Passage II (Questions 7 - 12)

Dry cell batteries are common in many household products such as flashlights and radios. They contain no aqueous solution through which ions migrate, but instead contain a gelatinous paste of concentrated aqueous NH_4Cl. It is important that the electrons can easily flow through the membrane. Dry cell batteries are convenient because of their small size and long lifetime. A similar battery is the alkaline manganese cell, which exploits the same reaction, but in a basic medium. In a basic medium, the battery employs the following two half-cell reactions:

Anode: $Zn + 2\ OH^- \rightarrow ZnO(s) + H_2O + 2\ e^-$

Cathode: $MnO_2 + \frac{1}{2}\ H_2O + 1\ e^- \rightarrow \frac{1}{2}\ Mn_2O_3 + OH^-$

In lieu of manganese oxide, the cells can also use silver oxide and mercury oxide. In acidic medium, the dry cell battery employs the following two half-cell reactions.

Anode: $Zn \rightarrow Zn^{2+} + 2\ e^-$

Cathode: $MnO_2 + NH_4^+ + 1\ e^- \rightarrow \frac{1}{2}\ Mn_2O_3 + \frac{1}{2}\ H_2O + NH_3$

The overall cell potential (E˚) for the dry cell battery is slightly greater than 1.50 V. The nickel-cadmium battery is a rechargeable battery as well. The nickel-cadmium battery (also known as the *nicad battery*) is found in calculators and electric shavers. The following two reactions are employed for the nickel-cadmium battery:

Anode: $Cd + 2\ OH^- \rightarrow Cd(OH)_2 + 2\ e^-$

Cathode: $NiOOH + H_2O + 1\ e^- \rightarrow Ni(OH)_2 + 1\ OH^-$

A typical nickel-cadmium (NiCad) battery has a fairly low voltage. The outer wall of the anode solution is initially the cadmium metal, but as the cell runs, the cadmium dissolves away. Figure 1 shows a cross section of a typical NiCad battery. As drawn, the outer casing contains zinc metal (in lieu of cadmium) in a basic potassium hydroxide solution. The cathode is made of HgO (NiO_2H in typical nicad batteries), which reduces on the surface of a stainless steel electrode. The electrons flow to the top of the cathode. The insulation holds the cell together.

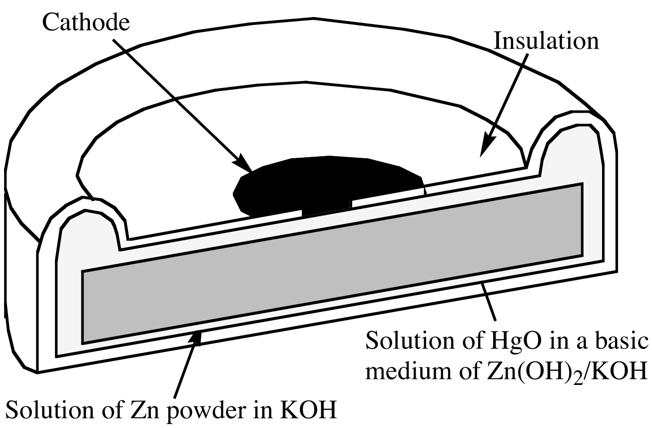

Figure 1

All of the cells function in a similar manner, allowing substitutions to be made to achieve different voltages. The lifetime of a battery is determined by the quantity of species.

7. What is the overall balanced reaction for a nickel-cadmium battery?

A. $Cd + 2\ NiO_2H + 2\ OH^- \rightarrow Cd(OH)_2 + 2\ Ni(OH)_2$
B. $Cd + 2\ NiO_2H + 2\ H_2O \rightarrow Cd(OH)_2 + 2\ Ni(OH)_2$
C. $2\ Cd + NiO_2H + 2\ OH^- \rightarrow 2\ Cd(OH)_2 + Ni(OH)_2$
D. $2\ Cd + NiO_2H + 2\ H_2O \rightarrow 2\ Cd(OH)_2 + Ni(OH)_2$

8. What is the oxidation state change for manganese in the Zn/MnO_2 battery?

A. Mn goes from +4 to +6
B. Mn goes from +4 to +3
C. Mn goes from +2 to +6
D. Mn goes from +2 to +3

9. Which of the following reactions represents the cathode reaction in a zinc-mercury oxide battery at pH = 10?

A. $Zn \rightarrow Zn^{2+} + 2\ e^-$
B. $Zn + 2\ OH^- \rightarrow ZnO + H_2O + 2\ e^-$
C. $HgO + 2\ NH_4^+ + 2\ e^- \rightarrow Hg + H_2O + 2\ NH_3$
D. $HgO + H_2O + 2\ e^- \rightarrow Hg + 2\ OH^-$

10. Which of the following reactions CANNOT take place at the anode?

A. $2\ FeO + 2\ OH^- \rightarrow Fe_2O_3 + H_2O + 2\ e^-$
B. $Ag_2O + H_2O + 2\ e^- \rightarrow Ag + 2\ OH^-$
C. $Ti(OH)_2 + 2\ OH^- \rightarrow TiO_2 + H_2O + 2\ e^-$
D. $V_2O_3 + 4\ OH^- \rightarrow V_2O_5 + 2\ H_2O + 4\ e^-$

11. The electrons in a dry cell battery flow from:

A. the outer casing to the surface of the stainless steel cap.
B. one wall of the core to the other wall of the core.
C. bottom of the insulator to the top of the stainless steel cap.
D. from the stainless steel cap to the wall of the core.

