Homework #1 - SOLUTIONS

Due: Apr 05, 23:59

1. Read the following article to provide a brief summary (1-2 paragraphs).

D. G. J. Larsson and C. -F. Flach, Antibiotic resistance in the environment. Nature Reviews Microbiology, 20, 257-269, 2022.

avaiable at: https://www.nature.com/articles/s41579-021-00649-x

(30 points)

2. Follow the instructions below to rewrite half reactions given in the lecture note.

1) Sulfide-Sulfate couple (Reaction # I-9): Use bisulfate (HSO_4^-) as the only oxidized sulfur species and hydrogen sulfide (H_2S) as the only reduced sulfur species [may represent highly acidic conditions].

(15 points)

Solution)

I-9: $\frac{1}{8}SO_4^{2-}+\frac{19}{16}H^++e^- = \frac{1}{16}H_2S+\frac{1}{16}HS^-+\frac{1}{2}H_2O$

+) $\frac{1}{8}HSO_4^- = \frac{1}{8}SO_4^{2-}+\frac{1}{8}H^+$

+) $\frac{1}{16}HS^-+\frac{1}{16}H^+ = \frac{1}{16}H_2S$

$\frac{1}{8}HSO_4^-+\frac{9}{8}H^++e^- = \frac{1}{8}H_2S+\frac{1}{2}H_2O$

2) Carbon dioxide-Glutamate couple (Reaction # O-8): Use bicarbonate (HCO_3^-) as the only oxidized carbon species, free ammonia (NH_3) and

ammonium ion (NH_4^+) at a molar ratio of 1:1 as reduced nitrogen species, and the deprotonated form for glutamate [may represent a condition of pH = pK_a of ammonia].

(15 points)

Solution)

O-8:

$$\frac{1}{6}CO_2 + \frac{1}{9}HCO_3^- + \frac{1}{18}NH_4^+ + H^+ + e^- = \frac{1}{18}COOHCH_2CH_2CHNH_2COO^- + \frac{4}{9}H_2O$$

+) $$\frac{1}{6}HCO_3^- + \frac{1}{6}H^+ = \frac{1}{6}H_2O + \frac{1}{6}CO_2$$

+) $$\frac{1}{36}NH_3 + \frac{1}{36}H^+ = \frac{1}{36}NH_4^+$$

$$\frac{5}{18}HCO_3^- + \frac{1}{36}NH_4^+ + \frac{1}{36}NH_3 + \frac{43}{36}H^+ + e^- = \frac{1}{18}COOHCH_2CH_2CHNH_2COO^- + \frac{11}{18}H_2O$$

3. You want to develop an eco-friendly and cost-effective process for removal of nitrate (NO_3^-) from groundwater. Your plan is to supply molasses, a byproduct of sugar manufacturing, as an e^- donor to enhance denitrification in groundwater. Assuming that the molecular formular of molasses can be represented by $C_{12}H_{22}O_{11}$ (same as that for sugar), answer the following.

1) Write the electron donor half reaction, R_d, in an electron-equivalent form. Use HCO_3^- as an only form of an oxidized carbon species. (20 points)

Solution)

Step 1: $HCO_3^- = C_{12}H_{22}O_{11}$

Step 2: $HCO_3^- + H_2O + e^- = C_{12}H_{22}O_{11}$

Step 3: $12HCO_3^- + H_2O + e^- = C_{12}H_{22}O_{11}$

Step 4: $12HCO_3^- + e^- = C_{12}H_{22}O_{11} + 25H_2O$

Step 5: $12HCO_3^- + 60H^+ + e^- = C_{12}H_{22}O_{11} + 25H_2O$

Step 6: $12HCO_3^- + 60H^+ + 48e^- = C_{12}H_{22}O_{11} + 25H_2O$

Step 7: $\frac{1}{4}HCO_3^- + \frac{5}{4}H^+ + e^- = \frac{1}{48}C_{12}H_{22}O_{11} + \frac{25}{48}H_2O$

