

Key

Chem 111000-2 Fall 2021 Final Review

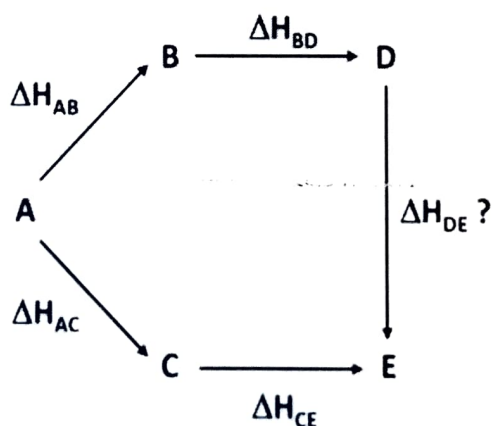
The following questions cover content from the entire quarter but in no way represent everything that you can be tested on. These questions should be supplemented with understanding of all homework problems, discussion worksheet problems, as well as the 3 midterms. Furthermore, the only additional material that should be needed to complete these questions is a calculator, ruler, and a periodic table (in addition to the constants/values provided on this front page).

Some useful constants:

1. Boltzmann Constant $k = 1.38 \times 10^{-23}$ J/K
2. Avogadro Number $N_A = 6.02 \times 10^{23}$
3. Gas Constant $R = 8.314$ J / (mol K) = 0.0821 (1 atm)/(mol K) = 2.00 cal/(mol K)
4. Specific Heat Capacity of Water $c_{water} = 1.0$ cal/(g °C)
5. Specific Heat Capacity of Ice $c_{ice} = 0.5$ cal/(g °C)
6. Specific Heat of Fusion (water) $\Delta H_{fus} = 80.0$ cal/g
7. Specific Heat of Vaporization (water) $\Delta H_{vap} = 540$ cal/g

1. For the following questions, select the ONE correct answer for each multiple choice question.
- (a) Which of the following contains the smallest percent of oxygen by mass?
- A) 1.02 g of water (H_2O)
 - B) 5.21 g of hydrogen peroxide (H_2O_2)
 - C) 1.40 g of ethanol ($\text{C}_2\text{H}_4\text{OH}$)
 - D) 1.67 g of liquefied sugar ($\text{C}_6\text{H}_{12}\text{O}_6$)
 - E) 8.27 g of vinegar ($\text{C}_2\text{H}_4\text{O}_2$)
- (b) Which of the following is closest to the mass of an oxygen atom?
- A) 2.66×10^{-23} grams
 - B) 5.32×10^{-23} grams
 - C) 16 grams
 - D) 32 grams
 - E) 9.63×10^{24} grams
- (c) The equation $\text{Na} + \text{energy} \longrightarrow \text{Na}^+ + \text{e}^-$ best represents which of the following?
- A) non-metal character
 - B) electron affinity
 - C) ionization energy
 - D) electronegativity
 - E) effective nuclear charge
- (d) Which of the following statements is true?
- A) Two objects will always reach thermal equilibrium at a temperature exactly halfway between the starting temperatures of the two objects.
 - B) Work and heat are both state functions.
 - C) Energy cannot be created, destroyed, or change forms.
 - D) Thermal energy is based on the position or composition of the chemical involved.
 - E) If equal amounts of heat energy are transferred to two objects, the objects with the higher specific heat capacity will experience a smaller change in temperature.

- (e) In which of the following reactions would gases behave most ideally?
- A) At low altitudes in an extremely cold climate.
 - B) At high altitudes in an extremely cold climate.
 - C) At low altitudes in an extremely hot climate.
 - D) At high altitudes in an extremely hot climate.
 - E) At sea level in an average-temperature climate.
- (f) Which of the following pairs would you expect to form the strongest ionic bond?
- A) Cobalt and silicon
 - B) Chromium and selenium
 - C) Calcium and sodium
 - D) Chlorine and strontium
 - E) Carbon and sulfur
- (g) In the reaction cycle below, the enthalpies are known for four of the five reactions (for example, the enthalpy for the reaction $A \rightarrow B$ is ΔH_{AB}). Which of the following is equal to the reaction enthalpy for $D \rightarrow E$?



