

**Sample Question Solutions for the Chemistry of Industry Topic Test****1. Fuel Cells**

Many car developers are trying to find more efficient methods of powering automobiles while also being environmentally friendly. A more recent option being implemented into modern cars has been to use Hydrogen Fuel Cells as an alternative to gasoline and diesel.

a. The following is the overall reaction for a hydrogen fuel cell occurring at 25 °C, under basic conditions. From this reaction, write out the half-cell reactions that take place for a hydrogen fuel cell. Then, state which half reaction is the cathode and which is the anode.



b. Calculate the  $E^\circ$  (Standard EMF) of the Cell at 25 °C, using the standard reduction potentials chart found at the end of these sample questions. Show all work to support answer and box or circle the final answer.

From the standard reduction table, the potential for the anode reaction is + 0.83 V

The potential for the cathode reaction is +0.40 V

Overall potential of the cell = 0.83 V + 0.40 V = 1.23 V

**(This question continues on the next page.)**

c. While the  $E^\circ$  found in part (b) is accurate under standard conditions, the environment of your automobile might not always be standard. Using the Nernst equation, calculate the cell potential of the hydrogen fuel cell when the temperature is 38 °C. Assume your fuel cell has 100 mL of  $H_2$  gas at 0.5 atm and 100 ml of  $O_2$  gas at 1.0 atm.

$$E = 2.23 - \frac{(8.314 \frac{J}{mol \cdot K})(311K)}{(4 \text{ mol } e^-)(96485 \frac{C}{mol e^-})} \left( \ln\left(\frac{1}{(0.5)(0.1)}\right) \right) = 2.25 \text{ V}$$

d. If your car has a reader indicating that 0.058 moles of  $O_2$  was consumed in one hour, calculate the charge (in Coulombs) that has been given to your car.

$$(0.058 \text{ moles } O_2) \left( \frac{4 \text{ mol } e^-}{1 \text{ mol } O_2} \right) \left( \frac{96485 \text{ C}}{1 \text{ mol } e^-} \right) = 2.238 \times 10^4 \text{ C}$$

## 2. Magnetic Resonance Imaging

Magnetic Resonance Imaging, otherwise known as MRI, is a safe, non-invasive technique for physicians to see inside the body. For some procedures, a gadolinium contrast solution is injected into the patient via intravenous injection, better known as IV. The contrast solution improves the visibility of inflammation, tumors, blood vessels and, for some organs, blood supply.

a. At 8:00 am, a 15 mL dose of a gadolinium contrast dye is injected into a patient. Assume the gadolinium immediately mixes uniformly with the blood in circulation. The average body contains 5.1 liters of blood. What is the initial concentration of gadolinium (Gd) in circulation after injection? Assume the dye contains 1.825 mmol/mL of gadolinium, and ignore the increase in blood volume from the injection of the 15 mL dose. Give answer in mg/dL. (Note: 1 dL = 100 mL, 1 mol = 1000 mmol). Show work for full credit.

Atomic mass of Gd is 157.25 g/mol.

$$\text{Amount of Gd} = (15 \text{ mL}) \left( 1.825 \frac{\text{mmol}}{\text{mL}} \right) \left( \frac{1 \text{ mol}}{1000 \text{ mmol}} \right) \left( 157.25 \frac{\text{g}}{\text{mol}} \right) = 4.305 \text{ g Gd}$$

$$\left( \frac{4.305 \text{ g}}{5.1 \text{ L}} \right) \left( \frac{1000 \text{ mg}}{1 \text{ g}} \right) \left( \frac{1 \text{ L}}{10 \text{ dL}} \right) = 84.4 \frac{\text{mg}}{\text{dL}}$$

b. A patient is about to undergo a procedure that requires a blood gadolinium level below 20 mg/dL. The elimination half-life of a gadolinium contrast agent is 1.5 hours. For the part described in part a, can doctors proceed with this procedure at 11:00 am? If not, what time will it be when it is safe for them to proceed? Show work for full credit.

