Worksheet 5

February 2nd, 2022

Collaborations are encouraged and students must report all collaborators on each assignment. All external sources (websites, books) must be cited. An *extra credit* (*EC*) problem will be available per assignment. Please submit a completed homework on-time to receive *EC* and no partial *EC* (all parts must be correct) will be given out. Additional problems are listed at the end of each assignment. This week's assignment is due *Tuesday, Feb 8th at 10:00am.*

Enthalpy ΔH, Entropy ΔS, and Free Energy ΔG

1. (2 pts) Determine ΔS_{sys}, ΔS_{surr}, and ΔS_{tot} for the following processes of 1.48 mols of ideal gas molecules from 13.17 atm and 0.447 atm and 1.29 L at 350K. Report results to 3 significant figures.

(a) A reversible isothermal expansion

(b) A isothermal irreversible free expansion

2. (2 pts) Determine the change in entropy if 2 gallons of water at 93°C is added to 1.25 gal of water at 25°C. Report results to 3 significant figures.

3. (4 pts) Diethyl zinc is a highly reactive compound when it comes into contact with oxygen molecules to form zinc oxide, carbon dioxide, and water at 298K. Determine the following and report results to 3 significant figures.

(a) Write a balanced chemical equation including states.

(b) Calculate the enthalpy of reaction and entropy change.

(c) Determine whether this reaction is exothermic or endothermic. Is this reaction spontaneous at room temperatue?

4. (4 pts) Acetic acid, $CH_3COOH(l)$, could be produced from the reactions of methanol with carbon monoxide, the oxidation of ethanol, or the reaction of carbon dioxide with methane.

(a) Write balanced chemical equations including states for each process.

(b) Compute the enthalpy of reaction and change in entropy for each process. Report the results to 4 significant figures.

(c) Determine which process would be the easiest to produce acetic acid. Justify your choice.

5. (8 pts) **Carnot Cycle** The steam engine played an important role during the industrial revolution. A French engineer Nicolas Léonard Sadi Carnot investigated the efficiency of the heat engine. For an ideal gas, he developed the most efficient engine known as the Carnot cycle, see Fig. 1. The cycle consists of four processes: (i) Reversible isothermal expansion, (ii)Reversible adiabatic expansion, (iii) Reversible isothermal compression, and (iv) Reversible adiabatic compression.

(a) Determine the heat Q, the work W, the entropy ΔS, and the internal energy ΔU at each step of the Carnot cylce. Define all variables.

(b) What is the total W, Q, ΔS, and ΔU for 1 cycle ($1 \to 2 \to 3 \to 4 \to 1$)?

(c) Using part b), calculate the efficiency of this engine.

(d) You are operating a Carnot engine with a heat reservoir of 500K and heat sink of 298K. What is the efficiency of your engine?

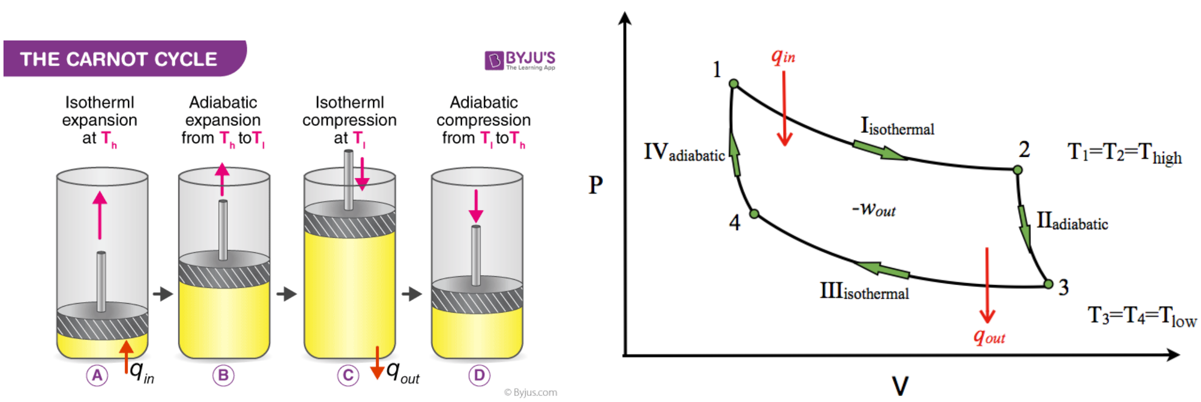

Figure 1: Illustration of the carnot cycle and PV diagram.

Gibbs Free Energy

6. (7 pts) *Extra Credit:* In biology, biochemical processes are often unfavorable and requires coupling them to a favorable reaction. For example, adenosine triphosphate (ATP) is the primary energy source for living cells and drives vital nonspontaneous chemical reactions. However, the formation of ATP is an unfavorable process. Cells use oxidative phosphorylation to generate ATP at pH = 7:

1. $ADP^{3-}(aq) + HPO_4^{2-}(aq) + H^+(aq) \rightarrow ATP^{4-}(aq) + H_2O(l)$ $\Delta G = +30.5\text{kJ}$
2. $NADH(aq) \rightarrow NAD^+(aq) + H^+(aq) + 2\ e^-$ $\Delta G = -158.3\text{kJ}$
3. $\frac{1}{2}\ O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O(l)$ $\Delta G = -61.9\text{kJ}$

Report all results to 3 significant figures.

(a) The oxidative phosphorylation is highly efficient.[1] Assuming 90% efficiency, what amount (in moles) of ATP could be formed if 4.50 mol NADH were used to generate ATP?

(b) Since only 90% of the energy goes into synthesizing ATP, what happened to the remaining energy?

(c) In bacteria, acetyl phosphate plays an important role to regulate metabolic functions. When there is a lack of acetate, bacteria hydrolyze acetyl phosphate to release acetate and continue the Kreb Cycle. This reaction has $\Delta G = -41\text{kJ/mol}$ at pH = 7. To replenish acetyl phosphate, what is the minimum amount of ATP molcules (in moles) that would have to be hydrolyzed to form 1.37 mol acetyl phosphate molecules by phosphorylation of acetic acid?

Optional Additional Problems: Ch. 18 - odd problems 43 - 67