YILDIZ TECHNICAL UNIVERSITY
FACULTY OF ELECTRICAL AND ELECTRONICS ENGINEERING
DEPARTMENT OF BIOMEDICAL ENGINEERING

BME 3711 – BIOTHERMODYNAMICS
2020 – FALL

MIDTERM

1. State whether the following phrases pertain to (A) the First Law of Thermodynamics, (B) the Second Law, (C) both the First and Second Law, or (D) neither of the Laws. Write A, B, C or D only. (10 points)

(i) For an isolated system the total energy is constant. **A**

(ii) It is concerned with the transfer of heat and the performance of work. **A**

(iii) It indicates whether a process will proceed quickly or slowly. **D**

(iv) It predicts the direction of a reaction. **B**

(v) It says that a quantity of heat cannot be converted into an equivalent amount of work. **B**

(vi) It is a statement of the conservation of energy. **A**

(vii) It says that the capacity to do work decreases as the organization of a system becomes more uniform. **C**

(viii) It says that the capacity to do work decreases as objects come to the same temperature. **A**

(ix) Every energy transfer that takes place reduce the amount of usable energy available to do work. **B**

(x) At rest organisms have a basal metabolic rate. **B**

2. Write two distinct efforts of human kind towards inventing an engine that violates a) the first law of thermodynamics and b) the second law of thermodynamics. **Explain** your reasoning giving information about the laws. (10 points)

a) Perpetual Motion Machines: They aim to create energy without any input. However, the first law states that energy can not be destroyed nor created.

b) Heat Engines with 100% efficiency: They aim to convert the heat energy into work with a 100% efficiency without involving a cold sink to dissipate the energy as waste. However, it is against the second law of thermodynamics sice it states that the entropy of the universe will always increase.

3. Undernutrition may arise due to reduced dietary intake or reduced absorption of macro- and/or micronutrients from the intestine. It causes reduced muscle mass, fatigue and hypothermia. **Discuss** undernutrition and related complications in terms of the First and Second Laws of thermodynamics. (10 points)

Organisms need energy to maintain life. This energy should come from a source according to the energy conservation law (1st law). The source of this energy for the heterotrophs is the food they intake. When food intake is low, organisms first burn stored carbohydrates and fats. If undernutrition continues for a long time and there is still not enough nutrient intake, then the proteins in our muscles will be catabolized resulting in reduced muscle mass. The body will also slow down its metabolism, saving the energy for the urgent metabolic events. Energy cannot be supplied for the events that are not that urgent. This makes the organism to feel fatigue. Body temperature maintanence also requires energy usage and it uses heat dissipated as a result of metabolic events. When there is not enough energy available, homeostasis cannot be

maintained and hypothermia may be seen. The dissipation of energy as heat to the environment increases the entropy of the universe. When it decrease, organisms come closer to an equilibrium with their surroundings which is a life threatening event.

4. Without performing a calculation, **predict** whether the standard entropies of the following reactions are positive or negative: (8 points)

a) Ala–Ser–Thr–Lys–Gly–Arg–Ser → Ala–Ser–Thr–Lys + Gly–Arg **(+)**

b) $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$ **(-)**

c) $4\ C_2H_5O_2N(s) + 9\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(l) + 2\ N_2(g)$ **(+)**

d) $NaNO_3(s) \longrightarrow Na^+(aq) + NO^{-3}(aq)$ **(+)**

5. The protein myoglobin unfolds at a transition temperature of 69.0°C, and the standard enthalpy of transition is 625 kJ mol^{-1}. Calculate the entropy of unfolding of myoglobin at 25.0°C, given that the difference in the constant-pressure heat capacities upon unfolding is 6.28 kJ K^{-1} mol^{-1} and can be assumed to be independent of temperature.

Hint: Imagine that the transition at 25.0°C occurs in three steps: (i) heating of the folded protein from 25.0°C to the transition temperature, (ii) unfolding at the transition temperature, and (iii) cooling of the unfolded protein to 25.0°C. (15 points)

$T_i = 25 + 273.15 = 298.15 \text{ K}$

$T_{trs} = 69 + 273.15 = 342.15 \text{ K}$

$\Delta_{trs} H = 625 \text{ kj/mol}$

$\Delta C_p = 6.28 \text{ kj/Kmol}$

$$\Delta S_1 = C_{p1} \cdot \ln \frac{T_{trs}}{T_i} = C_{p1} \cdot \ln \frac{342.15}{298.15}$$

$$\Delta S_1 = 0.14\, C_{p1}$$

$$\Delta S_{trs} = \frac{\Delta_{trs} H}{T_{trs}} = \frac{625 \text{ kj/mol}}{342.15 \text{ K}}$$

$$\Delta S_{trs} = 1.83 \text{ kj/mol K}$$

$$\Delta S_2 = C_{p2} \ln \frac{T_i}{T_{trs}} = C_{p2} \cdot \ln \frac{298.15}{342.15}$$

$$\Delta S_2 = -0{,}14\, C_{p2}$$

$$\Delta S_{TOTAL} = \Delta S_1 + \Delta S_{TRS} + \Delta S_2$$

$$= 0{,}14\, C_{p1} + 1.83 \text{ kj/mol K} - 0{,}14\, C_{p2}$$

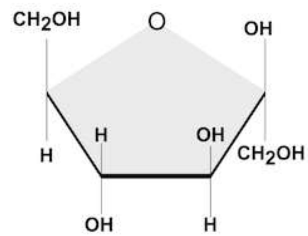
$$= 0{,}14\,(C_{p1} - C_{p2}) + 1{,}83 \text{ kj/mol K}$$

$$= 0.14 \cdot 6.28 \text{ kj/mol K} + 1{,}83 \text{ kj/mol K}$$

$$= 2.70 \text{ kj/Kmol}$$

6. Structure and the reaction of formation of fructose from CO_2 and H_2O is given below :

$$6\ CO_2\ (g) + 6\ H_2O\ (l) \rightarrow C_6H_{12}O_6\ (s) + 6\ O_2\ (g)$$



FRUCTOSE

a) Estimate the enthalpy of formation of fructose using the bond ethalpies. (Use tables given) (10 points)

b) Estimate the enthalpy of formation of fructose using standard enthalpy of formation of the reactants and products. (ΔH_f (CO_2) = -393.51 kJ/mol, ΔH_f (H_2O) = -285.83) (7 points)

c) Estimate the standard enthalpy of combustion of fructose without performing any calculation. (3 points)

