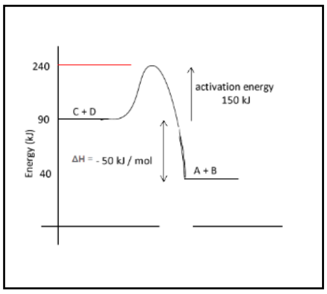
iv. Calculate the volume, in litres, of gaseous product formed if 102.9 kJ of energy is released during the complete combustion of propene in atmospheric oxygen.

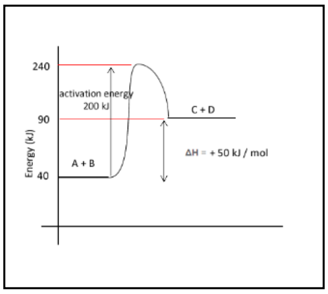
The only gaseous product is CO_2 gas
Step 1 Apply the ratio given by the thermochemical equation in question a ii. above.
=> 6 mol of CO_2 / 4114 kJ released = mol of CO_2 / 102.9 kJ
=> (6 X 102.9 kJ) / 4114 kJ = mol of CO_2
=> 0.150 mol of CO_2

Step 2 Find the volume at SLC.
=> 0.150 X 24.8 = 3.72 litres.

b. During the following reaction $A(g) + B(g) \rightarrow C(g) + D(g)$ 200kJ of energy is required to break bonds while 150 kJ of energy is released during bond formation. Given the total chemical energy of the reactants (A and B) is 40 kJ, complete the two energy profiles shown below. Drawings do not have to be to scale. In each clearly label and give the value of the:

i. ΔH
ii. Activation energy
iii. Energy content of the products





c. Which one of the following two reactions occurs at the faster rate? Justify your answer with reference to the energy profiles drawn in question b. above.
i. $A(g) + B(g) \rightarrow C(g) + D(g)$

ii. $C(g) + D(g) \rightarrow A(g) + B(g)$

Reactions with lower activation energy occur at a faster rate than those with a higher activation energy at any given temperature. As shown in the diagram on the right of the Maxwell-Boltzman energy distribution curve, more particles have the lower activation than the higher. As such, more particles will be able to react with the lower activation energy and so the reaction that has the lowest activation energy will proceed at a faster rate than the reaction with the higher activation energy.