

1) At one end of a long room there is a container of  ${}^4\text{He}$  gas (atomic weight = 4 g/mole) and a container of  ${}^3\text{He}$  gas (atomic weight 3 g/mole). At the other end of the room, there is a machine that can detect both  ${}^3\text{He}$  and  ${}^4\text{He}$ . The machine is equidistant from the two gas containers. When a tiny amount of  ${}^4\text{He}$  is released, the machine detects it in 5 sec. If, instead, a tiny amount of  ${}^3\text{He}$  is released, after how many seconds will it be detected? Assume that the helium isotopes have identical mean free paths.

- a. 2.8 s
- b. 4.3 s**
- c. 3.8 s
- ~~d. 5.8 s~~
- ~~e. 6.7 s~~

$\langle x \rangle = 0$        $\langle x^2 \rangle = 2Dt$        $v_{rms} = \sqrt{\frac{3kT}{m}}$   
 $t \propto \frac{1}{D} = \frac{1}{\frac{1}{3} \lambda v}$        $D = \frac{1}{3} \lambda v$   
 $v \propto v_{rms} = \sqrt{\frac{3kT}{m}}$   
 $\frac{1}{2} m \langle v^2 \rangle = \frac{3}{2} kT$   
 $\langle v^2 \rangle \propto \frac{1}{m}$

$$\frac{t_{3\text{He}}}{t_{4\text{He}}} = \sqrt{\frac{m_{3\text{He}}}{m_{4\text{He}}}} = \sqrt{\frac{3}{4}}$$

$$t_{3\text{He}} = t_{4\text{He}} \sqrt{\frac{3}{4}} = 5 \cdot \sqrt{\frac{3}{4}}$$

2) Liquid water ( $\text{H}_2\text{O}$ ) has a specific heat of  $75.31 \text{ J/mole} \cdot \text{K}$ . Based upon this information, if you treated each water molecule in the liquid as if it obeyed equipartition, approximately how many degrees of freedom would it have? You may ignore the difference between  $C_v$  and  $C_p$  for this problem.

- a. 6
- b. 9
- c. 21
- d. 12
- e. 18

Equipartition: Every degree of freedom (DOF) (w/ a quadratic energy dependence) has average thermal energy  $\frac{1}{2}kT$

DOF

$$3 - C_{\text{monatomic}} = Nk \frac{3}{2}$$

5

$$C_{\text{diatomic}} = Nk \frac{5}{2}$$

$$C = \frac{dU}{dT}$$

$$U = \frac{1}{2} NkT \Rightarrow Nk \frac{7}{2}$$

$$c \text{ per molecule} = \frac{R}{2} (N_{\text{DOF}})$$

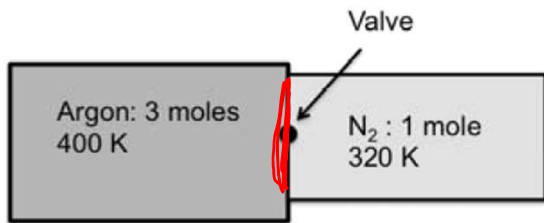
$$= \frac{75.31 \text{ J}}{\text{mole} \cdot \text{K}} \cdot \frac{1 \text{ mole}}{N_A}$$

$$N_{\text{DOF}} = 2 \frac{75.31}{R}$$

$$= 2 \frac{75.31}{8.314}$$

$$= \frac{2 \cdot 75.31}{8.314} = 18.1$$

3) Two containers of gas are separated by a closed valve. Container A holds 3 moles of Argon gas at temperature 400 K. Argon is monatomic. Container B holds 1 mole of nitrogen gas at temperature 320 K. Nitrogen is diatomic. Now the valve is opened, allowing the gases to mix. What is the final temperature of the gas mixture? Assume (1) no heat enters or leaves from the environment, (2) no work is performed and (3) the containers themselves have negligible heat capacity.



