

## Midterm 1 solutions

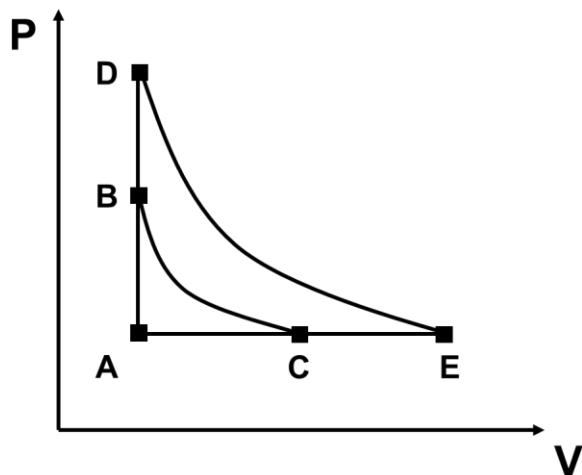
1. (3 points) It is possible to calculate the absolute entropy of a pure substance (T/F).

T - See the Third Law – the absolute entropy is zero for all perfect crystalline substances at absolute zero

2. (3 points) The thermal efficiency of a proposed process between two heat reservoirs at 298 K and 750 K is said to be 70% ( $\eta_{proposed} = 0.7$ ). This process is possible (T/F).

F -  $\eta_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{298\text{ K}}{750\text{ K}} = 0.6$ , thus  $\eta_{proposed} > \eta_{max}$  which violates the Second Law

3. (3 points) Two reversible cycles are shown on a PV diagram. Which has a larger value of Q?



- a)  $A \rightarrow B \rightarrow C \rightarrow A$
- b)  $A \rightarrow D \rightarrow E \rightarrow A$
- c) Q is the same for both processes

Multiple choice ans: B

$$dU = dQ + dW$$

As internal energy is a state function, the internal energy change for a cycle is zero. Therefore, the path in which the system performs more work must absorb more heat. More work is done in

B as  $dW = -pdV$  or work is equal to the area outlined by the cycle. Therefore more heat must be absorbed in B.

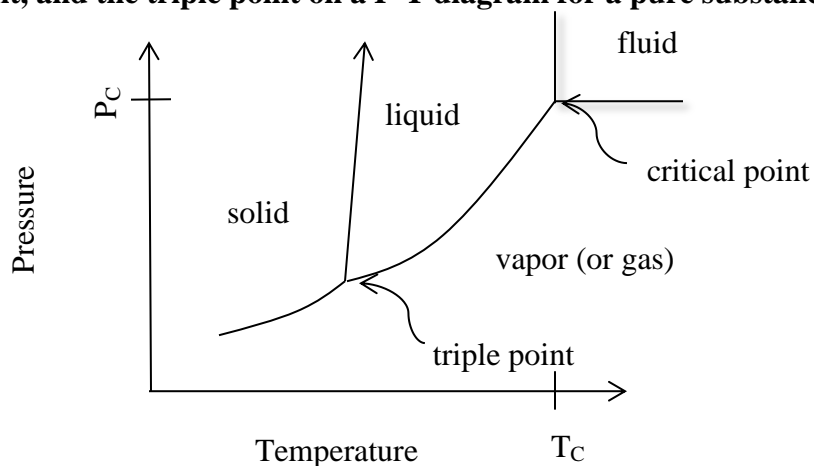
4. (3 points) An ideal gas is compressed to 10x its initial pressure. The final volume is smaller for
- a) An isothermal compression
  - b) An adiabatic compression
  - c) Same for both

Multiple choice ans: A

When you compress the gas, work is being done on the system. If the compression is adiabatic the temperature of the gas will therefore increase. As  $PV = RT$ , if the pressure and is the same in both cases, a higher temperature corresponds to a larger volume.

You can also remind yourself that an adiabatic curve is more steep than an isotherm, so for a compression the final volume will be smaller for the isothermal compression

5. (5 points) Draw and clearly label the vapor, liquid, fluid, and solid phases, the critical point, and the triple point on a P-T diagram for a pure substance.



6. (4 points) Write in the heat effect that corresponds to the given definition.

- a) Heat transfer required to either liquefy a solid or vaporize a liquid of a pure substance at constant pressure.

Latent Heat

- b) Heat transfer associated with a reaction that forms a single compound from its constituent elements.

Heat of Formation

- c) Heat transfer to a system in which there are no phase transitions, no chemical reactions, and no changes in composition that results in a temperature change of the system.

Sensible Heat Effects

- d) Heat transfer that occurs during the course of a chemical reaction.

Heat of Reaction

7. (4 points) Draw a line to connect the reversible process to its corresponding equation for process calculations for an ideal gas in a closed system. Not every item below may have a match.

Process Equation	Process
$W = \Delta U$	Isothermal
$Q = \Delta H$	Isentropic
$Q = \Delta U$	Isobaric
$Q = -W$	Isochoric
	Adiabatic
	Isenthalpic

8. (25 points) A power plant rated at 1,000 MW (megawatts), generates steam at 600 K and discards heat to a cooling pond at 300 K.

- a) If the thermal efficiency of the plant is 80% of the maximum possible value, how much heat is discarded to the cooling pond when the plant is operated at rated power?
- b) How much heat would be discarded to the cooling pond if the process was completely reversible? Assume the same amount of heat is absorbed by the process.
- c) How much power is lost due to irreversibilities in the process?

