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1. (15 points, 5 points each): 1.00 mol of air (29.0 g/mol) at 1.00 atm and 20°C exists in a rigid container. The container is placed in a bathtub full of water also at 20°C, and the water is slowly heated up to its boiling point.

   (a) What is the volume of the rigid container?

   (b) What is the final pressure of the gas inside the rigid container?

   (c) What kind of process is this? Draw the process on a pV diagram. (Note: label your axes, including the initial and final points, and provide as much information as possible).

(a) $pV = nRT \Rightarrow V = \frac{nRT}{p} = \frac{(1.00\text{ mol})(8.31\ \frac{J}{K})(293\text{ K})}{1.01325\times10^5\text{ Pa}}$

$= \boxed{2.4\times10^{-2}\text{ m}^3}$

$= 24\text{ L}$

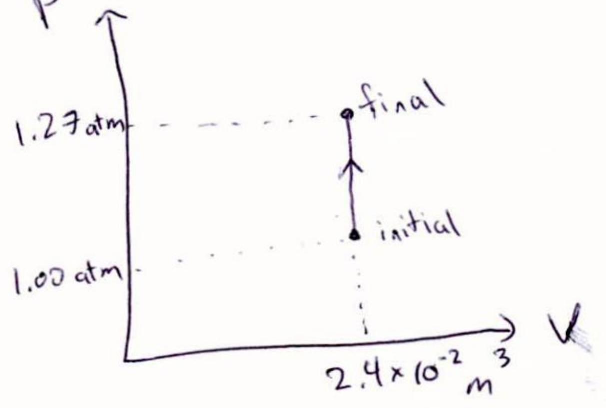
(b) rigid container

$\Rightarrow V_f = V_i \Rightarrow \frac{T}{p} = \text{const},\ p_f = \left(\frac{T_f}{T_i}\right)p_i = \left(\frac{373\text{ K}}{293\text{ K}}\right)(1.00\text{ atm})$

$\boxed{p_f = 1.27\text{ atm}}$

$= 1.29\times10^5\text{ Pa}$

(c) Assuming it's heated slowly enough to be reversible, this is an $\boxed{\text{isochoric}}$ process



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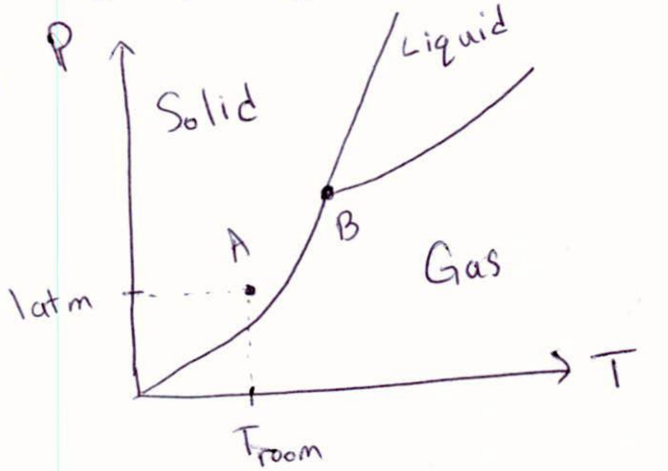
2. (10 points, 5 points each) Material X undergoes sublimation when heated at 1atm, starting from room temperature. In addition, when subjected to higher and higher pressures at room temperature (starting at 1 atm), the material does not undergo any phase changes.

   (a) Draw a phase diagram for material X, assuming it has gaseous, liquid, and solid phases. Label two points on your diagram: one point indicating room temperature and atmospheric pressure (call this point A), and also label the triple point (call this point B). Is the triple point at higher or lower temperature than room temperature? Is the triple point at higher or lower pressure than 1 atm?