- a. 278.5 K
- b. 371.4 K
- c. 305.2 K
- d. 381.1 K
- e. 360.0 K

Temperature of each component is not affected by spreading, only affected by thermalization w/ other gas

$$Q_{\text{into } N_2} = Q_{\text{out of } Ar}$$

$$Q_{N_2} + Q_{Ar} = 0$$

$$(T_f - T_{N_2})C_{N_2} + (T_f - T_{Ar})C_{Ar} = 0$$

$$T_f = \frac{T_{N_2}C_{N_2} + T_{Ar}C_{Ar}}{C_{N_2} + C_{Ar}} = \frac{320 \cdot \frac{5}{2} \cdot 1R + 400 \cdot \frac{3}{2} \cdot 3R}{\frac{5}{2} \cdot 1R + \frac{3}{2} \cdot 3R} = 371.4$$

$$C_{N_2} = \frac{5}{2} NR = \frac{5}{2} nR$$

$$C_{Ar} = \frac{3}{2} nR$$

What if  $T_{Ar} = 400K$   
 $T_{N_2} = 320K$   $C_{N_2} = 1$

What is entropy change of Ar?

Quasi-static  $\rightarrow$  Heat flow  $dS = \frac{dq}{T} = \frac{C dT}{T}$   
 $\Delta S_T = C \ln \frac{T_f}{T_i}$

free expansion:

$$\frac{d\alpha_{He}}{dU_{He}} = \frac{d\alpha_{N_2}}{dU_{N_2}} = \frac{1}{kT}$$

$$\Omega = \frac{(n_1 V)^{N_1}}{N!}$$

$$S = k \sigma = k R R R$$

$$\Delta S_V = k N \ln \frac{V_f}{V_i}$$

Which is bigger?

$$\Delta S_{Ar, T} < 0 \quad \Delta S_{Ar, V} > 0$$

Which is bigger?

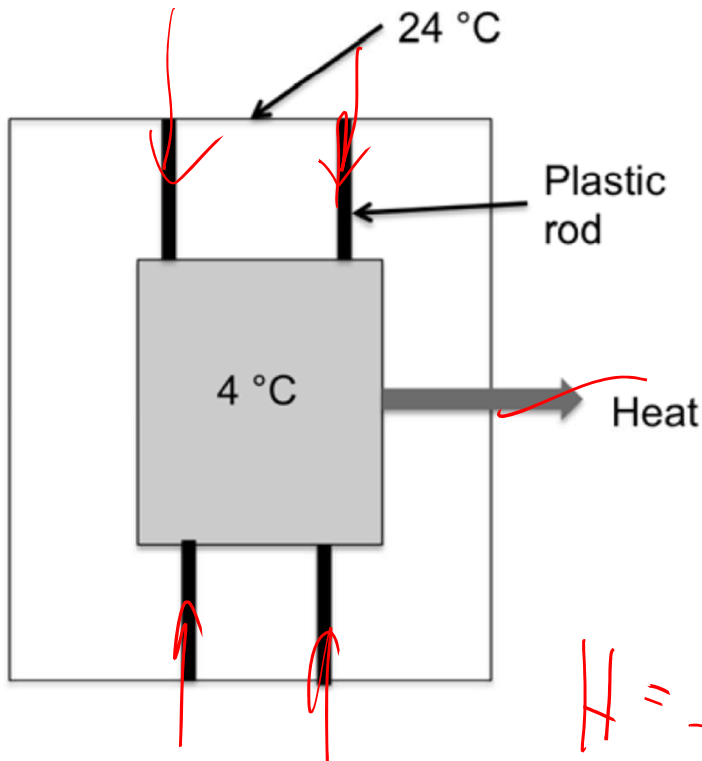
$$\Delta S_{Ar, T} < 0 \quad \Delta S_{N_2, T} > 0$$

$$dS = \frac{dq}{T}$$

$$|\Delta S_{Ar, T}| < |\Delta S_{N_2, T}| \quad \Delta S_{Ar} + \Delta S_{N_2} \neq 0$$

irreversible

4) We wish to maintain the inside of a refrigerator at  $4^\circ\text{C}$ . The inside compartment is connected to the outside by 4 plastic rods each 10 cm long with cross sectional area  $1\text{ cm}^2$  and thermal conductivity =  $2\text{ W/m-K}$ . If the outside of the refrigerator is always at  $24^\circ\text{C}$ , how much heat must be removed each second (in watts) by the refrigerator?