- A) $\Delta H_{AB} + \Delta H_{AC} + \Delta H_{BD} + \Delta H_{CE}$
- B) $\Delta H_{AB} + \Delta H_{AC} - \Delta H_{BD} + \Delta H_{CE}$
- C) $-\Delta H_{AB} + \Delta H_{AC} - \Delta H_{BD} + \Delta H_{CE}$
- D) $-\Delta H_{AB} - \Delta H_{AC} - \Delta H_{BD} - \Delta H_{CE}$
- E) $\Delta H_{AB} - \Delta H_{AC} + \Delta H_{BD} - \Delta H_{CE}$

2. How many electrons are in the valence shell of each atom?

- (a) Carbon 4
 (b) Nitrogen 5
 (c) Chlorine 7
 (d) Aluminum 3

3. Which statements are true about resonance contribution structures?

- (a) All contributing structures must have the same number of valence electrons. *True*
 (b) All contributing structures must have the same arrangement of atoms. *True*
 (c) All atoms in a contributing structure must have complete valence shells. *False*
 (d) All bond angles in sets of contributing structures must be the same. *True*

4. Cyanic acid, HOCN, and isocyanic acid, HNCO, dissolve in water to yield the same anion on loss of H^+ .

(a) Write a Lewis structure for cyanic acid.



(b) Write a Lewis structure for isocyanic acid.

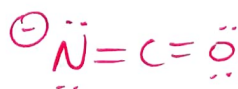


(c) Account for the fact that each acid gives the same anion on loss of H^+ .

Cyanic Acid Anion



Isocyanic Acid Anion



Same resonance
Structures

\Rightarrow same anion

5. A certain sample of solid aluminum oxide (Al_2O_3) contains 10.0 grams of aluminum. How many grams of oxygen are present in this same sample?

$$10.0 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \times \frac{3 \text{ mol O}}{2 \text{ mol Al}} \times \frac{16.0 \text{ g O}}{1 \text{ mol O}} = \boxed{8.89 \text{ g Oxygen}}$$

6. Answer the following questions about the element tellurium, Te.

- (a) Samples of natural tellurium contain eight different stable isotopes of the element. In terms of atomic structure, explain what these isotopes have in common and how they differ.

In common: same # of protons (not necessarily same # e^-)

Differ: number of neutrons (also in their mass)

- (b) How would you expect the electron affinity of tellurium to compare with that of sulfur and with that of xenon? In your answer, define electron affinity and briefly explain your comparisons.

Te has lower EA than S because larger \therefore has better shielding
Te has higher EA than Xe since noble gases are unreactive

7. A 0.7549 gram sample of an oxygen-containing hydrocarbon called wampetin burns in oxygen gas to produce 1.9061 grams of carbon dioxide gas and 0.3370 grams of gaseous water.

(a) Determine the empirical formula of wampetin.

$$1.9061 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.0 \text{ g}} \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.04332 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.5203 \text{ g C}$$

$$0.3370 \text{ g H}_2\text{O} \times \frac{1 \text{ mole H}_2\text{O}}{18.0 \text{ g}} \times \frac{2 \text{ mol H}}{1 \text{ mole H}_2\text{O}} = 0.03744 \text{ mol H} \times \frac{1.01 \text{ g H}}{1 \text{ mol H}} = 0.03782 \text{ g H}$$

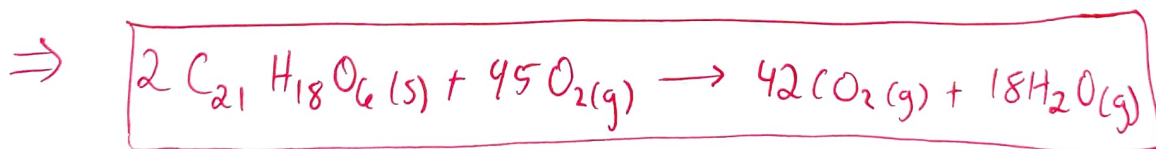
$$0.07549 \text{ g sample} - 0.5203 \text{ g C} - 0.03782 \text{ g H} = 0.19678 \text{ g O} \times \frac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.01230 \text{ mol O}$$

$$\frac{0.04332 \text{ mol C}}{0.01230} = 3.5 \text{ mol C/mol O} \quad \frac{0.03744 \text{ mol H}}{0.01230 \text{ mol O}} = 3 \text{ mol H/mol O}$$

$$\Rightarrow \text{multiply by 2} \Rightarrow \boxed{\text{C}_7\text{H}_6\text{O}_2}$$

(b) Write a balance molecular equation for the combustion of this solid hydrocarbon, which is known to have a molar mass somewhere in the range of 350 g/mol - 400 g/mol.