2) Write the energy reaction, R_e, in an electron-equivalent form. How much grams of molasses are needed per g of NO_3-N consumed for the energy reaction? (20 points)

Solution)

R_a (I-7): $\frac{1}{5}NO_3^- + \frac{6}{5}H^+ + e^- = \frac{1}{10}N_2 + \frac{3}{5}H_2O$

$-R_d$: $\frac{1}{48}C_{12}H_{22}O_{11} + \frac{25}{48}H_2O = \frac{1}{4}HCO_3^- + \frac{5}{4}H^+ + e^-$

R_e: $\frac{1}{48}C_{12}H_{22}O_{11} + \frac{1}{5}NO_3^- = \frac{1}{10}N_2 + \frac{1}{4}HCO_3^- + \frac{1}{20}H^+ + \frac{19}{240}H_2O$

Molasses molecular weight: $12 \times 12 + 1 \times 22 + 16 \times 11 = 342$

g molasses needed/g NO_3-N consumed = $\dfrac{\frac{1}{48}\,mole \times 342\ g\ molasses/mole}{\frac{1}{5}\,mole \times 14\ g\ NO_3 - N/mole} = 2.54$

3) Write the cell formation half reaction, R_c, in an electron-equivalent form. Use the cell formula of $C_5H_7O_2N$ and NO_3^- as a source of nitrogen (not NH_4^+). Also use HCO_3^- as an only form of oxidized carbon species. (20 points)

Solution)

Step 1: $HCO_3^- = C_5H_7O_2N$

Step 2: $HCO_3^- + NO_3^- + H_2O + e^- = C_5H_7O_2N$

Step 3: $5HCO_3^- + NO_3^- + H_2O + e^- = C_5H_7O_2N$

Step 4: $5HCO_3^- + NO_3^- + e^- = C_5H_7O_2N + 16H_2O$

Step 5: $5HCO_3^- + NO_3^- + 34H^+ + e^- = C_5H_7O_2N + 16H_2O$

Step 6: $5HCO_3^- + NO_3^- + 34H^+ + 28e^- = C_5H_7O_2N + 16H_2O$

Step 7: $\frac{5}{28}HCO_3^- + \frac{1}{28}NO_3^- + \frac{17}{14}H^+ + e^- = \frac{1}{28}C_5H_7O_2N + \frac{4}{7}H_2O$

4) Write the overall cell synthesis reaction, R_s, in an electron-equivalent form. Use the R_d derived from 1) and the R_c derived from 3). How much grams of molasses are needed per g of NO_3-N consumed for the cell synthesis reaction? (20 points)

Solution)

R_c: $\frac{5}{28}HCO_3^- + \frac{1}{28}NO_3^- + \frac{17}{14}H^+ + e^- = \frac{1}{28}C_5H_7O_2N + \frac{4}{7}H_2O$

$-R_d$: $\frac{1}{48}C_{12}H_{22}O_{11} + \frac{25}{48}H_2O = \frac{1}{4}HCO_3^- + \frac{5}{4}H^+ + e^-$

R_s: $\underline{\frac{1}{48}C_{12}H_{22}O_{11} + \frac{1}{28}NO_3^- = \frac{1}{28}C_5H_7O_2N + \frac{1}{14}HCO_3^- + \frac{1}{28}H^+ + \frac{17}{336}H_2O}$

g molasses needed/g NO_3-N consumed = $\underline{\frac{\frac{1}{48}\,mole \times 342\ g\ molasses/mole}{\frac{1}{28}\,mole \times 14\ g\ NO_3 - N/mole} = 14.25}$

5) From the calculations you did for 2) and 4), which growth state do you think is more favorable for efficient use of molasses? (A) a rapidly growing state or (B) a slowly growing state? Briefly describe the reason for your selection. (10 points)

Solution)

<u>(B)</u>

At a slowly growing state, the f_e value is greater, meaning that the overall stoichiometry is more weighted to R_e than it is for a slowly growing state. Therefore, at a slowly growing state the amount of molasses needed to remove a gram of NO_3-N will be greater (more efficient use of molasses).