

### Question 1:

Liquid supersaturated sugar solution can evaporate in an open beaker. What is left is a solid of sugar crystals.

- Did the sugar gain or lose entropy going from a liquid to crystalline form? Explain.
- Does this violate the second law of thermodynamics? Explain using *sign* sensemaking. Make sure to state a prediction for whether or not your answer to part (a) violates the second law of thermodynamics. Then provide an explanation making sure to use the signs of the entropies involved.

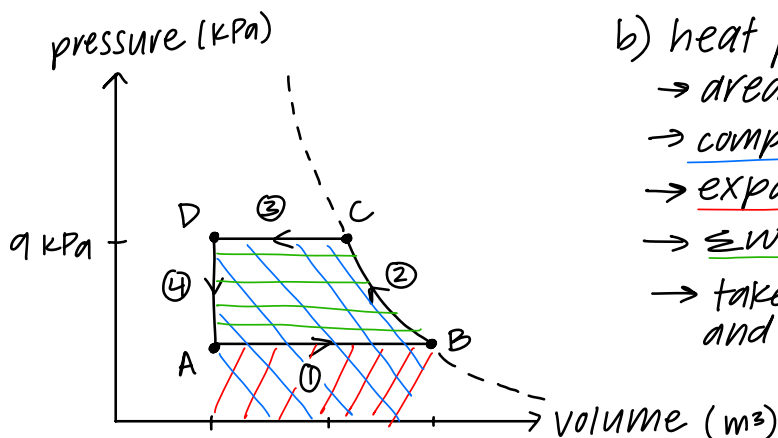
- a) The sugar **lost entropy** going from a liquid to crystalline form. The solid is more ordered than the liquid state because it has a smaller multiplicity. A solid state of matter has smaller entropy than its liquid form. There are fewer micro configurations that a solid can have vs. a liquid.
- b) No, this **doesn't violate the 2nd law**. Even though the entropy of the sugar solution decreased, the entropy of the environment increased when the liquid evaporated into gas. Gas has more disorder than a liquid.

### Question 2:

3.0 moles of an ideal gas are subjected to the following processes. First the volume is tripled in an isobaric process. Then it undergoes an isothermal process to a pressure of 9.0 kPa. The volume is then halved in another isobaric process. Finally, it returns to the original state in an isochoric process.

- Draw a PV diagram of the cycle. Label each state (vertex) with a letter (A, B, ...) and each transition with a number and arrow showing the direction of the process.
- Is this a heat engine or heat pump? Explain **without** using "clockwise" or "counterclockwise".
- Begin the *sign* sensemaking process by making a prediction for the sign of the total work done on the gas. Briefly explain your prediction using your answer to part (b)
- If the isothermal process occurs at a temperature of 900 K, what is the pressure, temperature, and volume for each state.
- Find the work done on the gas, the heat in and out of the gas, and the change in thermal energy for each of the processes.
- Complete the *sign* sensemaking process by comparing your answer to part (e) with your prediction in part (c). Explain why this mean your answer to part (e) is reasonable (or not).

- a)  $A \rightarrow B$  : volume tripled (isobaric — constant pressure)  
 $B \rightarrow C$  :  $P = 9.0 \text{ kPa}$  (isothermal  $\rightarrow$  temp stays the same  
 —  $P_B V_B = P_C V_C$ )  
 $C \rightarrow D$  : volume halved (isobaric — constant pressure)  
 $D \rightarrow A$  : goes to original state (isochoric — constant volume)



- b) heat pump  
 $\rightarrow$  area is work  
 $\rightarrow$  compression = + work  
 $\rightarrow$  expansion = - work  
 $\rightarrow$  work is positive  
 $\rightarrow$  takes work to remove heat and flow against natural direction

c) Prediction: work is positive b/c more + areas than -areas  
and net area = work

Why: area under ① is negative (expansion = -work)

area under ② is positive (compression = +work)

area under ③ is positive (compression = +work)

area under ④ is zero

$$\text{net area} = \text{①} + \text{②} + \text{③} = (-) + (+) + (+) = +$$

\* adding the positive works together (2+3) creates an area that looks larger than the negative work area (1); reasonable to predict net work (1+2+3+4) will be net positive.

