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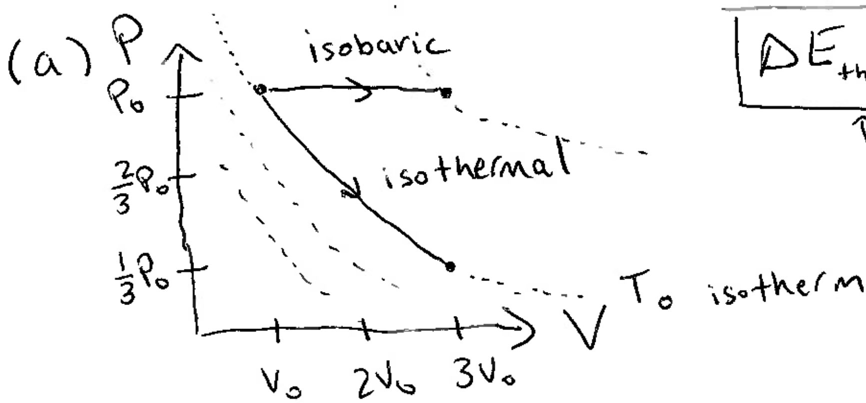
1. (10 points, 5 points each): A gas can expand to three times its volume two different ways: if it does so through an isobaric expansion, then the gas requires an amount of heat Q_1. However, if the expansion instead occurs via an isothermal expansion, the gas requires heat Q_2.

   (a) Draw these two processes on a pV diagram. Which of the two processes has a greater increase in internal (thermal) energy?

   (b) Which is bigger: Q_1 or Q_2? Provide a proof.

(a)



$$\boxed{\Delta E_{th,\,isobaric} > 0 = E_{th,\,isothermal}}$$

since $\Delta T > 0$ since $\Delta T = 0$

(b) For process 2, $\Delta E_{th,2} = 0 = W_2 + Q_2 \Rightarrow Q_2 = -W_2$

$$W_2 = -\int_{V_0}^{3V_0} p\,dV = -\int_{V_0}^{3V_0} \frac{nRT_0}{V}\,dV = -nRT_0 \ln(3) = -p_0V_0\ln(3)$$

$$\Rightarrow Q_2 = p_0V_0\ln(3)$$

For process 1, $\Delta E_{th,1} = (W_1 + Q_1) > 0$ (from part a)

$W_1 = -p_0(2V_0) = -2p_0V_0 \Rightarrow Q_1 = \Delta E_{th,1} - W_1$

$$= \underbrace{\Delta E_{th,1}}_{(>0)} + \underbrace{2p_0V_0}_{(>p_0V_0\ln(3))}$$

$$\Rightarrow \boxed{Q_1 > Q_2}$$

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2. (20 points, 5 points each): Short-answer questions on unrelated topics. Provide an explanation / justification for each; correct answers without explanation receive no credit.

   (a) An absolute temperature scale, degrees Duarte, has the freezing point of water at 50°D. What is the boiling point of water in °D?

   (b) How much space does 1.0 mol of gas take up at room temperature and atmospheric pressure? (estimate "room temperature" inside the classroom.)

   (c) Two identical gas-cylinder systems expand from the same initial state (p_i, V_i) to final states that share the same volume $V_f > V_i$. One system expands isothermally and one isobarically. Draw these two processes on the same pV diagram. Also, rank the two processes according to the work done on the gas, greatest first.

   (d) A chemical compound has its solid-liquid-gas triple point at pressure 2.0 atm and temperature 100.0°C. Also, its critical point occurs at pressure 10.0 atm and at temperature 300.0°C. Draw a reasonable phase diagram for this substance. Under what condition(s) on temperature and/or pressure can the material boil and undergo a distinct phase change?

(a) To convert, it's a linear transform $(y)^\circ D \equiv (X)\ K$ with $y = mx + b$

$x = 0,\ y = 0$ (abs. temp. scales) $\Rightarrow b = 0$

$50^\circ D \equiv 273\ K \Rightarrow 50 = m(273) \Rightarrow m = \frac{50}{273}$

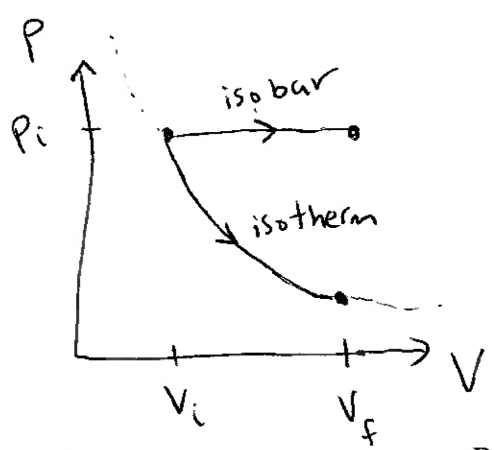
(@ boiling pt.) So $y = \left(\frac{50}{273}\right)(373) = \boxed{68.3}$

