19.2 Electrolysis of water

Subject: Electrochemistry, electrolysis

Description: The splitting of water into hydrogen and oxygen gas is demonstrated.

Materials (no bin):
Hoffman Apparatus and leads(located on the shelf above the central bench)
Power supply – located in cabinet under bench labeled electrochemistry)
Sodium sulfate (Na_2SO_4)‡

Optional materials:
Indicator solution (phenolphthalein or universal indicator)
Matches
2 large test tubes
Wood splint

‡Sodium sulfate solution is located in the chemical storage cabinets.

Pre-Class Preparation:
1. Fill the Hoffman Apparatus if not already filled.
2. If using indicator solution, first pour the sodium sulfate into a beaker and add the indicator. Adjust to neutral pH if necessary.
3. To fill the apparatus, close the stopcocks on the arms. Fill the bulb with the sodium sulfate solution. Open the stopcock on one arm allowing the arm to fill with solution. Add more solution to the bulb if necessary. Close the stopcock and repeat with the other arm.

Procedure:
1. Connect the wire leads from the power supply to the connections on the apparatus.
2. Turn on the power supply and adjust the voltage to approximately 10 volts (no higher than 100 milliamps)
3. Gas bubbles will begin to form immediately on the electrodes. The gas will collect at the top of each arm, displacing the liquid. The liquid will flow into the central tube and bulb as it is displaced.
4. The solutions in each arm will change color as the pH of the solution changes turning pink at the anode (acidic) and purple/blue at the cathode (basic).
5. When enough gas has collected over the cathode arm (hydrogen), disconnect the power. Hold a test tube inverted over the tube with oxygen (anode) and open the stopcock to collect the oxygen. Cap with a thumb. Light a wood splint with the match. Blow out the flame, leaving glowing embers and place inside the test tube with oxygen. The splint will burst into flame.
6. Repeat with the hydrogen. The gas will explode with a loud pop.

Discussion:

When a DC current is passed through an aqueous solution of sodium sulfate, water is oxidized at the anode and reduced at the cathode. The equations for the reactions are given below:

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

Cathode: $4\ H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4\ OH^-(aq)$

The equations show that the number of moles of hydrogen produced is twice as much as oxygen. Thus, the volume of hydrogen gas that collects in the cathode tube is double that of oxygen. The equation also shows that hydrogen ions are produced at the anode, making it acidic and hydroxide ions are produced at the cathode, making it basic. The number of hydrogen ions produced is equal to the number of hydroxide ions produced. Thus if you recombine the solutions after the demonstration, they will completely neutralize each other, returning the pH to neutral.

Sodium sulfate or sulfuric acid is used because pure water doesn't contain a high enough concentration of ions to produce a current. In other words, its resistance is high. Adding ions from an electrolyte lowers the resistance and increases the conductivity. The electrolyte used must not contain ions that react with the electrodes. Sodium sulfate and sulfuric acid fits these requirements. Sodium sulfate is also convenient because it allows us to see the color changes with the indicator as the pH changes.

The minimum standard potential needed for the electrolysis of water is -0.83 volt for reduction and -1.23 volts for oxidation. Thus a potential of 2.06 volts would cause the electrolysis of water. However, this standard electrode potential applies to equilibrium conditions and the cell is not at standard conditions. A higher voltage needs to be used in order to achieve a higher current. The current is proportional to the voltage as described by the following equation:

$V = IR$

Shakhashiri states that a voltage of between 20 and 25 V should be used used. This compensates for non-standard conditions and allows the reaction to go quickly in order to collect enough gas in a shorter period of time. When tested, a voltage of about 10 worked well.

Safety:
Hydrogen gas is flammable and yields explosive mixtures with oxygen. Keep ignition sources clear when collecting hydrogen.

Disposal: Sodium sulfate can be reused.

References:

1. B.Z. Shakhashiri; *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; Wisconsin 1992; Volume 4; p. 156