Molar mass of $\text{C}_7\text{H}_6\text{O}_2 = 122 \text{ g/mol}$. Triple this to get correct molecular formula: $\text{C}_{21}\text{H}_{18}\text{O}_6$



(c) Calculate the mass of oxygen gas that must react with the 0.7549 grams of wampetin in this reaction to form the exact amounts of products listed in this problem.

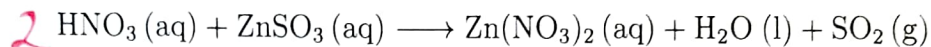
Conservation of mass

$$\text{Mass of products} = 1.9061 \text{ g} + 0.3370 \text{ g} = 2.2431 \text{ g}$$

$$\text{Mass O}_2 = 2.2431 \text{ g} - 0.7549 \text{ g wampetin} = \boxed{1.4882 \text{ g O}_2}$$

3. 20.0 grams of nitric acid are added to 1.20 L of 0.180 M aqueous zinc sulfite in a flask. (Assume no change in volume when the nitric acid is added). Recall that M is moles/Litre.

(a) Balance the molecular equation for this chemical reaction (below).



(b) How many moles of which reactant will be left over at the end of this reaction?

$$20.0 \text{ g HNO}_3 \times \frac{1 \text{ mol HNO}_3}{63.0 \text{ g HNO}_3} \times \frac{1 \text{ mol SO}_2}{2 \text{ mol HNO}_3} = 0.1587 \text{ mol SO}_2$$

$$0.180 \text{ M}(1.20 \text{ L}) = 0.216 \text{ mol ZnSO}_3 \times \frac{1 \text{ mole SO}_2}{1 \text{ mole ZnSO}_3} = 0.216 \text{ mol SO}_2$$

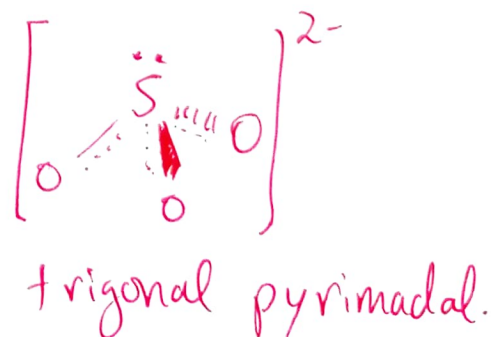
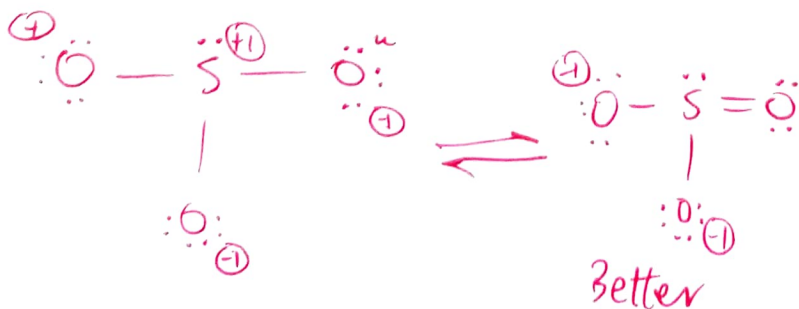
HNO₃ is LR

$$\Rightarrow 20.0 \text{ g HNO}_3 \times \frac{1 \text{ mole HNO}_3}{63.0 \text{ g HNO}_3} \times \frac{1 \text{ mole ZnSO}_3}{2 \text{ mole HNO}_3} = 0.1587 \text{ mole ZnSO}_3 \text{ used.}$$

$$0.216 \text{ mole initial} - 0.1587 \text{ mole used} = \boxed{0.057 \text{ mole ZnSO}_3 \text{ left over}}$$

0 mole HNO₃ since LR

(c) Draw the 2D Lewis dot structure and 3D VSEPR structure for a sulfite ion. (Be sure to minimize formal charges. If multiple resonance structures are possible, draw them all.) Indicate the name of the geometry that describes the structure of the molecule.