(b) estimate room temp as $20^\circ C$

$pV = nRT$

$(1.013 \times 10^5\ Pa)V = (1\ mol)(8.31\ \frac{J}{mol \cdot K})(293\ K)$

$\Rightarrow \boxed{V = 0.024\ m^3 = 24\ L}$

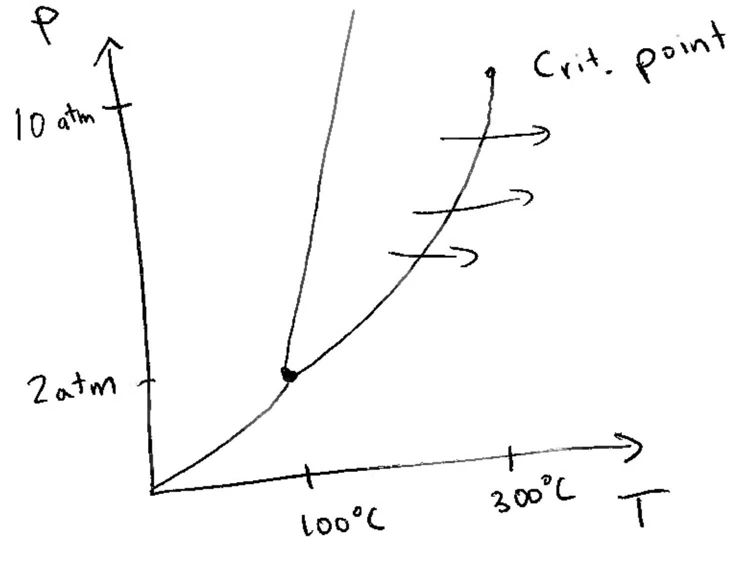
(c) 

For work done on the gas,

$0 > W_{isotherm} > W_{isobar}$

(Note negative sign! $|W_{isobar}| > |W_{isotherm}|$)

(d)



To boil (liquid → gas phase trans.) the pressure must be

$2\,atm < p < 10\,atm$

and T_{boil} is

$100°C < T_{boil} < 300°C$

depending on the pressure.

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3. (10 points, 5 points each): A microwave can heat up 1 cup of water (237 mL) $\approx 237\text{ g}$ from room temperature (20°C) to 80°C in 90 seconds. Recall the specific heat of water is 4.19 kJ/(kg·K), the latent heat of fusion is 333 kJ/kg, and the latent heat of vaporization is 2260 kJ/kg.

   (a) What is the power delivered to the water?

   (b) Assuming the same rate of power delivered to the water, how much additional time would it take to completely boil all of the water?

(a) $$\text{Power} = \frac{\text{heat energy}}{\text{time}} = \frac{Q}{\Delta t} = \frac{m\,C_{water}\,\Delta T}{\Delta t}$$

$$= \frac{(0.237\text{ kg})(4.19\,\frac{\text{kJ}}{\text{kg K}})(60\text{ K})}{90\text{ s}}$$

$$= \boxed{662\text{ W}}$$

(b) $$Q_{total} = Q_{80°C \to 100°C} + Q_{water \to steam}$$

$$= m\,C_{water}\,\Delta T + m L_v$$

$$= (0.237\text{ kg})(4.19\,\frac{\text{kJ}}{\text{kg K}})(20\text{ K}) + (0.237\text{ kg})(2260\text{ kJ/kg})$$

$$= 19.9\text{ kJ} + 536\text{ kJ} \approx 556\text{ kJ}$$

$$t = \frac{556 \times 10^{3}\text{ J}}{662\text{ J/s}} = \boxed{840\text{ s}}$$

$$\boxed{14\text{ min}}$$

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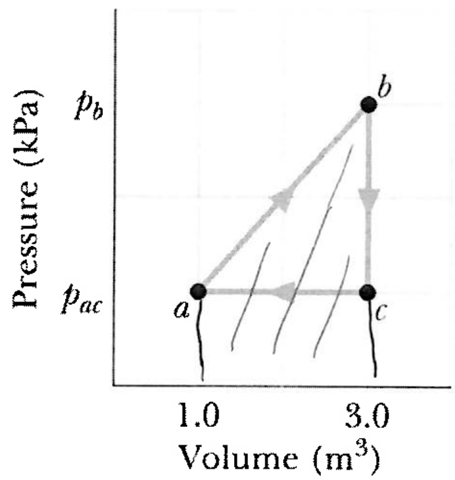
4. (15 points, 5 points each) A sample of a monoatomic ideal gas is taken through the cyclic process $a \to b \to c \to a$ shown in the figure below. The pressures satisfy $p_b = 3.00 \times 10^5$ Pa and $p_{ac} = 1.00 \times 10^5$ Pa. In addition, for point a, the gas is at a temperature of 100.0 K.