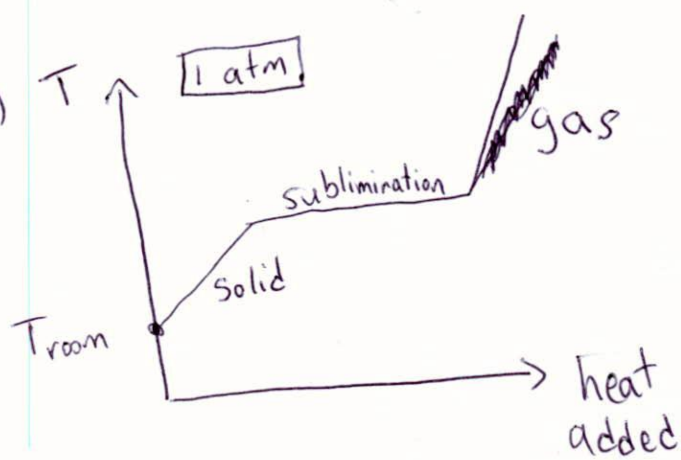
   (b) Suppose the specific heat of material X at 1 atm is greatest in the solid phase and smallest in the gaseous phase. Draw a graph of temperature vs. heat added for material X, starting with a sample at room temperature, and assuming the heating process is undergone at 1 atm. It should be clear from your diagram which slope is biggest. Also, label all phases and phase changes on your diagram.

(a)



$$\boxed{\begin{array}{l} P_{triple} > 1\,atm \\ T_{triple} > T_{room} \end{array}}$$

(b)



$$\Delta Q = m c \Delta T$$

$$\frac{\Delta T}{\Delta Q} = (\text{slope}) \propto \frac{1}{c}$$

$$c_{solid} > c_{gas}$$

$$(\text{slope})_{solid} < (\text{slope})_{gas}$$

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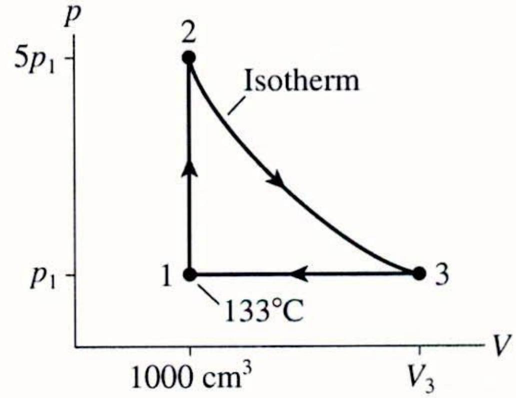
3. (16 points, 4 points each) Consider the pV diagram shown below of a thermodynamic process followed by 120 mg of helium. Note the molar mass of helium is 4.00 g/mol.



(a) Find the pressure p_1 of the gas at point 1 (in Pa).
(b) Find the temperature T_2 of the gas at point 2 (in K).
(c) Find the volume V_3 of the gas at point 3 (in m^3).
(d) How much work is done on the gas ~~after 1 cycle?~~ for $3 \to 1$ (in J)?

(a) $n = \dfrac{(0.12\,g)}{4\,g/mol} = 0.03\ mol$

$$P_1 = \frac{nRT_1}{V_1} = \frac{(0.03\ mol)(8.31\ J/mol\cdot K)(406\ K)}{0.001\ m^3}$$

$\boxed{P_1 = 1.012 \times 10^5\ Pa} = 1\ atm$

(b) isochoric $V_2 = V_1 \Rightarrow \dfrac{T_2}{P_2} = \dfrac{T_1}{P_1} \Rightarrow T_2 = \left(\dfrac{P_2}{P_1}\right) T_1 = (5)\,406\ K$ $\boxed{T = 2030\ K}$

(c) isothermal $T_2 = T_3 \Rightarrow P_2 V_2 = P_3 V_3 \Rightarrow V_3 = \left(\dfrac{P_2}{P_3}\right) V_2 = (5)(0.001\ m^3)$ $\boxed{V_3 = 0.005\ m^3}$

(d) isobaric $W_{on} = -P_1 \Delta V = -P_1(V_1 - 5V_1)$
$= 4P_1V_1 = 4(1.012\times10^5\ Pa)(0.001\ m^3)$

$\boxed{W_{on} = 405\ J}$

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(15 points, 3 points each): 5 Multiple-choice questions / fill-in-the-blanks on various topics.

Directions for multiple-choice questions: COMPLETELY FILL IN THE SQUARE for the answer. Directions for fill-in-the-blank questions: Your answer should be entirely in the boxed region. Include the number of significant figures ("sig. figs.") requested in the problem.

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4. The surface area of a rare coin made of an exotic metal alloy increases by 0.1% when heated by 160°C. Which of the following is closest to the average coefficient of linear expansion for the metal alloy that comprises the coin?