I admit that this question is confusing and not clear. I will give a clearer version of it to you as a homework. I will mark the homework on 20 points and add this grade to your midterm grades.

7. A carnot engine operates between two reservoirs of 100 K and 300 K. The system contains 2.5 mol ideal Argon gas. Based on the pressure-volume diagram of a Carnot cycle calculate the following terms given that $V_1 = 10\ m^3$, $V_2 = 100\ m^3$, $V_3 = 120\ m^3$, $V_4 = 12\ m^3$. Use the formula $W = nC(T_f - T_i)$ for the adiabatic processes. [$R = 8.314\ J\ mol^{-1}\ K^{-1}$, $C_{Ar} = 20.79\ J\ mol^{-1}\ K^{-1}$ (Heat capacity of Argon is constant over the temperature and volume changes)] (15 points)

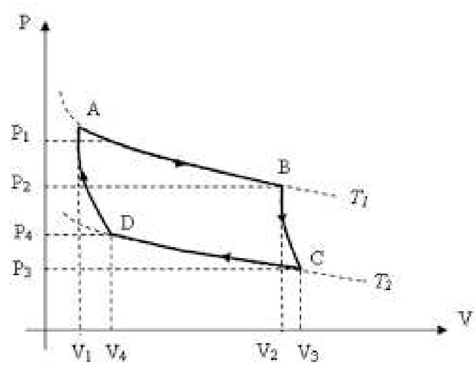
a) $W_{A \to B}$

b) $W_{B \to C}$

c) $W_{C \to D}$

d) $W_{D \to A}$

e) W_{total}. What does it mean?



$V_1 = 10 m^3$

$V_2 = 100 m^3$

$V_3 = 120 m^3$

$V_4 = 12 m^3$

$n = 2{,}5$ mol

$T_1 = 300$ K

$T_2 = 100$ K

$R = 8{,}314$ J/mol K

$C_{Ar} = 20.79$ J/mol K

$$W_{A \to B} = -nRT_1 \ln \frac{V_2}{V_1}$$

$$W_{A \to B} = -2{,}5 \text{ mol} \times 8{,}314 \text{ J/mol K} \cdot 300 \text{ K} \ln \frac{100 m^3}{10 m^3}$$

$$W_{A \to B} = -14.36 \text{ kj}$$

$$W_{B \to C} = n . C . (T_2 - T_1)$$

$$W_{B \to C} = 2{,}5 \text{ mol} \times 20.79 \text{ J/mol K} \cdot (100 - 300)$$

$$= -10.39 \text{ kj}$$

$$W_{C \to D} = -nRT_2 \ln \frac{V_4}{V_3}$$

$$W_{C \to D} = -2{,}5 \text{ mol} \times 8{,}314 \text{ J/mol K} \cdot 100 \text{ K} . \ln \frac{12 m^3}{120 m^3}$$

$$W_{C \to D} = 4{,}79 \text{ kj}$$

$$W_{D \to A} = n . C . (T_1 - T_2)$$

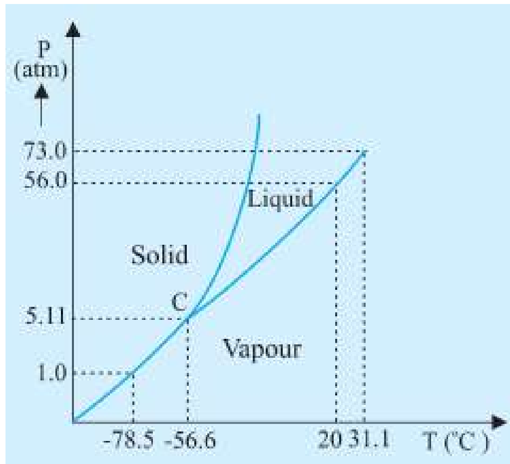
$$W_{D \to A} = 2.5 . 20.79 . 200$$

$$= 10.39 \text{ kj}$$

$$W_{TOTAL} = W_{A \to B} + W_{B \to C} + W_{C \to D} + W_{D \to A} = -9{,}57 \text{ kj}$$

Cycle produces energy to do work

8. Answer the following questions based on the below P-T phase diagram of carbon dioxide:



(a) Which temperature is the triple point for the CO_2. What happens at this temperature? (3 points)

b) What is the effect of decrease of pressure on the fusion and boiling point of CO_2? (3 points)

(c) What are the critical temperature and pressure for CO_2? What is their significance? (3 points)

(d) Is CO_2 solid, liquid or gas at (i) −70°C under 1 atm, (ii) −60°C under 10 atm, (iii) 15°C under 56 atm? (1 point each)

a) T_{tp} = -56.6 °C

At 56.6 °C under 5.11 atm pressure CO2 exists in solid, liquid and gas phase.

b) Fusion point decreases.

Boiling point decreases

c) Tc = 31.1 °C

Pc = 73.0 atm

After critical point CO_2 cannot exist in liquid form. It behaves like a supercritical fluid.

d) i) vapor (gas)

ii) solid

iii) liquid