Physics 3410 Exam 2 Solutions

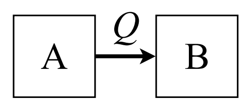
April 13, 2016

---

1. Heat flows from system A to system B.

$\boxed{3}$ (a) **C** During the heat flow, the entropy of A

A) increases **B)** stays the same **C)** decreases

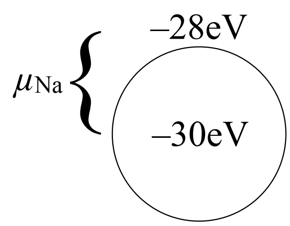


$\boxed{3}$ (b) If U_A and U_B are the energies of the two systems, what is $\frac{dU_A}{dU_B}$?

$\frac{dU_A}{dU_B} = \boxed{-1}$ because as A loses energy, B gains the same amount of energy.

$\boxed{3}$ 2. **A** The chemical potential of sodium inside a cell is $\mu_{\rm Na} = -30\,\text{eV}$; outside the cell, $\mu_{\rm Na} = -28\,\text{eV}$. For the two sides to reach equilibrium, sodium would have to flow

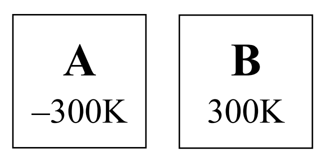
A) into the cell **B)** out of the cell



Particles flow from higher to lower chemical potential

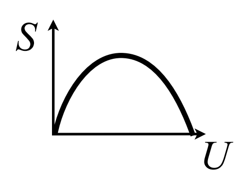
$\boxed{3}$ 3. **A** System A has a temperature of $T = -300\,\text{K}$, and system B has a temperature of $T = 300\,\text{K}$. If the systems are placed in contact,

A) heat will flow from A to B
B) heat will flow from B to A
C) they will undergo matter-antimatter annihilation
D) none of the above



$\boxed{2}$ 4. **B** A paramagnet in a magnetic field has an entropy $S(U)$ as shown. It has negative temperature when its energy is

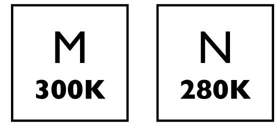
A) low **B)** high **C)** never



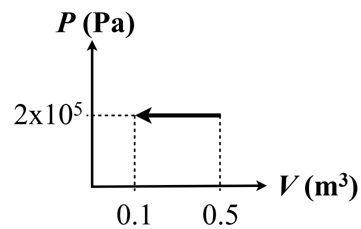
$S(U)$ for a paramagnet

$\boxed{3}$ 5. **A** A miserly system at $T = 300\,\mathrm{K}$ is placed in contact with a normal system at $T = 280\,\mathrm{K}$. What happens initially?

A) Both systems get hotter **B)** Both systems get colder
C) M gets colder, N gets hotter **D)** None of these.



6. The figure shows a process of an ideal gas with $f = 3$, on a PV diagram. The internal energy decreases by $-120\,\mathrm{kJ}$ during the process.



$\boxed{3}$ (a) **C** How much work is done during this process? (Positive means work flows into the gas.)

A) $+10\,\mathrm{kJ}$ **B)** $+20\,\mathrm{kJ}$ **C)** $+80\,\mathrm{kJ}$
D) $-10\,\mathrm{kJ}$ **E)** $-20\,\mathrm{kJ}$ **F)** $-80\,\mathrm{kJ}$

Area under the rectangle, positive because the work flows inward. $(0.4\,\mathrm{m}^3)(2 \times 10^5\,\mathrm{Pa}) = +80 \times 10^3\,\mathrm{J}$

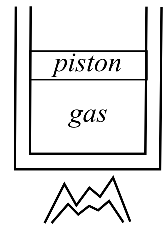
$\boxed{3}$ (b) **D** *How much* heat Q flows into or out of the gas?

A) $0\,\mathrm{kJ}$
B) $-80\,\mathrm{kJ}$ **C)** $-120\,\mathrm{kJ}$ **D)** $-200\,\mathrm{kJ}$
E) $+80\,\mathrm{kJ}$ **F)** $+120\,\mathrm{kJ}$ **G)** $+200\,\mathrm{kJ}$

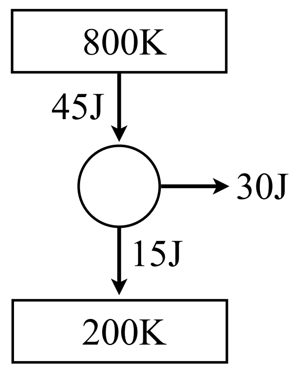
$80\,\mathrm{kJ}$ of work flows into the gas, but the internal energy still decreases by $120\,\mathrm{kJ}$, so heat must flow out: $-120 - 80 = -200\,\mathrm{kJ}$