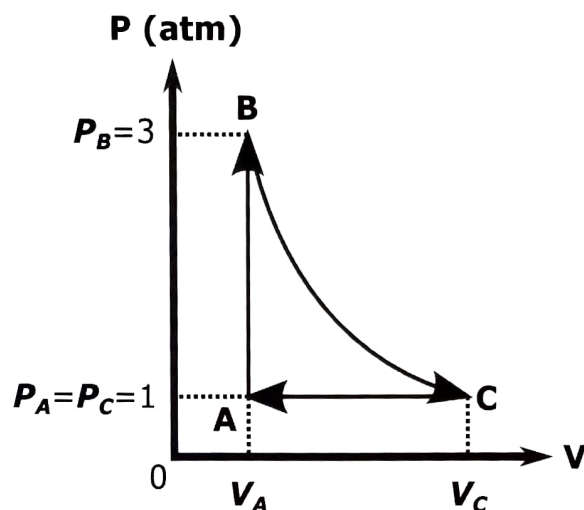


9. Let's consider a closed system consisting of one mole of ideal gas. As shown in the $p-V$ diagram below, it starts from Point A, then follows the process $A \rightarrow B \rightarrow C \rightarrow A \rightarrow B \rightarrow C \dots$ and so on repeatedly, spending one second between each point.

Point A ($t = 0$ sec): $(p, V, T) = (p_A, V_A, T_A) = (1 \text{ atm}, V_A, 300\text{K})$

Point B ($t = 1$ sec): $(p, V, T) = (p_B, V_B, T_B) = (3 \text{ atm}, V_A, T_B)$

Point C ($t = 2$ sec): $(p, V, T) = (p_C, V_C, T_C) = (1 \text{ atm}, V_A, 300\text{K})$



- (a) Write down the ideal gas equation for n moles of the ideal gas with (p, V, T) .

$$pV = nRT$$

- (b) In general, what is the internal energy (E_{int}) of the ideal gas with n moles at temperature T ? Express it in terms of n, T and then in terms of p, V .

$$E_{int} = \frac{3}{2} nRT = \frac{3}{2} pV$$

- (c) Using the equation E_{int} above, calculate the internal energy E_A at Point A for one mole of the ideal gas at 300 K (in calories).

$$E_{int} = \left(\frac{3}{2}\right)(1)(2)(300\text{K}) = \boxed{900 \text{ cal}}$$

- (d) Next consider the isovolumetric process: $A \rightarrow B$. What is the temperature T_B ? Express it in terms of T_A and then calculate it.

$$\frac{P_A}{T_A} = \frac{P_B}{T_B} \Rightarrow T_B = \frac{P_B T_A}{P_A} = \left(\frac{3 \text{ atm}}{1 \text{ atm}} \right) T_A = \boxed{3T_A} = \boxed{900 \text{ K}}$$

- (e) Express the internal energy at Point B (E_B) in terms of E_A .

$$E_B = \frac{3}{2} n R T_B = 3 \left(\frac{3}{2} n R T_A \right) = \boxed{3E_A}$$

- (f) How much heat ($= Q$) is required in the isovolumetric process $A \rightarrow B$? Express it in terms of E_A .

$$\Delta E_{\text{int}} = 3E_A - E_A = 2E_A \quad \text{isovolumetric} \Rightarrow w = 0$$

$$\Delta E_{\text{int}} = Q \Rightarrow \boxed{Q = 2E_A}$$

- (g) Next, consider the isothermal process: $B \rightarrow C$. What is the volume V_C ? Express it in terms of V_A .

$$P_B V_A = P_C V_C \Rightarrow \boxed{3V_A = V_C}$$

- (h) What is the relation between the internal energy at point B ($= E_B$) and that at point C ($= E_C$)?

$$\boxed{E_B = E_C} \quad \text{since } T \text{ doesn't change}$$

- (i) How much work ($= W$) is done by the expansion $B \rightarrow C$? Express it in terms of E_A .

$$W = - \int_{V_A}^{V_C} p dV = -n R T_B \ln \left(\frac{V_C}{V_A} \right) = \boxed{-2 \ln 3 E_A}$$

$$= \boxed{-2.197 E_A}$$

- (j) How much heat ($= Q$) must be injected into the system during $B \rightarrow C$? Express it in terms of W (from part (i)).

