Electrolyser worksheet – green hydrogen

1. Consider the electrolysis of water using a PEM electrolyser.
   a. Write the half-equations for both the oxidation and reduction reactions that occur at the electrodes labelled A and B in the box provided in fig 1. States required.
      B =>$2H^+(aq) + 2e \rightarrow H_2(g)$
      A => $2H_2O(l) \rightarrow 4e^- + 4H^+(aq) + O_2(g)$
   b. In the red box, identify the species moving through the semipermeable membrane and draw an arrow to indicate the direction of flow.
   c. Give the polarity of electrodes:
      A ___*Positive*
      B ___*Negative*

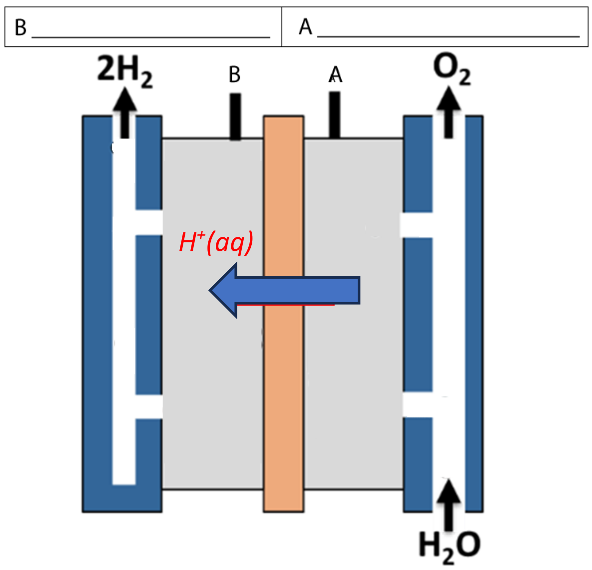

Figure 1

   d. A current of 5.0 A is applied for 2.0 hours.

      i. Calculate the total charge passed through the electrolyser.

      $Q = I \times t = 5.0 \times 2 \times 60 \times 60 = 3.6 \times 10^4 C$

      ii. Calculate the mass, in grams, of hydrogen produced, assuming 80% efficiency. Express the answer to the right number of significant figures.

      Mol of electrons (n_e) = $3.6 \times 10^4 / 96500 = 0.373$
      $2H^+(aq) + 2e \rightarrow H_2(g)$
      Mass of hydrogen gas (H_2) at 100% efficiency = 0.373 X ½ X 2.0 = 0.373 grams
      Mass of hydrogen gas at 80% = 0.373 X 0.80 = $3.0 \times 10^{-}$ grams

2. Consider the design of an AEM electrolyser shown in fig. 2. It operates at a current of 20 amps.
   a. In the blue and red boxes give the two species moving through the membrane and draw the arrow to indicate the direction of travel.
   b. Identify electrodes A and B as either the cathode or anode.

      A ___*Anode*_______________

      B ___*Cathode*_______________

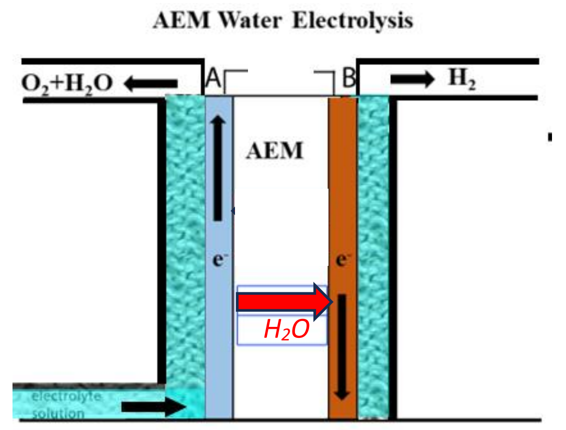

Figure 2

   c. Write the balanced half equations, states included, for the reactions taking place at the:

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

      Cathode __________________ $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ _______________

   d. Identify an appropriate electrolyte solution

      _____________________*KOH(aq) or NaOH(aq)*__________________________

   e. Calculate the time, in hours, required to produce 2.000 kg of green hydrogen. Assume 100% efficiency in the electrolysis process.

      Step 1 - Mol of hydrogen gas = 2000 / 2.0 = 1000
      Step 2 - Mol of electrons required to deposit 1000 mol of H_2 => 2 X 1000 = 2000 mol of electrons.
      Step 3 - Charge => 2000 X 96500 = 1.93×10^8C
      Step 4 – Find time in hours
      => 1.93×10^8C / 20 = 9.65×10^6
      => 9.7×10^6 hours.

3. Compare two scenarios of water electrolysis using a PEM electrolyser. In Scenario A, a current of 15 amps is applied for 3 hours, and in Scenario B, a current of 10 amps is applied for 5 hours.
   a. Determine which scenario produces more hydrogen gas, and discuss the factors influencing the comparison.

   For scenario A

   Q = 15 X 3 X 60 X 60 = 162000C

   For scenario B

   Q = 10 X 5 X 60 X 60 = 180000C

   Hydrogen is directly proportional to the charge delivered via these two equations

   $Q = It$ and $n_{electrons} = Q/96500$

   Hence scenario B will produce more hydrogen gas.

   b. Calculate the mass, in grams, of hydrogen gas produced using your answer to a. above. Give the answer to the right number of significant figures.