$$H = \frac{\Delta T}{R_{th}} \quad R_{th} = \frac{d}{KA}$$

4 parallel rods  
 $\approx 1$  rod with  $4\times$  area

$$R_{th} = \frac{d}{4KA}$$

$$H = \frac{20^\circ}{0.1\text{m}} (4) (2 \frac{\text{W}}{\text{m-K}}) \frac{1\text{cm}^2}{100^2\text{cm}^2} \frac{1\text{m}^2}{100^2\text{cm}^2}$$

a.  $0.040\text{ W}$

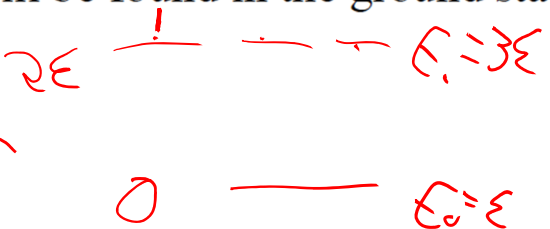
b.  $0.08\text{ W}$

c.  $0.160\text{ W}$

Consider a spinless particle having four allowed discrete energy states. There is a ground state with energy  $E_0 = \epsilon$  and three degenerate excited states with energy  $E_1 = 3\epsilon$ . where  $\epsilon = 9 \text{ meV}$ .

5) If such a particle is in thermal equilibrium with a 300K thermal reservoir, what is the probability that it will be found in the ground state?

- a. 0.59
- b. 0.67
- c. 0.4**
- d. 0.49
- e. 0.25



$$P(E) = \frac{e^{-E/kT}}{Z}$$

$$P_g = \frac{e^0}{1 + (e^{-2\epsilon/kT})^3}$$

$$e^{-\epsilon/kT} / (e^{-\epsilon/kT} + 3e^{-3\epsilon/kT})$$

$$\frac{2\epsilon}{kT} = \frac{0.018 \text{ eV}}{8.6 \times 10^{-5} \text{ eV/K} \cdot 300 \text{ K}}$$

$$= 0.7$$

What is prob. to not be in ground state?

$$\frac{1}{1 + 3e^{-0.7}}$$

$$P(E = \frac{3\epsilon}{E_1}) = \frac{e^{-2\epsilon/kT} + e^{-2\epsilon/kT} + e^{-2\epsilon/kT}}{1 + 3e^{-2\epsilon/kT}} = 0.6$$

$$P(1) = 0.2$$

Consider a spinless particle having four allowed discrete energy states. There is a ground state with energy  $E_0 = \varepsilon$  and three degenerate excited states with energy  $E_1 = 3\varepsilon$ . where  $\varepsilon = 9 \text{ meV}$ .

6) Consider now a collection of 1000 particles, each having the described single-particle energy level structure. What is the entropy of this system as its temperature approaches infinity?

a.  $1000 k_B \ln(3)$

b. 0

c.  $1000 k_B \ln(4)$

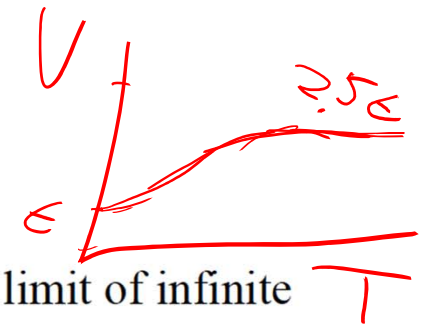


$T \rightarrow \infty$  all states equally likely

$$\Omega = 4^{1000}$$

$$\sigma = \ln \Omega = 1000 \ln 4$$

$$S = k_B \sigma$$



7) What is the heat capacity of this same collection of 1000 particles in the limit of infinite temperature?

a.  $500 k_B T$

b. 0

c.  $2000 k_B T$

You've already put in as much energy as you can (in equilibrium)

$$\therefore C \rightarrow 0$$

$$C = \frac{dU}{dT}$$

$$\langle E \rangle = \sum_n E_n P_n = \varepsilon \frac{1}{4} + 3\varepsilon \frac{3}{4} = \varepsilon \left( \frac{1}{4} + \frac{9}{4} \right) = 2.5\varepsilon$$