$$\Delta E_{\text{int}} = 0 \Rightarrow \boxed{W = -Q} \Rightarrow Q = 2.197 E_A$$

- (k) Lastly, consider the isobaric process: $C \rightarrow A$. How much work ($= W'$) is done by the gas system? Express it in terms of E_A .

$$W' = -P\Delta V \Rightarrow -P_A(V_A - V_C) = 2P_A V_A = 2\left(\frac{2}{3}\right)\left(\frac{3}{2}P_A V_A\right)$$

$$\boxed{W' = \frac{4}{3} E_A}$$

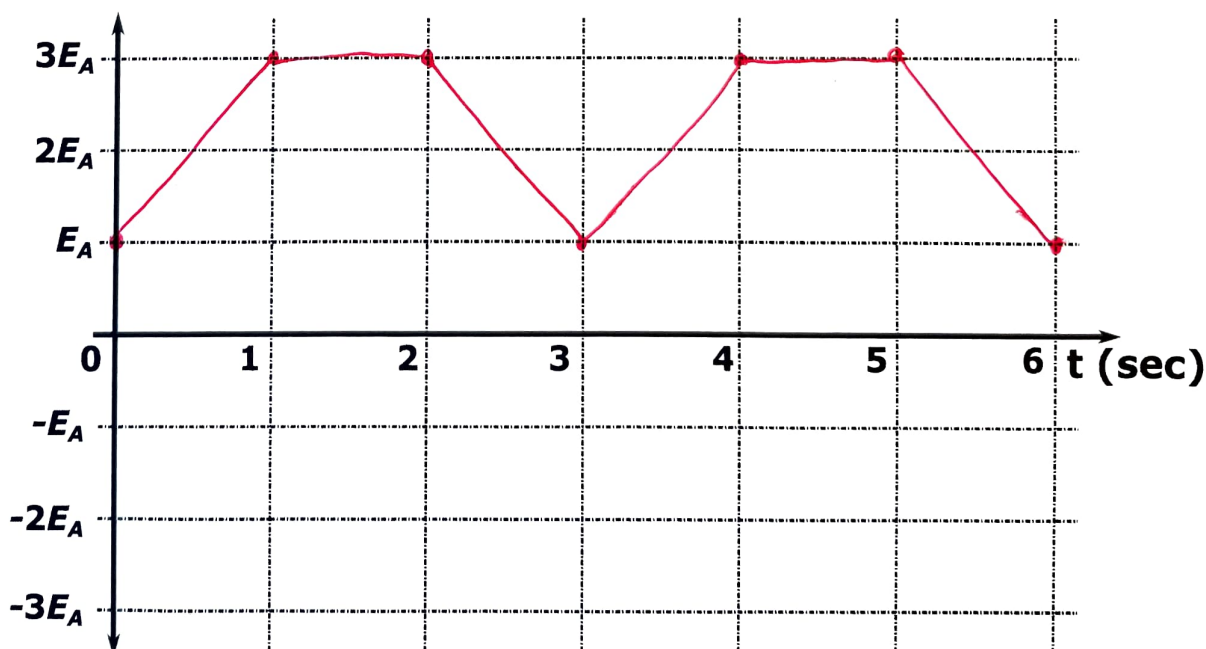
- (l) During one full cycle of $A \rightarrow B \rightarrow C \rightarrow A$, how much total work ($= W_{total}$) is done by this system? Express it in terms of E_A first, then calculate it (in calories).

$$W_{TOT} = -2.197 E_A + \frac{4}{3} E_A = \boxed{-0.864 E_A = -377.5 \text{ cal}}$$

