

GEORGIA INSTITUTE OF TECHNOLOGY
School of Civil & Environmental Engineering
CEE 2300 – Environmental Engineering Principles

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EXAM 1 – SOLUTIONS

1. (25 points) Briefly explain/answer the following:

1-a) The meaning of “the tragedy of the commons”; provide an example related to environmental degradation/pollution.

Meaning: The use of common resources leading to overexploitation/degradation.

Examples: CO₂ emissions to air; pollutant discharge in a river

1-b) What were/are the environmental and socio-economic impacts of the April 20, 2010 BP oil spill?

Marine pollution leading to:

- depletion of dissolved oxygen
- air toxics directly (e.g., methane) and indirectly due to burning (e.g., CO₂)
- direct toxicity and death of fish, wildlife, etc. due to the oil and toxicity indirectly due to dispersants used to disperse oil
- coastline and wetland contamination
- economic damage (e.g., fishing, tourism, etc.)

1-c) When was the US Environmental Protection Agency (US EPA) established, who was the US President at that time, and what was/were the purpose/reasons for the establishment of the US EPA?

When: December 2, 1970; Who: Richard Nixon

Purpose/reasons: to consolidate in one agency a variety of federal research, monitoring, standard-setting and enforcement activities to ensure environmental protection.

1-d) Globally speaking, what are the environmental and social consequences of large-scale biofuel production? List at least four (4) such impacts.

- land clearance and conversion (loss of natural habitats, soil erosion, etc.)
- introduction of potentially invasive species
- overuse of water and nutrients
- effects on the global food market, especially meat
- purchase or leasing of land by foreign investors, typically in developing and sometimes in semi-arid countries.

1-e) Explain why in the last two decades the CO₂ emissions due to consumption of goods and services in developed countries exceeded the CO₂ emissions due to production of goods and services.

It is the direct result of increased imports of goods and services from developing countries combined with the decrease in manufacturing in the developed countries. The opposite is true in the developing countries, i.e., CO₂ emissions due to production of goods and services exceeded the CO₂ emissions due to consumption of goods and services.

2. (25 points) Methane (CH₄) can be produced by microorganisms by the reduction of CO₂ by molecular hydrogen (H₂) as follows:

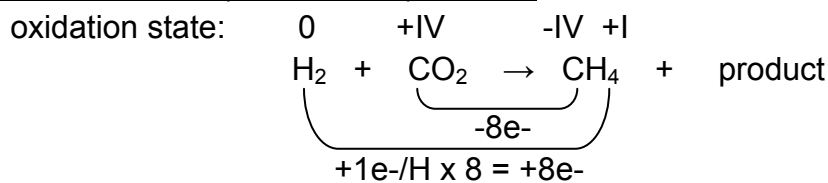


A. Balance the above equation and name the product on the right.

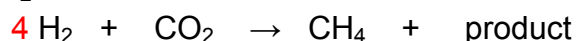
B. If H₂ and CO₂ are supplied in a gas mixture of N₂, H₂, and CO₂ at a total pressure of 1 atm and in which the partial pressure of N₂ (i.e., p_{N_2}) is 0.5, calculate the partial pressures of H₂ and CO₂ according to the balanced stoichiometric equation you completed in part A, above.

Solution:

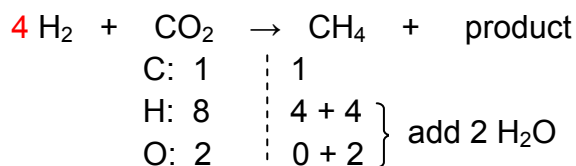
A-1) Oxidation/reduction (i.e., electron) balance:



Thus, there are 8 H or 4 H₂



A-2) Atom balance:



Thus, complete equation: $4 \text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O}$ (eqn. 1)

B) According to the stoichiometric equation 1, above, and given that the p_{N_2} in the gas mixture is equal to 0.5, the following equations apply:

$$p_{\text{N}_2} + p_{\text{H}_2} + p_{\text{CO}_2} = 1 \quad (\text{eqn. 2}) \quad \text{or} \quad p_{\text{H}_2} + p_{\text{CO}_2} = 1 - p_{\text{N}_2} = 1 - 0.5$$

$$p_{\text{H}_2} + p_{\text{CO}_2} = 0.5 \quad (\text{eqn. 3})$$

$$p_{\text{H}_2} = 4 p_{\text{CO}_2} \quad (\text{eqn. 4})$$

Substitute p_{H_2} from eqn. 4 into eqn. 3: $4 p_{\text{CO}_2} + p_{\text{CO}_2} = 0.5 = 5 p_{\text{CO}_2}$