The time elapsed is 3 hours, or the equivalent of two half-lives. The concentration will be  $21.1 \frac{\text{mg}}{\text{dL}}$ , so the doctors cannot proceed at 11:00 a.m.

$$t_{\text{half-life}} = \frac{\ln(2)}{k} \Rightarrow k = \frac{\ln(2)}{1.5 \text{ hr}} = 0.4621 \text{ hr}^{-1}$$

$$N(t) = N_0 e^{-kt} \Rightarrow t = \frac{\ln\left(\frac{N(t)}{N_0}\right)}{-k} \Rightarrow t = \frac{\ln(0.23697)}{-0.4621 \text{ hr}^{-1}} = 3.116 \text{ hr} \approx 3 \text{ hours and 7 minutes}$$

11:07 a.m is when it will be safe for the doctors to proceed.

### 3. Cadmium Toxicity

According to the EPA, the highest tolerable concentration of Cd<sup>2+</sup> in drinking water is 0.005 mg/L. Super Batteries Inc. uses cadmium in its battery production but has found high levels of cadmium ions in the wastewater. It is your job to determine the best method of cadmium removal.

a. Express the high tolerable concentration of Cd<sup>2+</sup> in drinking water in molar units (mol/L). Show your work and circle your final answer.

$$\left(\frac{0.005 \text{ mg}}{1 \text{ L}}\right) \left(\frac{1 \text{ g}}{1000 \text{ mg}}\right) \left(\frac{112.411 \text{ g}}{1 \text{ mol}}\right) = 4.44 \times 10^{-8} \text{ M}$$

b. Given the table of solubility constants at 25°C for some of the species below, only based on the pK<sub>sp</sub>, what would be the best anion to add in order to precipitate the most Cd<sup>2+</sup> ion? Explain how you came to your conclusion. Hint: if you do not know what pK<sub>sp</sub> is, consider how to calculate pH from hydronium concentration.

Species	pK <sub>sp</sub>
Cd <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub>	32.66
CdC <sub>2</sub> O <sub>4</sub>	7.8
CdS	27.92
Cd(OH) <sub>2</sub>	13.64
CdCO <sub>3</sub>	11.3

Two answers are acceptable here, as long as the corresponding justification is given: (1) Cadmium arsenate, because the pK<sub>sp</sub> is the highest, likely resulting in lowest Cd concentration; (2) CdS, considering that the K<sub>sp</sub> expression for cadmium arsenate has higher order exponents than CdS, and that will lead to lower cadmium concentrations in CdS in actuality.

(This question continues on the next page.)

c. Super Batteries Inc. wants to treat its wastewater before releasing it back into the local river, so the wastewater is currently in a tank for treatment.

i. After adding a reactant containing your chosen anion, the  $\text{Cd}^{2+}$  in the tank is now at the highest tolerable concentration level by EPA standards. If you did not find an answer to part (a), use a concentration of  $10^{-7}$  M for cadmium. What is the concentration of the remaining anion?

$$K_{\text{sp}} = [\text{AsO}_4^{2-}]^2 [\text{Cd}^{2+}]^3 = 10^{-32.66}$$

$$[\text{AsO}_4^{2-}] = \sqrt{\frac{K_{\text{sp}}}{[\text{Cd}^{2+}]^3}} = 4.98E - 6 \text{ M}$$

ii. From the table in part (b), choose the anion that would precipitate the second-most cadmium (II) ion. Repeat the calculation from part c (i) for this anion.

$$K_{\text{sp}} = [\text{Cd}^{2+}][\text{S}^{2-}] = 10^{-27.92}$$

$$[\text{S}^{2-}] = \frac{K_{\text{sp}}}{[\text{Cd}^{2+}]} = 2.70E - 21 \text{ M}$$

The answers to parts c(i) and c(ii) will be switched if the answer to part b was  $\text{CdS}$ . Both will be accepted as long as they correspond with the answer given in part b.

iii. Assuming that the best anion has the least concentration of cadmium (II) ion remaining, do you still agree with your answer for part b? Explain, referencing your answers to part c (i) and c (ii).

Sulfide ion will be the best anion to use, because less is required to bring Cd concentrations to acceptable levels. Either agree or disagree with part (b), depending on the answer to that part.

**(This question continues on the next page.)**

d. What would happen if one of the other waste products also had the ability to precipitate with the added anion from part b? Explain your answer.