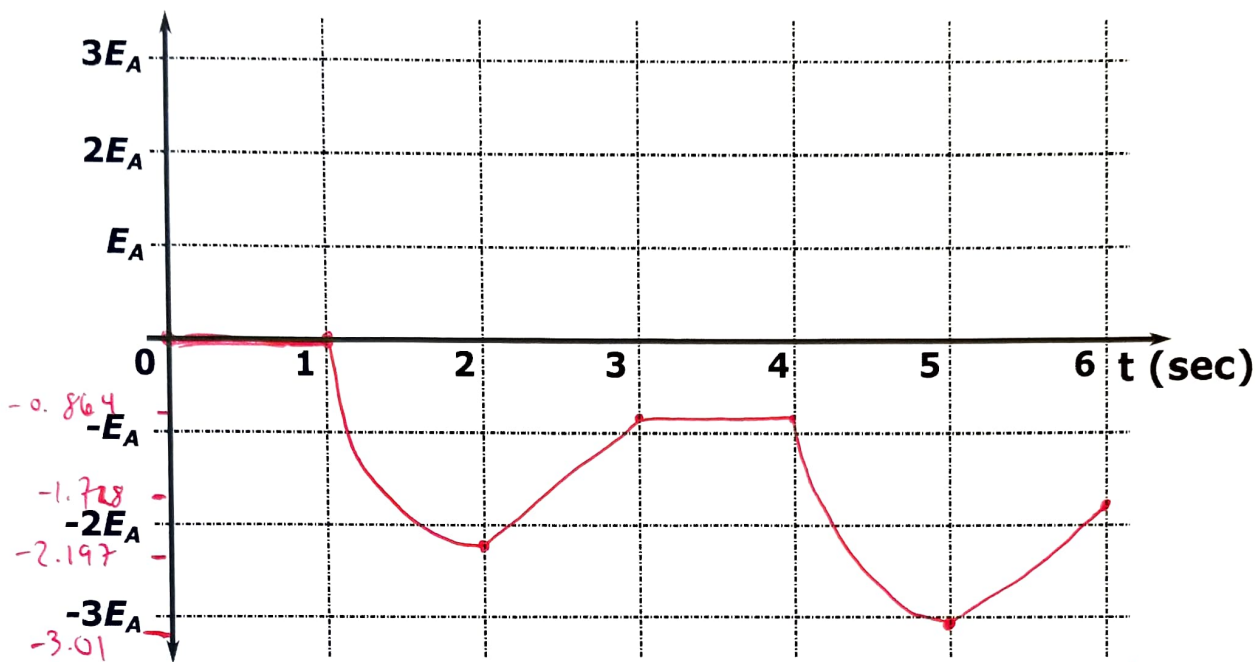
- (m) During the one cycle of $A \rightarrow B \rightarrow C \rightarrow A$, how much heat ($= Q_{total}$) is injected to the gas system? Express it in terms of W_{total} .