\* see colors above on graph to better visualize

d)  $PV = nRT$

KNOWN:

$$n = 3 \text{ mol}$$

$$R = 8.314 \text{ J/mol}\cdot\text{K}$$

$$T_{B,C} = 900 \text{ K}$$

$$P_{C,D} = 9 \text{ kPa} = 9000 \text{ Pa}$$

$$V_B = 3V_A$$

$$P_A = P_B$$

$$V_A = V_D$$

$$V_D = \frac{1}{2}V_C$$

$$\text{① } V_D = \frac{1}{2}V_C$$

$$V_D = \frac{1}{2}(2.5)$$

$$V_D = 1.25 \text{ m}^3$$

$$P_D V_D = nRT_D$$

$$T_D = \frac{P_D V_D}{nR}$$

$$T_D = \frac{9000(1.25)}{3(8.314)}$$

$$T_D = 450 \text{ K}$$

$$\text{② } P_C V_C = nRT$$

$$9000(V_C) = 3(8.314)(900)$$

$$V_C = \frac{3(8.314)(900)}{9000}$$

$$V_C = 2.5 \text{ m}^3$$

$$\text{③ } V_A = V_D = 1.25 \text{ m}^3$$

$$V_B = 3V_A = 3(1.25) = 3.75 \text{ m}^3$$

$$P_B V_B = P_C V_C \text{ b/c isothermal process}$$

$$P_B(3.75) = 9000(2.5)$$

$$P_B = 6000 \text{ Pa}$$

$$\text{④ } P_A V_A = nRT_A$$

$$T_A = \frac{P_A V_A}{nR}$$

$$T_A = \frac{6000(1.25)}{3(8.314)} = 300 \text{ K}$$

## final table of values:

	pressure	volume	temperature
(A)	6000 Pa	1.25 m <sup>3</sup>	300 K
(B)	6000 Pa	3.74 m <sup>3</sup>	900 K
(C)	9000 Pa	2.5 m <sup>3</sup>	900 K
(D)	9000 Pa	1.25 m <sup>3</sup>	450 K

$$e) \Delta E^{th} = n \frac{3}{2} R \Delta T$$

$$\textcircled{1} \Delta E^{th} = n \frac{3}{2} R (T_B - T_A)$$

$$\Delta E^{th} = 3 \left( \frac{3}{2} \right) (8.314) (900 - 300)$$

$$\Delta E^{th} = 22,448 \text{ J}$$

$$\textcircled{2} \Delta E^{th} = 0 \text{ b/c } \Delta T = 0$$

$$\textcircled{3} \Delta E^{th} = n \frac{3}{2} R (T_D - T_C)$$

$$\Delta E^{th} = 3 \left( \frac{3}{2} \right) 8.314 (450 - 900)$$

$$\Delta E^{th} = -16,836 \text{ J}$$

$$\textcircled{4} \Delta E^{th} = n \frac{3}{2} R (T_A - T_D)$$

$$\Delta E^{th} = 3 \left( \frac{3}{2} \right) (8.314) (300 - 450)$$

$$\Delta E^{th} = -5612 \text{ J}$$

W = area under curve

$$\textcircled{1} W = -(3.75 - 1.25)(6000) = -15,000 \text{ J}$$

$$\textcircled{3} W = (2.5 - 1.25)(9000) = 11,250 \text{ J}$$

$$\textcircled{2} |W| = N k_B T \left| \ln \frac{V_f}{V_i} \right| = 3(6.022 \times 10^{23})(1.38 \times 10^{-23})(900) \left| \ln \left( \frac{2.5}{3.75} \right) \right|$$

$$= 9098 \text{ J}$$

$$\Delta E^{th} = W + Q$$

$$Q = \Delta E^{th} - W$$

$$\textcircled{1} \quad Q = 22,448 - (-15,000) = 37,488 \text{ J}$$

$$\textcircled{2} \quad Q = 0 - 9098 = -9098 \text{ J}$$

$$\textcircled{3} \quad Q = -16,836 - 11,250 = -28,086 \text{ J}$$

$$\textcircled{4} \quad Q = -5612 - 0 = -5612 \text{ J}$$

final table of values:

	W	Q	$\Delta E^{th}$
$\textcircled{1}$	-15,000 J	37,488 J	22,448 J
$\textcircled{2}$	9098 J	-9098 J	0 J
$\textcircled{3}$	11,250 J	-28,086 J	-16,836 J
$\textcircled{4}$	0 J	-5612 J	-5612 J

f) prediction:  $\textcircled{1} + \textcircled{2} + \textcircled{3} = (-) + (+) + (+) = + \text{ work}$

$$\text{actual: } -15,000 \text{ J} + 9098 \text{ J} + 11,250 \text{ J} = 5,348 \text{ J}$$

The net work is positive, and we predicted it would be.

They match!