$T_a = 100\ K$



(a) Find the temperature of the gas at point b and the number of moles of gas.

(b) Find the work done on the gas along the path $a \to b$.

(c) Find the heat added to the gas along the path $a \to b$.

(a) $n = \dfrac{p_a V_a}{R T_a} = \dfrac{10^5\ J}{831\ J/mol} = \boxed{120\ mol}$

$p_b V_b = n R T_b \Rightarrow T_b = \dfrac{p_b V_b}{n R} = \dfrac{9 \times 10^5\ J}{(120\ mol)(8.31 \frac{J}{mol \cdot K})} = \boxed{900\ K}$

Conversely, both V and p triple and $T \propto pV$ so T goes up by 9x

(b) $W^{(ab)} = -\int_a^b p\,dV = -4\left[\begin{matrix}\text{area of} \\ 1\ \text{sq.}\end{matrix}\right] = 4\left[10^5\ J\right] = \boxed{400\ kJ}$

(c) from 19.7 (should be given in prob)

$\Delta E_{th}^{(ab)} = n C_v \Delta T = (120\ mol)\left(\frac{3}{2}\right)\left(8.31 \frac{J}{mol \cdot K}\right)(800\ K)$

$= 1200\ kJ$

$C_v = \frac{3}{2} R$ for monotamic gas

$\Delta E_{th}^{(ab)} = Q^{(ab)} + W^{(ab)}$

$1200\ kJ = Q^{(ab)} - 400\ kJ$

$\Rightarrow \boxed{Q^{(ab)} = 1600\ kJ}$

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5. (15 points, 5 points each) Suppose you have a sealed container with a 1 kg block of ice at −20°C and 1.0 atm. You continuously heat up the ice until it melts into water, and you continue heating up the water until it reaches 20°C.

   (a) Given the specific heat of ice $c_{\text{ice}} = 2.090$ kJ/(kg·K), how much heat Q_1 do you have to add to reach the melting point temperature (note: not all of the ice melts at this point)?

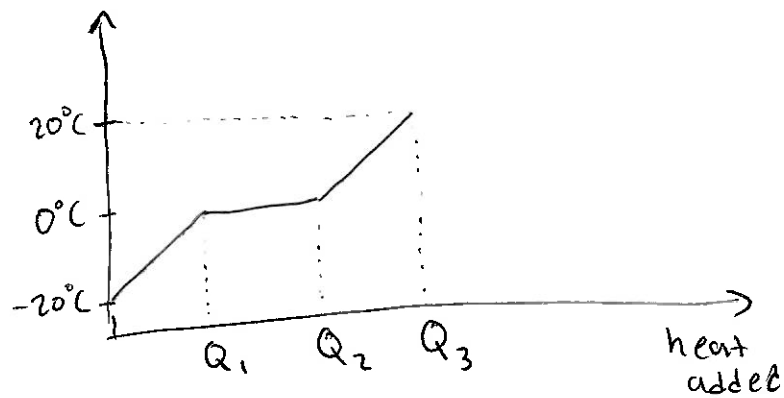
   (b) Sketch the graph of T vs Q. On the T-axis, there should be 3 significant temperature labels, including −20°C and 20°C. On the Q-axis, there should be 3 significant heat added labels, including Q_1, which you calculated in part (a), and Q_3 (the total heat added).

   (c) Given the heat of fusion $L_f = 0.333$ MJ/kg and the specific heat of water $c_{\text{water}} = 4.190$ kJ/(kg·K), compute the remaining variables Q_2 and Q_3.

(a) $Q_1 = m c_{ice} \Delta T$ $\qquad \Delta T = 20\ K$

$= (1\ kg)(2.090\ kJ/kg\cdot K)(20\ K) = 41.8\ kJ$

(b)



(c) $Q_2 = Q_1 + m L_f = 41.8\ kJ + (1\ kg)(333\ kJ/kg)$

$\boxed{Q_2 = 375\ kJ}$

$Q_3 = Q_2 + m\, c_{water} \Delta T$

$= 375\ kJ + (1\ kg)(4.19\ \frac{kJ}{kg\cdot K})(20\ K)$

$\boxed{Q_3 = 459\ kJ}$

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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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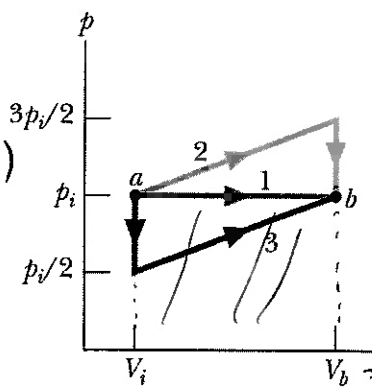
6. Shown below are three processes: 1, 2, and 3. All three processes have the same starting point a and the same final point b. $V_b = 5V_i$, and the heat added to the gas in process 1 is $10p_iV_i$. What is the change in internal energy the gas undergoes in process 3?