$$\Delta E_{TOT} = 0 \Rightarrow \boxed{Q_{TOT} = -W_{TOT}}$$

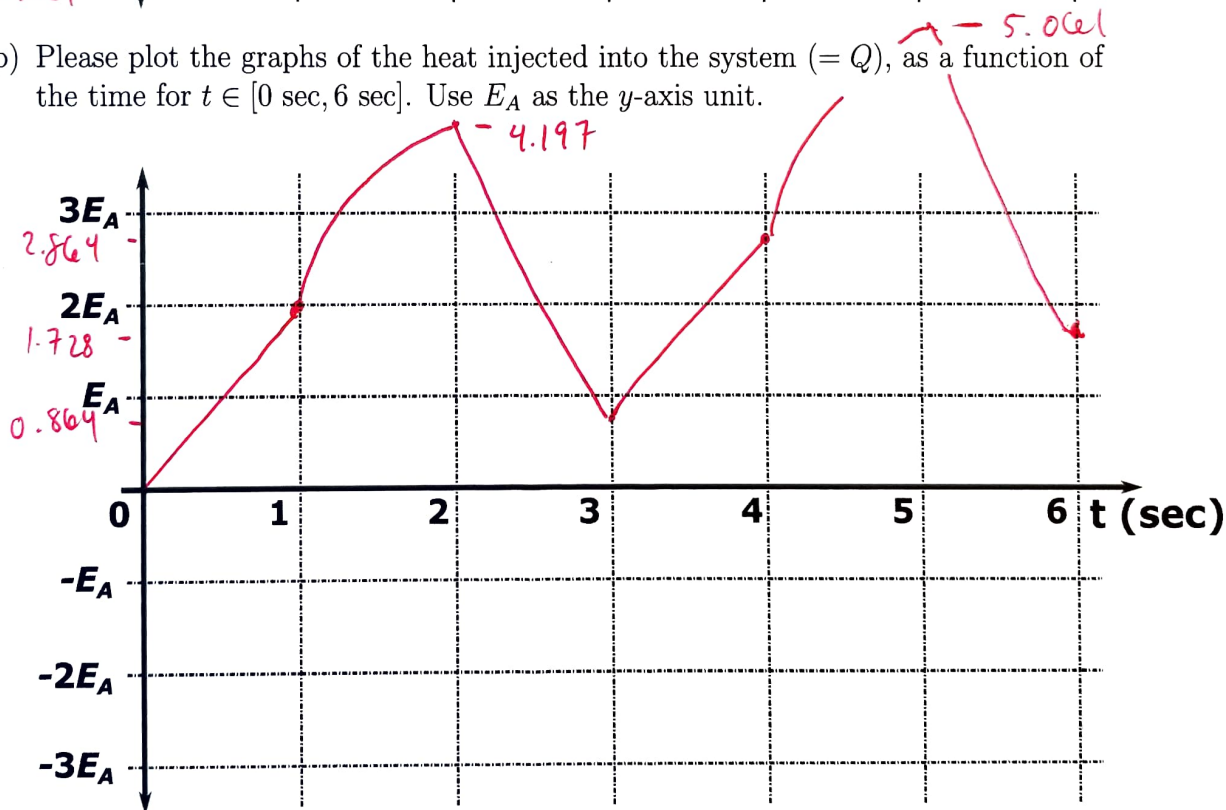
- (n) Please plot the graph of the total internal energy ($= E_{int}$) as a function of time for $t \in [0 \text{ sec}, 6 \text{ sec}]$. Use E_A as the unit of E_{int} . Assume that gas expansion and compression rates $\frac{dV}{dt}$ are constant, and that heat injection rates $\frac{dQ}{dt}$ during $A \rightarrow B$ and $C \rightarrow A$ are constant.



- (o) Please plot the graphs of the work done by the system ($= W$), as a function of the time for $t \in [0 \text{ sec}, 6 \text{ sec}]$. Use E_A as the y -axis unit.



- (p) Please plot the graphs of the heat injected into the system ($= Q$), as a function of the time for $t \in [0 \text{ sec}, 6 \text{ sec}]$. Use E_A as the y -axis unit.



10. Lets consider making hot water (100°C) from a chunk of ice in a freezer (-20°C): Here are the assumptions

1. Mass of ice: $m = 200$ grams (initially at -20°C).

2. For simplicity, assume 1 calorie = 4 Joules.

(a) First we must heat up 200 grams of ice from -20°C to 0°C . How much heat energy (Q_{ice}) is required (in units of calories)?

$$Q_{ice} = (200\text{g}) \left(\frac{0.5\text{cal}}{\text{g}\cdot^{\circ}\text{C}} \right) (20^{\circ}\text{C}) = \boxed{2000\text{cal}}$$

(b) Next we must melt the ice to water at 0°C . How much heat energy (Q_{fusion}) is required (in units of calories)?

$$Q_{fus} = m \Delta H_{fus} = (200\text{g}) \left(\frac{80.0\text{cal}}{\text{g}} \right) = \boxed{16000\text{cal}}$$

(c) Next we must heat up water from 0°C to 100°C . How much heat energy (Q_{water}) is required (in units of calories)?

$$Q_{water} = (200\text{g}) \left(\frac{1\text{cal}}{\text{g}\cdot^{\circ}\text{C}} \right) (100^{\circ}\text{C}) = \boxed{20000\text{cal}}$$

- (d) We would like to make a perfect icy-cold iced tea ($= 0^\circ\text{C}$). We will start from 200 grams of ice (at -20°C) only. We have no liquid water to begin with. We first take a fraction of ice, melt it, and heat it up to make a hot tea. The optimum temperature to make a hot tea is 90°C . Once you make the hot tea at 90°C , you will then drop the remaining ice (-20°C) into the hot tea. To make the largest amount of icy-cold iced tea (i.e. 200 g of 0°C water, with no remaining ice), how many grams of ice do we need to heat up from -20°C to 90°C ?