   => 180000 / 96500 = 1.86

   $2H^+ + 2e^- \rightarrow H_2$

   => 1.86 X ½ X 2.0 = 1.9 grams => 2 grams (1 sig fig) (hours was given to one sig fig and was used to calculate charge)

   c. Suggest under what conditions is the hydrogen produced by an electrolyser considered green-hydrogen.

   When the power source is considered sustainable and renewable.

      i. Give three examples of green hydrogen production.

      Eg if the power comes from wind, solar, biofuels.

      ii. Give three examples of the production of non-green hydrogen production.

      Power that ultimately is generated via fossil fuels does not qualify for the production of green hydrogen. Any process that uses a non-renewable energy source or one that produces CO_2

   d. Bioethanol is used as a fuel in an ethanol/oxygen fuel cell to generate power to drive an PEM electrolyser. Ethanol is produced via fermentation of corn starch and then purified via distillation. The process of distillation, in this case, requires heat generated from the burning of natural gas. Using this scenario explain the meaning of the terms "sustainable" and "renewable" .

   Renewable focuses on the resource that can be replenished in a reasonably short amount of time so that it never becomes depleted. Corn can be grown to extract the starch to replenish the bioethanol in a reasonable timeframe so there is chance of being depleted.

   Sustainable encompasses the broader issue of responsible practices in the fuel's production. Ethanol production uses natural gas for distillation. Being a fossil fuel this practice is not sustainable.

      i. Is the hydrogen gas produced via this method considered "Green hydrogen"?

Students need to mention the source of the energy needed to distill and purify the ethanol. It is green only if the production and use of the energy source does not cause a net increase in atmospheric green house gases.

ii. Is the hydrogen gas produced via this method "sustainable" and "renewable"?

Students can argue that hydrogen produced in this manne is renewable but not sustainable, as the production of bioethanol competes with food crops for land.

iii. Ethanol can also be used directly in a decomposition reaction to produce hydrogen gas according to the equation below.

$$C_2H_5OH \rightarrow H_2 + CO + CH_4 \qquad \Delta H = 51.3kJ/mol$$

Is the hydrogen gas produced in this decomposition reaction sustainable and renewable if the heat energy required comes from wind turbines? Explain.

It is not sustainable as it produces a powerful green house gas, namely CH_4.

4. A green hydrogen production facility utilizes a AEM electrolyzer that operates with a current of 30.0 A for 8.0 hours. The overall water electrolysis reaction is given below

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Calculate the:

i. Total charge passed through the electrolyser. Give your answer to the right number

Charge = It => 30.0 X 8.0 X 60 X 60 = 8.6 X 10^5C

ii. Give the balanced half equation occurring at the cathode.

=> $2H_2O (l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

iii. Mol of electrons that pass through the electrolyser.

=> 8.6 X 10^5C/96500 = 9.0

iv. The theoretical yield of green hydrogen, in grams.

=> 9.0 X ½ = 4.5

=> 4.5 X 2.0 = 9.0 grams

v. The percentage yield given that the hydrogen gas produced occupied a volume of 99.2 litres at SLC.

=> Find the mol of H_2 actually formed.
=> 99.2 / 22.4 = 4.0
=> %v yield = (actual/theoretical) X 100 = (4.0 / 4.5) X 100 = 89%

vi. What conditions must apply for the hydrogen produced in the electrolyser to be considered green hydrogen?

Power must come from a renewable and sustainable source such as wind, solar, hydro or biofuels that are net zero contributors to atmospheric CO_2.

5. Compare and contrast a PEM electrolyser with a hydrogen fuel cell by discussing two similarities and two differences between the two.

Similarities may include but limited to:

- *Both fuels cells and electrolysers operate on redox reactions*
- *Both have electrodes where at the anode where oxidation takes p[lace and cathode where reduction takes place.*
- *Both employ membrane technology for the selective movement of $H^+(aq)$ towards the cathode.*
- *Both involve hydrogen gas, electrolyser produces H_2 whilst fuel cell uses H_2 as a fuel.*
- *Both use catalyst electrodes.*

Differences may include but limited to:

- *Operating mode where fuel cell operates as a galvanic cell whilst electrolyser acts as a electrolytic cell.*
- *The electrochemical reaction $2H_2O \rightarrow 2H_2 + O_2$ occurs in an electrolyser whilst in a fuel cell the reaction is reversed $2H_2 + O_2 \rightarrow 2H_2O$*
- *In a fuel cell hydrogen is a fuel whilst in an electrolyser it is produced.*
- *Electrolyser used in renewable energy systems to produce and store hydrogen, thus converting electrical energy into chemical energy, whilst a fuel cell is involved in direct conversion of chemical energy into electrical energy.*
- *Electyrolysers operate at much lower temperatures, 40 -70 ^oC, than fuel cells which have a greater range, 90 – 800 ^oC, but generally remain higher than electrolysers.*

In summary, while both PEM electrolysis and fuel cells involve hydrogen and proton exchange membranes, their primary functions, directions of reaction, and applications differ. PEM electrolysis is used for hydrogen production, while fuel cells are employed for the direct conversion of hydrogen into electricity.