- ☐ $2p_iV_i$
- ☐ $4p_iV_i$
- ☐ $4p_iV_i$
- ■ $6p_iV_i$
- ☐ $8p_iV_i$
- ☐ $10p_iV_i$

$$\Delta E_{th}^{(3)} = \Delta E_{th}^{(1)} = Q^{(1)} + W^{(1)} = 10p_iV_i - p_i(4V_i) = 6p_iV_i$$



$W^{(1)} = -4p_iV_i$

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7. A mercury thermometer has markings equally-spaced from 0.0°C to 30.0°C. The mercury in this region sits in a vertical cylinder of radius 1.0 mm, and the distance between the 0.0°C and 30.0°C markings is 10.0 cm. It works because of the expansion of the mercury when it gets warmer. Which of the following is closest to the total volume of mercury? The coeffcient of volume expansion of mercury is 2.0×10^{-4} per Kelvin.

- ☐ 0.05 cm^3
- ☐ 0.1 cm^3
- ☐ 0.5 cm^3
- ☐ 1 cm^3
- ☐ 5 cm^3
- ☐ 10 cm^3
- ■ 50 cm^3

$$\frac{\Delta V}{V} = \beta \Delta T = \left(2.0\times10^{-4}\ \frac{1}{K}\right)(30.0\ K)$$

$$V = \left(\frac{1}{0.0060}\right)\Delta V = (167)(\Delta V$$

$$\Delta V = \pi r^2 \Delta h = \pi (0.001\ m)^2 (0.100\ m) = 3.14\times10^{-7}\ m^3$$

$$V = 5.2\times10^{-5}\ m^3 = 52\ cm^3$$

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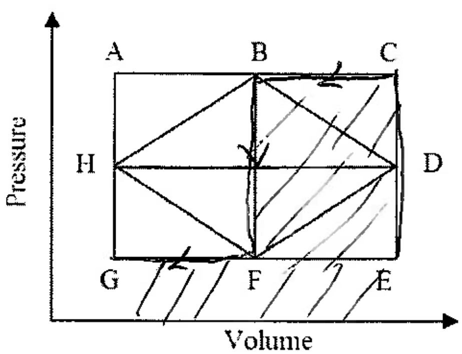
(Note: this prob. requires 19.17)

8. Which of the following statements is TRUE?

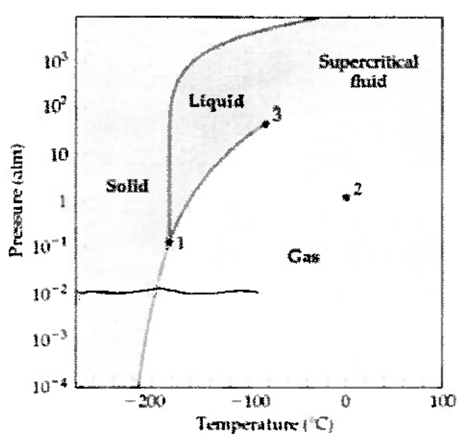
- [ ] When a fixed amount of ideal gas goes through an isobaric expansion, its thermal energy decreases. increases
- [ ] An ideal gas is compressed in a well-insulated chamber using a well-insulated piston. This process is best described as isobaric. adiabatic (no heat exchange)
- [x] In an adiabatic expansion, the thermal energy of a gas decreases.
- [ ] In an adiabatic compression, the thermal energy of a gas ~~remains constant~~. increases

9. Consider the pV diagram shown. There are eight points labeled and the choices below indicate possible multi-step processes. In which one of the processes does the work done on the gas have the greatest (most positive) value?



- [ ] G-H-B-D
- [ ] G-H-B-D
- [ ] H-A-B-D
- [ ] E-D-F-H
- [x] C-B-F-G

10. Which of the following is NOT true for the phase diagram shown below?



- [ ] The material is a gas at 1 atm and room temperature. True
- [ ] The maximum density of the material is in its solid phase. True
- [ ] The material sublimates at 0.01 atm. True
- [x] It is impossible to have the material in gas form, liquid form, and solid form at a single temperature.