12. What is observed with a NiCad battery over time?

A. Electrons build up in the anode.
B. Cadmium metal builds up in the anode.
C. Nickel hydroxide builds up in the anode.
D. Cadmium hydroxide builds up in the anode.

7. **Choice B is the best answer.** The two half reactions for the nickel-cadmium battery are given in the passage as:

Anode: $Cd + 2\ OH^- \rightarrow Cd(OH)_2 + 2\ e^-$

Cathode: $NiOOH + H_2O + 1\ e^- \rightarrow Ni(OH)_2 + 1\ OH^-$

To find the overall balanced equation, the number of electrons in each half-cell must be the same. In the oxidation half-cell, two electrons are produced, while in the reduction half-cell, only one electron is consumed. This means that the reduction half-cell must be multiplied by two. This yields the following two half-cells that upon addition yield the overall reaction:

Anode: $Cd + \cancel{2\ OH^-} \rightarrow Cd(OH)_2 + \cancel{2\ e^-}$

Cathode: $2\ NiOOH + 2\ H_2O + \cancel{2\ e^-} \rightarrow 2\ Ni(OH)_2 + \cancel{2\ OH^-}$

Overall: $Cd + 2\ NiOOH + 2\ H_2O \rightarrow Cd(OH)_2 + 2\ Ni(OH)_2$

The correct answer is choice **B**.

8. **Choice B is the best answer.** In the reduction half-cell, MnO_2 is converted to Mn_2O_3. In MnO_2, the oxidation state of Mn is +4. In Mn_2O_3, the oxidation state of Mn is +3. These can be determined by assuming that the oxidation state of oxygen is -2 in all of the compounds. The oxidation state of Mn goes from +4 to +3. Because zinc is oxidized, manganese must be reduced, making choices A, C, and D incorrect. The correct choice is answer **B**. Only one electron is absorbed, so it should be reduced by one electron.

9. **Choice D is the best answer.** Reduction takes place at the cathode, so choices A and B are immediately eliminated. Because at a pH equal to 10 the solution is basic, the correct answer must be choice **D**. Ammonium cation (NH_4^+) cannot exist at a pH of 10, because it has a pK_a value less than 10. It would exist as ammonia (NH_3) in a pH = 10 solution. The cell is basic, so choice **D** is best.

10. **Choice B is the best answer.** Oxidation takes place at the anode, meaning that the reaction that *cannot* occur at the anode is a reduction half reaction. Reduction involves the gain of electrons, so the electrons are on the reactant side of the equation in reduction. In choice **B**, the reactant side of the equation shows electrons, meaning that electrons are gained in the reaction. Gaining electrons is the definition of reduction, so choice **B** cannot occur at the anode.

11. **Choice A is the best answer.** The flow of electrons in any electrochemical cell is defined as being from the anode to the cathode (from the oxidation half-cell to the reduction half-cell). The trick to this question is therefore deciding where the anode and cathode actually are. The core of the dry cell battery carries out the oxidation half-reaction, while the stainless steel cap is the electrode on which manganese is reduced. In the battery drawing in Figure 1, the stainless steel cap is defined as the cathode. This means that the correct answer must have the electron flow going towards the stainless steel cap. This eliminates choices B and D. The insulator does not get involved in the reaction or the flow of electrons (hence the term "insulator"). This means that choice C is eliminated and makes the best answer (and only choice remaining) choice **A**. The electrons flow from the metal being reduced, which is found in the outer casing (as stated in the passage).

12. **Choice D is the best answer.** Electrons do not build up in a cell; potential difference builds up. The electrons flow, but they do not exactly collect. Choice A is therefore eliminated. Cadmium is oxidized in the reaction, meaning that cadmium metal disappears and does not build up, whether it's at the anode or the cathode. Choice B is therefore eliminated. Nickel hydroxide is a product of the reaction, so nickel hydroxide builds up somewhere. Nickel hydroxide does not build up at the anode, however, because nickel hydroxide is formed from the reduction half-reaction, so it builds up at the cathode, according to the two half-cell equations. Choice C is therefore eliminated. Cadmium hydroxide is formed from the oxidation half-reaction, so it builds up at the anode. The best answer is choice **D**.