$$p_{\text{CO}_2} = 0.5/5 = 0.1$$

$$\text{From eqn. 4: } p_{\text{H}_2} = 4 p_{\text{CO}_2} = 4 (0.1) = 0.4$$

Thus: $p_{\text{CO}_2} = 0.1$ and $p_{\text{H}_2} = 0.4$

Check: $p_{\text{N}_2} + p_{\text{H}_2} + p_{\text{CO}_2} = 0.5 + 0.4 + 0.1 = 1$

3. (25 points) A wastewater with nitrogen in the form of dissolved ammonia (NH_3) and ammonium (NH_4^+) has a total nitrogen (i.e., $[\text{NH}_4^+] + [\text{NH}_3]$) concentration of $7.1 \times 10^{-4} \text{ mol/L}$. The Henry's constant (K_H) at 25°C is $57 \text{ mol/L} \cdot \text{atm}$. The equilibrium equation is:



The fraction of nitrogen in the ammonia form, which is strippable, as a function of pH is given by the following equation:

$$\text{NH}_3 \text{ fraction} = \frac{[\text{NH}_3]}{[\text{NH}_3] + [\text{NH}_4^+]} = \frac{1}{1 + 10^{(9.26 - \text{pH})}}$$

The wastewater pH is raised to 10 and the incoming air used for stripping of ammonia out of the wastewater has an ammonia partial pressure of 5×10^{-10} .

A. What would be the equilibrium concentration of total nitrogen (i.e., $[\text{NH}_4^+] + [\text{NH}_3]$) in the wastewater after air stripping? Assume equilibrium between air and wastewater and total gas pressure equal to 1 atm.

B. Under the above conditions, what percentage of the total wastewater nitrogen would be removed?

Solution:

A. Total nitrogen concentration after air stripping

In this case, going from dissolved NH_3 to gaseous NH_3 via stripping, the Henry's law is written as follows:

$$[\text{NH}_3]_{\text{aq}} = K_H \cdot p_{\text{NH}_3, \text{g}} \quad P_T \quad (\text{eqn. 1})$$

Thus, at equilibrium: $[\text{NH}_3]_{\text{aq}} = 57 \text{ mol/L} \cdot \text{atm} \times 5 \times 10^{-10} \times 1 \text{ atm} = 2.85 \times 10^{-8} \text{ mol/L}$

At pH = 10, the NH_3 fraction is: $[\text{NH}_3]/([\text{NH}_4^+] + [\text{NH}_3]) = 1/[1 + 10^{(9.26-10)}] = 0.846$

Thus, $[\text{NH}_4^+] + [\text{NH}_3] = [\text{NH}_3]/0.846 = (2.85 \times 10^{-8} \text{ mol/L})/0.846 = 3.37 \times 10^{-8} \text{ mol/L}$

B. Total nitrogen removal

Removal, % = $[(\text{Total } N_{\text{in}} - \text{Total } N_{\text{left}})/\text{Total } N_{\text{in}}] \times 100 = [1 - (\text{Total } N_{\text{left}}/\text{Total } N_{\text{in}})] \times 100 =$

$= \{1 - [(3.37 \times 10^{-8} \text{ mol/L})/(7.1 \times 10^{-4} \text{ mol/L})]\} \times 100 = 99.995\%$

4. (25 points) Ozone (O_3) is a highly reactive oxidant used for the disinfection of drinking water. It is found that the ozone destruction in water follows first-order kinetics with respect to the aqueous ozone concentration, such that its concentration decreases by 50% in 12 minutes (i.e., $t_{1/2} = 12$ minutes). Estimate the initial ozone concentration in mg/L necessary to treat water for 40 minutes and result in a residual ozone concentration of 1 mg/L.

Solution:

For the ozone destruction, the first-order rate equation is: $dO_3/dt = -k O_3$ (eqn. 1)

and its solution is: $[O_3]_t = [O_3]_0 \exp(-k t)$ (eqn. 2)

Based on the problem statement, calculate the value of the rate constant k at $t = t_{1/2} = 12$ min:

$$0.5 [O_3]_0 = [O_3]_0 \exp(-k t_{1/2}) \quad \text{and then} \quad t_{1/2} = -\ln 0.5/k = 0.693/k$$

$$k = 0.693/t_{1/2} = 0.693/12 \text{ min} = 0.0578 \text{ min}^{-1}$$

Calculate the initial ozone concentration:

From eqn. 2, $[O_3]_0 = [O_3]_t / \exp(-k t) = [O_3]_{40 \text{ min}} / \exp(-k t) =$

$$= (1 \text{ mg/L}) / \exp(-0.0578 \text{ min}^{-1} 40 \text{ min}) = 10 \text{ mg/L}$$