**Hint:** The plant generates power from steam driving a turbine to produce shaft work.

*Part (a):*

$$\eta_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{300\text{ K}}{600\text{ K}} = 0.5$$

$$\eta_{real} = 0.8 * \eta_{max} = 0.8 * 0.5 = 0.4$$

*We know that:*

$$|W| = |Q_H| - |Q_C| \quad \text{and} \quad \eta_{real} = \frac{|W|}{|Q_H|}$$

$$|Q_H| = |W| + |Q_C| \quad \text{and} \quad |Q_H| = \frac{|W|}{\eta_{real}} = \frac{1,000\text{ MW}}{0.4} = 2,500\text{ MW}$$

$$|Q_C| = |Q_H| - |W| = 2,500\text{ MW} - 1,000\text{ MW} = 1,500\text{ MW}$$

*Part (b):*

$$\text{We know:} \quad \eta_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{300\text{ K}}{600\text{ K}} = 0.5$$

$$\text{Also,} \quad \eta_{max} = 1 - \frac{|Q_C^{id}|}{|Q_H|} = 1 - \frac{|Q_C^{id}|}{2,500,000\text{ kW}} = 0.5$$

$$\text{Thus,} \quad |Q_C^{id}| = 1,250\text{ MW}$$

*Part (c):*

$$|W_{ideal}| = |Q_H| - |Q_C^{id}| = 2,500 \text{ MW} - 1,250 \text{ MW} = 1,250 \text{ MW}$$

$$W_{lost} = W_{ideal} - W_s = 1,250 \text{ MW} - 1,000 \text{ MW} = 250 \text{ MW}$$

9. (25 points) Steam is steadily pumped from a storage tank at a rate of 1 kg/s. The motor for the pump supplies shaft work at a rate of 100 J/s. The water goes through a heat exchanger, giving up heat at a rate of 50 J/s, and exits a valve at a velocity of 10 m/s, at a height 10 m above the first tank. What is the enthalpy change of the water exiting the valve (J/kg)?

For simplicity assume gravitational acceleration is  $10 \text{ m/s}^2$ .

$$\frac{d(mU)}{dt} + \left[ \left( \Delta H + \frac{\Delta u^2}{2} + g\Delta z \right) \dot{m} \right] = \dot{Q} + \dot{W}$$

Steady state, no initial velocity

$$\left[ \left( \Delta H + \frac{u_2^2}{2} + g\Delta z \right) \dot{m} \right] = \dot{Q} + \dot{W}$$

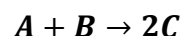
Mass flow rate is 1 kg/s

$$\Delta H = -\frac{u_2^2}{2} - g\Delta z + \dot{Q} + \dot{W}$$

$$\Delta H = -\frac{\left(10 \frac{m}{s}\right)^2}{2} - \frac{10m}{s^2} * 10 \text{ m} - 50 \frac{J}{s} \left(\frac{s}{kg}\right) + 100 \frac{J}{s} \left(\frac{s}{kg}\right)$$

$$\Delta H = -100 \frac{J}{kg}$$

10. (25 points) A reaction follows this scheme:



Reactants are supplied in a 1:1 ratio. Heat is supplied to the reactor so the products reach a temperature of 600K. If the reactants enter the reactor at standard state conditions and reactant *A* is completely converted, calculate the heat requirement for the reactor.

Assume that standard state temperature is 300 K and standard state pressure is 1 bar.

Assume heat capacity is independent of temperature

Heat of Formation data



Heat Capacity data

Chemical Species	C <sub>p</sub>
A	6
B	2
C	5

What is *Q* required to raise temp of products to 600 K?

$\Delta H = Q$  for mechanically reversible, constant pressure, closed system processes (at steady state).  
PE and KE negligible,  $W_s = 0$ . Get this from standard energy balance.

Because we only have one product for this reaction, we can show that the overall enthalpy change is given by

$$Q = \Delta H = \Delta H_{300}^{\circ} + \Delta H_P^{\circ} = \Delta H_{300}^{\circ} + n_P C_P (T - T_0)$$

What is  $\Delta H_{300}^{\circ}$  for the reaction? Need to take into account stoichiometry and heats of formation.  
Use basis of 1 mol *A* that reacts completely.

$$\Delta H_{300}^{\circ} = n_A \Delta H_{300,f,A}^{\circ} + n_B \Delta H_{300,f,B}^{\circ} + n_C \Delta H_{300,f,C}^{\circ}$$

$$\Delta H_{300}^{\circ} = (-1)(-100 \text{ kJ}) + (-1)(-25 \text{ kJ}) + (2)(-50 \text{ kJ}) = 25 \text{ kJ}$$

So the heat of reaction has been calculated at standard state conditions, what is the enthalpy change associated with raising the temperature of the products from 300 K to 600 K?

$$\Delta H_P^{\circ} = n_P C_P (T - T_0)$$

Get  $C_P$  from table so we can calculate enthalpy of temperature change

$$\Delta H_P^{\circ} = n_P C_P (T - T_0) = (2 \text{ mol}) \left( 5 \frac{\text{J}}{\text{mol K}} \right) (600 \text{ K} - 300 \text{ K}) = 3,000 \text{ J}$$

Note that we have 2 mol of product  $C$  (taken care of by  $n_C$ ) for our basis of 1 mol of reactant  $A$ .

The overall enthalpy change is then

$$\Delta H = \Delta H_{300}^{\circ} + \Delta H_P^{\circ}$$

$$\Delta H = 25 \text{ kJ} + 3 \text{ kJ} = 28 \text{ kJ}$$