■ 3×10^{-6} per K
☐ 5×10^{-6} per K
☐ 8×10^{-6} per K
☐ 3×10^{-5} per K
☐ 5×10^{-5} per K
☐ 8×10^{-5} per K

$$\frac{\Delta A}{A} = (2\alpha)\Delta T$$
$$\alpha = \frac{\Delta A / A}{2\,\Delta T} = \frac{0.001}{2(160\text{K})} \simeq 3\times10^{-6}/\text{K}$$

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5. An 1 kg aluminum pan ($c_{\text{Al}} = 900\ \text{J/kg·K}$) is removed from the stove and punged into a sink filled with 10 kg of water ($c_{\text{water}} = 4190\ \text{J/kg·K}$) at 20.0°C. The water temperature quickly rises to $\boxed{24.0°\text{C}}$. What was the initial temperature of the pan?

$T_f = 24°\text{C}$

☐ 186°C
☐ 166°C
☐ 162°C
■ 210°C
☐ 206°C

$$Q_{Al} + Q_{water} = 0$$
$$m_{Al} c_{Al} \Delta T_{Al} + m_{water} c_{water} \Delta T_{water} = 0$$
$$\cancel{(1\text{ kg}) c_{Al} \Delta T_{Al} + (10\text{ kg})}$$
$$\Delta T_{Al} = \frac{-m_{water} c_{water} \Delta T_{water}}{m_{Al} c_{Al}} = \frac{-(10\text{ kg})(4190\ \text{J/kg·K})(4\text{K})}{(1\text{ kg})(900\ \text{J/kg·K})}$$
$$T_f - T_i = -186\text{ K}$$
$$T_i = 210°\text{C}$$

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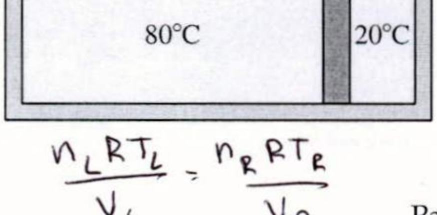
6. The cylinder in the figure below is divided into two compartments by a frictionless piston that can slide back and forth freely. Both compartments are filled with the same gas and the piston is in equilibrium. The compartment on the left, at temperature 80.0°C, is exactly four times the volume of the compartment on the right, which is at temperature 20.0°C. If the number of moles of gas in the right compartment is n, how many moles of gas is in the left compartment?

piston in equil. (Forces cancel out) $\Rightarrow P_L = P_R$



$$\frac{n_L R T_L}{V_L} = \frac{n_R R T_R}{V_R}$$

☐ Less than 3.00n
■ Between 3.00n and 4.00n
☐ Exactly 4.00n
☐ Between 4.00n and 5.00n
☐ Greater than 5.00n

$$n_L = 4n\left(T_R/T_L\right) = 4n\left(\frac{293\text{K}}{353\text{K}}\right) = 3.32n$$

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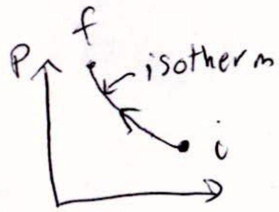
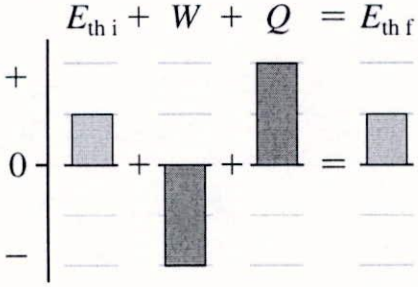
7. Which of the following is NOT true for the first-law bar chart of an ideal gas process shown below?





$\Delta E_{th} = 0 \Rightarrow \Delta T = 0$
$W < 0 \Rightarrow \Delta V > 0$

- ☐ The temperature of the gas remains the same.
- ☐ The volume of the gas increases.
- ■ The pressure of the gas increases.

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8. You have two temperature scales: °R and °S. The freezing point of water is −80.0°R, which is equal to +50.0°S. The boiling point of water is +20.0°R, which is equal to +250.0°S. Convert 0.0°R to °S. (express your answer in °S to 2 sig figs).

+20°R — +250°S
0°R
−80°R — +50°S

210°S

$y\,°S \equiv x\,°R$

$y = mx + b = 2x + 210 \Rightarrow @\ x = 0,\ y = 210$

$\Rightarrow 250 = m(20) + b$
$\quad 50 = m(-80) + b$

$\Rightarrow 200 = 100m \Rightarrow m = 2$
$\quad 250 = (2)(20) + b \Rightarrow b = 210$