CHEM 1032 – Spring 2023 - Challenge Question 9

Which metal is the best choice for a statue?

You are a scientist who has been asked to help an artist select a metal for a statue. Ideally the metal should be able to withstand potential exposure to acid rain. You construct two experiments that involve dipping metals into solutions. For the first experiment, the solutions contain metal ions. In the second experiment, you decide to dip metals in a solution of HNO_3. The tables below summarize your results.

Trial	Metal	Solution Ion	Observation
1	Mg	Al^{3+}	Mg dissolved
2	Al	Fe^{3+}	Al dissolved

Table 1: Experiment 1 Observations

Trial	Metal	Solution Ion	Observation
3	Al	H^+	Bubbles formed, temperature increased, and Al dissolved
4	Cu	H^+	No change observed
5	Fe	H^+	Fe dissolved

Table 2: Experiment 2 Observations

A. Write half reactions for each metal tested. Briefly justify why you selected an oxidation or a reduction half reaction.

Having trouble? Review questions from Chapter 16: 1, 2, and 16.

$Mg \longrightarrow Mg^{2+} + 2e^-$

$Al \longrightarrow Al^{3+} + 3e^-$

$Cu \longrightarrow$ No reaction

$Fe \longrightarrow Fe^{3+} + 3e^-$

The metals dissolved, therefore becoming an ion. Metals become CATIONS, which means they lose e-. Loss of e- is OXIDATION. (OIL RIG)

B. Using the observations, rank the half reactions in Part A from strongest to weakest potential. Explain your rankings.

Having trouble? Review questions from Chapter 16: 37.

Oxidation potentials

$Mg > Al > Fe > Cu$

Since the copper showed no reaction, it was not oxidized to a cation and therefore has the weakest oxidation potential. The Al dissolved in the Fe^{3+} solution indicating it was a stronger reducing agent than the Fe and thus had a greater oxidation potential. Finally, since the Mg was dissolved in the Al^{3+} solution, it was a stronger reducing agent than Al and thus had the greatest oxidation potential.

C. Using your half reactions from Part A, write balanced redox reactions for each Trial conducted.

Having trouble? Review questions from Chapter 16: 3.

(1) $3Mg + 2Al^{3+} \longrightarrow 3Mg^{2+} + 2Al$

(2) $Al + Fe^{3+} \longrightarrow Fe + Al^{3+}$

(3) $2Al + 6H^{+} \longrightarrow 2Al^{3+} + 3H_2$

(4) $Cu + 2H^{+} \longrightarrow Cu^{2+} + H_2$

(5) $2Fe + 6H^{+} \longrightarrow 2Fe^{3+} + 3H_2$

D. Based on your answers from Part A-C, and using a potential table from your textbook, calculate $E°_{cell}$, $\Delta G°$, and K for each Trial conducted. Assume standard conditions.
Having trouble? Review questions from Chapter 16: 27.

$E°_{cell} = E°_{cathode} - E°_{anode}$

$\Delta G = -n \mathcal{F} E°_{cell}$

$E°_{cell} = \frac{0.0592\,V}{n} \log K$

① $E°_{cell} = -1.66\,V - (-2.36\,V)$

$E°_{cell} = 0.70\,V$

$\Delta G° = -6(96{,}485\ C/mol\ e^-)(0.70\,V)$

$\Delta G° = -134.4\,kJ$

$K = 10^{(0.70 \times 6)/0.0592\,V}$

$K = 1 \times 10^{70}$

② $E°_{cell} = -0.04\,V - (-1.66\,V)$

$E°_{cell} = 1.62\,V$

$\Delta G° = -3(96{,}485\ C/mol\ e^-)(1.62\,V)$

$\Delta G° = -466.6\,kJ$

$K = 10^{(1.62 \times 3)/0.0592}$

$K = 1.3 \times 10^{82}$

$10^{82.1}$

③ $E°_{cell} = 0 - (-1.66\,V)$

$E°_{cell} = 1.66\,V$

$\Delta G° = -6(96{,}485\ C/mol\ e^-)(1.66\,V)$

$\Delta G° = -956.2\,kJ$

$K = 10^{(1.66 \times 6)/0.0592}$

$K = 4.8 \times 10^{167}$

④ $\mathcal{E}^{\circ}_{cell} = 0V - (0.34V)$

$\mathcal{E}^{\circ}_{cell} = -0.34V$

$\Delta G^{\circ} = -2(96,485\ C/mol\ e^-)(-0.34V)$

$\Delta G^{\circ} = 65.3\ kJ$

$K = 10^{(-0.34 \times 2)/0.0592}$

$K = 3.2 \times 10^{-12}$

⑤ $\mathcal{E}^{\circ}_{cell} = 0V - (-0.04V)$

$\mathcal{E}^{\circ}_{cell} = 0.04V$

$\Delta G = -6(96,485\ C/mole^-)(0.04V)$

$\Delta G = -23.04\ kJ$

$K = 10^{(0.04 \times 6)/0.0592}$

$K = 1.1 \times 10^{4}$

E. Using specifics from your answers in Parts A-D, make an argument for which metal is the **best** choice for the statue and which metal is the **worst** choice. Be sure to thoroughly explain!

Copper would be the best choice for the statue. As can be seen from the data in Table 2, the copper showed no reaction when exposed to acid indicating that the statue would not react with any acid rain. When looking at the relative rankings copper had the lowest oxidation potential compared to the other statue candidates. The ΔG, Ecell and K all indicate an unfavorable forward reaction with acid.

The worst choice would be magnesium. As seen in the ranking, magnesium has the highest oxidation potential. Despite not having data for acid, we know iron and aluminum are both very susceptible to oxidation in acid. Both iron and aluminum have very favorable ΔG, Ecell and K values from Part C. We can reasonably expect magnesium to have even more favorable values if tested with acid.