$$M_{\text{ice}} + M_{\text{tea}} = 200\text{g} \Rightarrow M_{\text{ice}} = 200\text{g} - M_{\text{Tea}}$$

$$M_{\text{ice}} \left(\frac{0.5 \text{ cal}}{\text{g} \cdot ^\circ\text{C}} \right) (20^\circ\text{C}) + M_{\text{ice}} \left(80.0 \frac{\text{cal}}{\text{g}} \right) + M_{\text{Tea}} \left(\frac{1 \text{ cal}}{\text{g} \cdot ^\circ\text{C}} \right) (-90^\circ\text{C}) = 0$$

$$\Rightarrow (200\text{g} - M_{\text{Tea}}) \left(\frac{90 \text{ cal}}{\text{g}} \right) - \left(90 \frac{\text{cal}}{\text{g}} \right) M_{\text{Tea}} = 0$$

$$\Rightarrow 200\text{g} - M_{\text{Tea}} = M_{\text{Tea}}$$

$$\Rightarrow \boxed{M_{\text{Tea}} = 100\text{g}}$$

So heat up 100g ice to 90°C for max. tea

11. One kilogram of water at 0°C is brought into contact with a large heat reservoir at 100°C.

(a) When the water has reached 100°C, what has been the change in entropy of the water (in cal/K)?

$$\begin{aligned}\Delta S_{\text{water}} &= m_{\text{cp}} \ln \frac{T_f}{T_i} = (1 \text{ kg}) \left(\frac{1.0 \text{ cal}}{\text{g} \cdot \text{K}} \right) \ln \left(\frac{373}{273} \right) \\ &= (1000 \text{ g}) \left(\frac{1.0 \text{ cal}}{\text{g} \cdot \text{K}} \right) \ln \left(\frac{373}{273} \right) = \boxed{312.11 \frac{\text{cal}}{\text{K}}}\end{aligned}$$

(b) What is the change in entropy of the heat reservoir (in cal/K)?

$$\Delta S_{\text{HR}} = \frac{-q}{T} \quad T = 373 \text{ K}$$

$$q = m_{\text{cp}} (100 \text{ K}) = (1000 \text{ g}) \left(\frac{1.0 \text{ cal}}{\text{g} \cdot \text{K}} \right) (100) = \boxed{100000 \text{ cal}}$$

$$\Delta S_{\text{HR}} = \frac{-100000 \text{ cal}}{373 \text{ K}} = \boxed{-268.10 \frac{\text{cal}}{\text{K}}}$$

(c) What is the change in entropy of the entire system, consisting of both water and heat reservoir (in cal/K)?

$$\begin{aligned}\Delta S_{\text{TOT}} &= \Delta S_{\text{wat}} + \Delta S_{\text{HR}} \\ &= 312.11 \frac{\text{cal}}{\text{K}} + (-268.10 \frac{\text{cal}}{\text{K}}) \\ &= \boxed{44.01 \frac{\text{cal}}{\text{K}}}\end{aligned}$$

12. Consider now a similar scenario as before, but instead the water is heated from 0°C to 100°C by first bringing it in contact with a reservoir at 50°C and then with a reservoir at 100°C .

(a) What would have been the change in the entropy of the entire system?

$$\Delta S_{\text{wat}} = 312.11 \frac{\text{cal}}{\text{K}} \quad (\text{same as before since } S \text{ state function})$$

$$\Delta S_{\text{HR1}} = \frac{-q_1}{323 \text{ K}} = \frac{(1000 \text{ g}) \left(\frac{1.0 \text{ cal}}{\text{g} \cdot \text{K}} \right) (50)}{323 \text{ K}} = \boxed{-154.80 \frac{\text{cal}}{\text{K}}}$$

$$\Delta S_{\text{HR2}} = \frac{-q_2}{373 \text{ K}} = \frac{70000 \text{ cal}}{373 \text{ K}} = \boxed{-134.05 \frac{\text{cal}}{\text{K}}}$$

$$\Delta S_{\text{TOT}} = \Delta S_{\text{wat}} + \Delta S_{\text{HR1}} + \Delta S_{\text{HR2}} = \boxed{23.26 \frac{\text{cal}}{\text{K}}}$$

(b) ... Starting from 0°C , we place the water in a bath of small ΔT . We allow to equilibrate. We then place the water in a bath of $2\Delta T$ and allow to equilibrate. We iterate this till the final bath temp is 100°C . Then we take the limit as $\Delta T \rightarrow 0$ for this process.