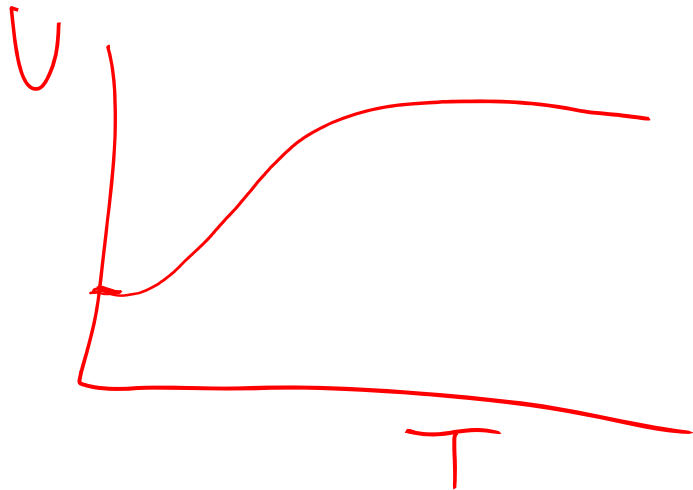
$$\langle E \rangle (T \rightarrow \infty) = 2\varepsilon$$

1000 particles  $\text{---}$   $\text{---}$   $\text{---}$   $\uparrow$   
 $2\epsilon$

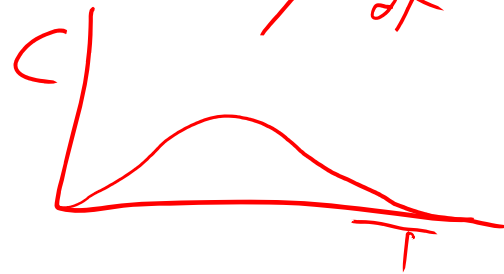
As  $T \rightarrow 0$

$$S = 0 = k_B \ln \Omega$$

$$C \rightarrow 0$$



If  $k_B T \ll 2\epsilon$ ,  
 not enough thermal  
 energy to excite  
 any of the molecules





Consider a simple model of a small block (consisting of three harmonic oscillators) brought into contact with a large block (consisting of 60 harmonic oscillators). All oscillators have the same frequency  $f$ . Before they are connected, each block has 6 total units of energy  $\varepsilon = hf$  ( $12\varepsilon$  total for both blocks combined), where  $h$  is Planck's constant.

8) Find the change in dimensionless entropy ( $\Delta\sigma = \sigma(\text{final}) - \sigma(\text{initial})$ ) of the entire system when the blocks are brought together and achieve thermal equilibrium. Please note: Stirling's approximation is not accurate enough for this calculation.

- a. 21.56
- ~~b. -21.56~~
- ~~c. -9.16~~
- ~~d. 0~~
- e. 9.16

$$\Omega = \frac{(q + N - 1)!}{q!(N-1)!}$$

$$\ln N! \approx N \ln N - N$$

$$\Omega_i = \Omega_1 \times \Omega_2 = \frac{(6+3-1)!}{6!(3-1)!} \cdot \frac{(6+60-1)!}{6!(60-1)!}$$

$$\sigma_1 = \ln \Omega_1 \quad \sigma_2 = \ln \Omega_2$$

$$\sigma_i = \sigma_1 + \sigma_2 = 21.56$$

$$\ln \Omega_1 + \ln \Omega_2$$

$$= \ln(\Omega_1 \times \Omega_2)$$

$$\Omega_f = \frac{(12 + 63 - 1)!}{12!(63-1)!}$$

$$\sigma_f = \ln \Omega_f = 30.7$$

Consider a simple model of a small block (consisting of three harmonic oscillators) brought into contact with a large block (consisting of 60 harmonic oscillators). All oscillators have the same frequency  $f$ . Before they are connected, each block has 6 total units of energy  $\epsilon = hf$  ( $12\epsilon$  total for both blocks combined), where  $h$  is Planck's constant.