3 7. **A** Which is faster?
A) an adiabatic process **B)** an isothermal process

3 8. **B** Suppose gas is in a container sealed by an ideal piston that is free to move. The gas is heated, and the gas expands. This is an ... expansion.
A) adiabatic **B)** isobaric **C)** isothermal



9. This figure shows a heat engine operating between 200 K and 800 K.



3 (a) **C** What is this engine's efficiency?
A) 25% **B)** 33% **C)** 67% **D)** 75%

$\eta = W/Q_{in} = 30/45 = 67\%$

3 (b) How much work would this engine produce for the same amount of heat $Q_{in} = 45\,\text{J}$, if it were a Carnot engine?

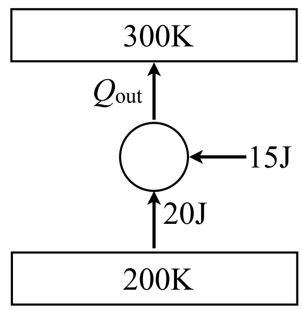
The efficiency in that case would be $\eta = 1 - \frac{T_C}{T_H} = 75\%$, which would mean $W = (45\,\text{J})(75\%) = \boxed{34\,\text{J}}$

$\boxed{3}$ 10. **A** Nitrogen gas ($f = 5$) at standard pressure ($P = 1\,\text{atm}$) expands adiabatically to twice its volume. What is the pressure of the gas after the expansion?
A) 0.38 atm **B)** 0.5 atm **C)** 1 atm **D)** 2 atm **E)** 2.6 atm

$P_i V_i^\gamma = P_f V_f^\gamma$ where $\gamma = \frac{f+2}{f} = \frac{7}{5}$.

$$P_f = P_i \left(\frac{V_i}{V_f}\right)^\gamma = (1\,\text{atm}) \left(\frac{V_i}{2V_i}\right)^{7/5} = 0.38\,\text{atm}$$

11. This figure shows a refrigerator.



$\boxed{3}$ (a) **D** How much heat Q_{out} flows into the hot reservoir?
A) 5 J **B)** 15 J
C) 20 J **D)** 35 J

$\boxed{3}$ (b) **D** What is its Coefficient of Performance?
A) 0.33 **B)** 0.43 **C)** 0.75
D) 1.33 **E)** 2 **F)** 2.33

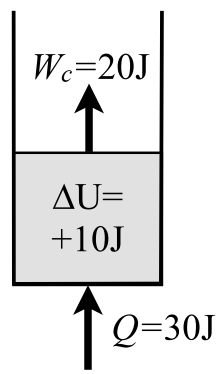
$$COP = \frac{Q_{in}}{W} = \frac{20\,\text{J}}{15\,\text{J}} = \boxed{133\%}$$

$\boxed{3}$ 12. **B** Which of these is an intensive quantity?
A) internal energy **B)** pressure **C)** volume

$\boxed{3}$ 13. **A** A car has two identical hubcaps: one is shiny and new, the other is rusty. Which has the larger Gibbs free energy?
A) the shiny one **B)** the rusty one

$\boxed{3}$ 14. **D** How does the van der Waals model differ from the ideal gas model?
A) it models a phase transition
B) it takes into account the minimum volume of atoms
C) it explains the critical point
D) all of the above

15. During a chemical process at constant temperature and pressure, 30 J of heat flows into the system, the internal energy increases by $\Delta U = +10\,\text{J}$, and 20 J of compression work flows outward to move the air out of the way.



$\boxed{2}$ (a) **F** What is the change ΔH in the enthalpy?
A) $-20\,\text{J}$ **B)** $-10\,\text{J}$ **C)** $0\,\text{J}$
D) $+10\,\text{J}$ **E)** $+20\,\text{J}$ **F)** $+30\,\text{J}$

Change in enthalpy is equal to the heat flow inward.

$\boxed{2}$ (b) **C** What is the change ΔG in the Gibbs free energy?
A) $-20\,\text{J}$ **B)** $-10\,\text{J}$ **C)** $0\,\text{J}$
D) $+10\,\text{J}$ **E)** $+20\,\text{J}$ **F)** $+30\,\text{J}$

There is no non-compression work.

16. We can write the thermodynamic identity of a rubber band as

$$dU = T\,dS + F\,dL$$

where L is the length of the rubber band, and F is the tension in the rubber band.

$\boxed{3}$ (a) What are the natural variables of U *in this case*?

S and L

$\boxed{3}$ (b) What is $\left(\frac{\partial S}{\partial L}\right)_U$?

$$-\left(\frac{F}{T}\right)$$

$\boxed{3}$ (c) __C__ Which of these is a pair of conjugate variables?