The common ion effect would lead to competing precipitation reactions, causing less cadmium to precipitate out because the added anion is reacting with other species as well.

e. Emily likes keeping the waste treatment room at high temperatures while Alex prefers colder temperatures. Assuming that the temperature change is significant, which condition is better for this precipitation reaction to occur? Explain.

$$\Delta G = \Delta H - T\Delta S$$

Precipitation is spontaneous, so  $\Delta G$  is negative. The entropy of the products is lower than its reactants, so  $\Delta S$  is negative. This means that change in enthalpy must be negative, so the reaction is exothermic. By LeChatelier's principle, colder temperatures will promote the precipitation.

Standard Potential (V)	Reduction Half-Reaction
2.87	$\text{F}_2(g) + 2\text{e}^- \longrightarrow 2\text{F}^-(aq)$
1.51	$\text{MnO}_4^-(aq) + 8\text{H}^+(aq) + 5\text{e}^- \longrightarrow \text{Mn}^{2+}(aq) + 4\text{H}_2\text{O}(l)$
1.36	$\text{Cl}_2(g) + 2\text{e}^- \longrightarrow 2\text{Cl}^-(aq)$
1.33	$\text{Cr}_2\text{O}_7^{2-}(aq) + 14\text{H}^+(aq) + 6\text{e}^- \longrightarrow 2\text{Cr}^{3+}(aq) + 7\text{H}_2\text{O}(l)$
1.23	$\text{O}_2(g) + 4\text{H}^+(aq) + 4\text{e}^- \longrightarrow 2\text{H}_2\text{O}(l)$
1.06	$\text{Br}_2(l) + 2\text{e}^- \longrightarrow 2\text{Br}^-(aq)$
0.96	$\text{NO}_3^-(aq) + 4\text{H}^+(aq) + 3\text{e}^- \longrightarrow \text{NO}(g) + \text{H}_2\text{O}(l)$
0.80	$\text{Ag}^+(aq) + \text{e}^- \longrightarrow \text{Ag}(s)$
0.77	$\text{Fe}^{3+}(aq) + \text{e}^- \longrightarrow \text{Fe}^{2+}(aq)$
0.68	$\text{O}_2(g) + 2\text{H}^+(aq) + 2\text{e}^- \longrightarrow \text{H}_2\text{O}_2(aq)$
0.59	$\text{MnO}_4^-(aq) + 2\text{H}_2\text{O}(l) + 3\text{e}^- \longrightarrow \text{MnO}_2(s) + 4\text{OH}^-(aq)$
0.54	$\text{I}_2(s) + 2\text{e}^- \longrightarrow 2\text{I}^-(aq)$
0.40	$\text{O}_2(g) + 2\text{H}_2\text{O}(l) + 4\text{e}^- \longrightarrow 4\text{OH}^-(aq)$
0.34	$\text{Cu}^{2+}(aq) + 2\text{e}^- \longrightarrow \text{Cu}(s)$
0	$2\text{H}^+(aq) + 2\text{e}^- \longrightarrow \text{H}_2(g)$
-0.28	$\text{Ni}^{2+}(aq) + 2\text{e}^- \longrightarrow \text{Ni}(s)$
-0.44	$\text{Fe}^{2+}(aq) + 2\text{e}^- \longrightarrow \text{Fe}(s)$
-0.76	$\text{Zn}^{2+}(aq) + 2\text{e}^- \longrightarrow \text{Zn}(s)$
-0.83	$2\text{H}_2\text{O}(l) + 2\text{e}^- \longrightarrow \text{H}_2(g) + 2\text{OH}^-(aq)$
-1.66	$\text{Al}^{3+}(aq) + 3\text{e}^- \longrightarrow \text{Al}(s)$
-2.71	$\text{Na}^+(aq) + \text{e}^- \longrightarrow \text{Na}(s)$
-3.05	$\text{Li}^+(aq) + \text{e}^- \longrightarrow \text{Li}(s)$

Credit for this table goes to the Department of Chemistry at Georgetown University. It can be found at the following url: <http://bouman.chem.georgetown.edu/S02/lect25/e6a.gif>