9) What is the average energy per oscillator in the small block after it has come into thermal equilibrium with the large block?

- a. 0.19  $\epsilon$
- b. 0.05  $\epsilon$
- c. 0  $\epsilon$
- d. 3  $\epsilon$
- e. 1  $\epsilon$

all oscillators have same average energy

$$\frac{12\epsilon}{60 \text{ oscillators}} = 0.19\epsilon$$

10) What is the most likely energy for each oscillator in the small block after thermal equilibration occurs?

- a. 0.19  $\epsilon$
- b. 3  $\epsilon$
- c. 0  $\epsilon$

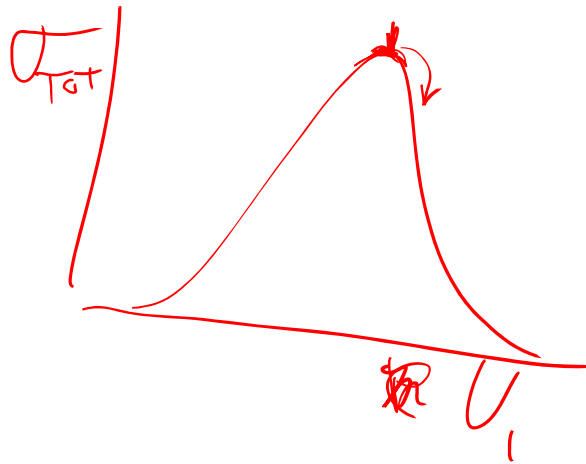
More microstates if you give energy to other 60 oscillators

Consider a simple model of a small block (consisting of three harmonic oscillators) brought into contact with a large block (consisting of 60 harmonic oscillators). All oscillators have the same frequency  $f$ . Before they are connected, each block has 6 total units of energy  $\varepsilon = hf$  ( $12\varepsilon$  total for both blocks combined), where  $h$  is Planck's constant.

11) Which of the following statements is true?

5

- a. in thermal equilibrium, transferring energy from one block to the other will decrease the entropy of the first block by more than it increases the entropy of the second block
- ~~b. the entropy of each block increases during the thermal equilibration process~~
- ~~c. the final entropy of the small block = the final entropy of the large block~~



$$dS = \frac{dQ}{T} = \frac{dU}{T}$$

In reaching thermal equil.  
Decrease of entropy of 1st block  
is less than increase of 2nd block

Consider a sealed container with a volume of  $1 \text{ m}^3$  filled with  $1 \times 10^{23}$  helium atoms and  $3 \times 10^{23}$  molecules of ammonia. Helium is a monatomic gas. The ammonia molecule ( $\text{NH}_3$ ) is a tetrahedron. Initially the temperature of the gas mixture is  $1000 \text{ K}$ . Assume throughout this problem that equipartition applies.

12) Find the pressure inside the container.

- a. 2760 Pa
- b. 1840 Pa
- c. 5520 Pa

$$pV = NkT$$
$$p_{\text{Tot}} = p_{\text{He}} + p_{\text{NH}_3} = \frac{kT}{V} [N_{\text{He}} + N_{\text{NH}_3}]$$
$$= \frac{1.38 \times 10^{-23} \cdot 1000}{1} [4 \times 10^{23}]$$

Doesn't matter what kind of molecule is bouncing off the wall

Consider a sealed container with a volume of  $1 \text{ m}^3$  filled with  $1 \times 10^{23}$  helium atoms and  $3 \times 10^{23}$  molecules of ammonia. Helium is a monatomic gas. The ammonia molecule ( $\text{NH}_3$ ) is a tetrahedron. Initially the temperature of the gas mixture is  $1000 \text{ K}$ . Assume throughout this problem that equipartition applies.

13) Find the ratio of the total molecular rotational energy to the total translational energy (helium + ammonia) inside the container.