A) T & U **B)** S & L **C)** F & L **D)** U & S

$\boxed{3}$ 17. What is $\left(\frac{\partial H}{\partial S}\right)_{P,N}$?

T

18. In the following equation, fill in the blanks.

$$\boxed{\left(\frac{\partial \boxed{\text{(a)}}}{\partial V}\right)_{T,N} = \boxed{\text{(c)}}\left(\frac{\partial P}{\partial N}\right)_{V,\boxed{\text{(b)}}}}$$

$\boxed{2}$ (a) μ

F) F μ**)** μ **N)** N **P)** P **S)** S **T)** T **V)** V

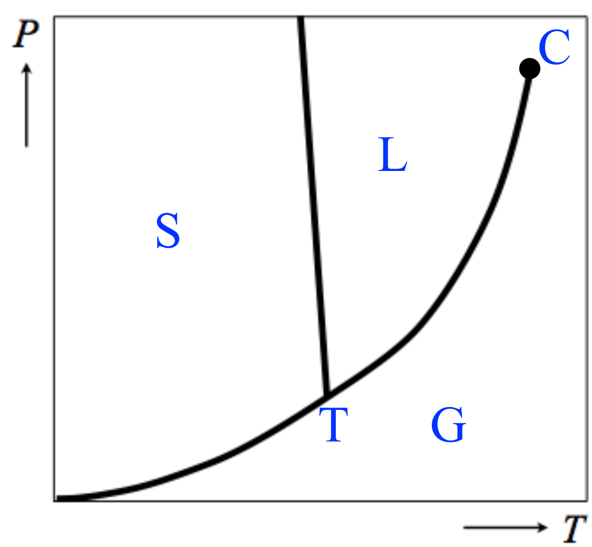
$\boxed{2}$ (b) **T**

F) F μ**)** μ **N)** N **P)** P **S)** S **T)** T **V)** V

$\boxed{2}$ (c) $-$

+) $+$ **−)** $-$

$\boxed{5}$ 19. This figure is the phase diagram of water. Label the following regions and points on the diagram. (You can use the letter or the word as you like.)
S) solid **L)** liquid **G)** gas **T)** triple point **C)** critical point



20. Consider a new material called *bowlingrene*. At standard atmospheric pressure, the Gibbs free energy (in joules per mole) of the solid and liquid phases of bowlingrene, as functions of temperature, are

$$\text{solid: } G_s(T) = -8000 - 30T \qquad \text{liquid: } G_l(T) = +8000 - 80T$$

The entropy of each phase is independent of temperature, and the pressure is held constant.

$\boxed{3}$ (a) Find the entropy (per mole) of solid bowlingrene.

$$S = -\frac{\partial G}{\partial T} = \boxed{30\,\mathrm{J/K}}$$

$\boxed{3}$ (b) <u>**A**</u> At 300 K, bowlingrene is

A) solid **B)** liquid

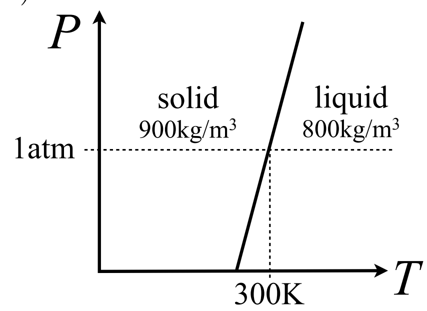
At 300 K, $G_s(300) = -8000 - 9000 = -17\,\mathrm{kJ}$ and $G_l(300) = +8000 - 24000 = -16\,\mathrm{kJ}$. The solid has the lower Gibbs free energy so it is the stable phase.

$\boxed{3}$ (c) Find the melting/freezing temperature of bowlingrene. *(Note: your answer shouldn't contradict your answer to part (b).)*

The melting temperature is where $G_s = G_l$:

$$-8000 - 30T = 8000 - 80T \implies 50T = 16000 \implies T = \boxed{320\,\mathrm{K}}$$

$\boxed{\text{3 XC}}$ 21. **Extra Credit:** The figure shows the boundary between the solid and liquid phases of a material. At $P = 1\,\text{atm}$, the solid phase has a density of $\rho = 900\,\text{kg/m}^3$, the liquid phase has a density of $\rho = 800\,\text{kg/m}^3$, and the latent heat of fusion is $L = 4000\,\text{J/kg}$. Find the slope of the boundary (with the correct units).



The slope is

$$\frac{dP}{dT} = \frac{L}{T\Delta(1/\rho)}$$

$$= \frac{4000\,\text{J/kg}}{(300\,\text{K})(1/800\,\text{kg/m}^3 - 1/900\,\text{kg/m}^3)}$$

$$= \boxed{96{,}000\,\text{Pa/K}}$$