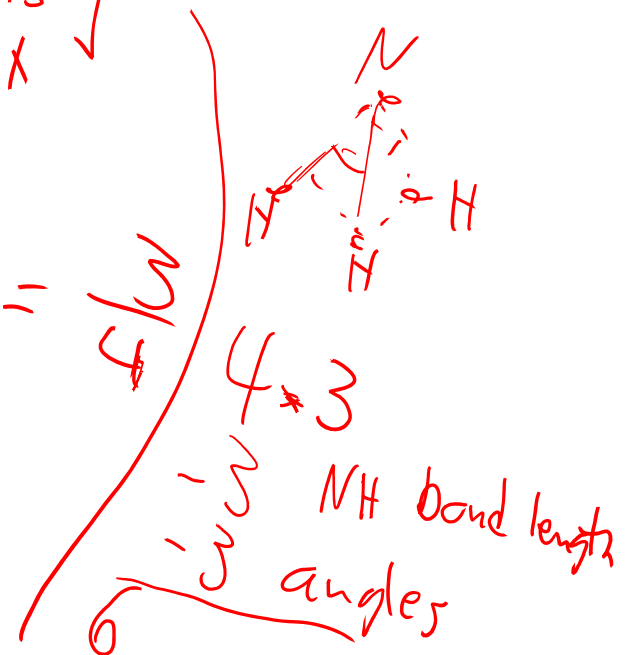
- a. 2.9
- b. 0.75
- c. 0.12
- d. 0.34
- e. 1

$$\langle \text{trans} \rangle = 3 \left( \frac{1}{2} kT \right) [N_{\text{He}} + N_{\text{NH}_3}]$$

$$\langle \text{rot} \rangle = \frac{1}{2} kT \times 3 [N_{\text{NH}_3}]$$

rotation about all 3 axes

$$\frac{\langle \text{rot} \rangle}{\langle \text{trans} \rangle} = \frac{N_{\text{NH}_3}}{N_{\text{NH}_3} + N_{\text{He}}} = \frac{3}{5+1} = \frac{3}{6} = \frac{1}{2}$$



$$\frac{\frac{3}{2} kT N_{\text{NH}_3}}{\frac{3}{2} kT N_{\text{NH}_3} + \frac{3}{2} kT N_{\text{NH}_3} + \frac{3}{2} kT N_{\text{He}}} = \frac{N_{\text{NH}_3}}{2N_{\text{NH}_3} + N_{\text{He}}} = \frac{1}{2}$$

Consider a sealed container with a volume of  $1 \text{ m}^3$  filled with  $1 \times 10^{23}$  helium atoms and  $3 \times 10^{23}$  molecules of ammonia. Helium is a monatomic gas. The ammonia molecule ( $\text{NH}_3$ ) is a tetrahedron. Initially the temperature of the gas mixture is  $1000 \text{ K}$ . Assume throughout this problem that equipartition applies.

14) We next raise the temperature of the gas in the container from  $1000 \text{ K}$  to  $1250 \text{ K}$ . How much heat must the gas in the container absorb, assuming that the volume is held constant?

- a. 3624 J
- b. 11004 J
- c. 109 J

$$Q = C \Delta T = 250 \text{ K} \left[ \frac{3}{2} N_{\text{He}} R + \frac{6}{2} N_{\text{NH}_3} R \right]$$

$$= 250 \left[ \frac{3}{2} 1.38 + \frac{6}{2} \cdot 3 \cdot 1.38 \right]$$

$$C = \alpha N R$$

$$= \left[ \text{Num Dof} \right] \frac{R}{2} \cdot N$$

$$\alpha_{\text{mon}} = \frac{3}{2}$$

$$\text{diatomic} = \frac{5}{2}$$

$$\text{Non-linear} = \frac{6}{2}$$

Consider a sealed container with a volume of  $1 \text{ m}^3$  filled with  $1 \times 10^{23}$  helium atoms and  $3 \times 10^{23}$  molecules of ammonia. Helium is a monatomic gas. The ammonia molecule ( $\text{NH}_3$ ) is a tetrahedron. Initially the temperature of the gas mixture is  $1000 \text{ K}$ . Assume throughout this problem that equipartition applies.

15) Calculate the ratio of the r.m.s. velocity of the helium atoms to the r.m.s. velocity of the ammonia molecules. The atomic weight of helium is  $4 \text{ g/mole}$  and the molecular weight of ammonia is  $17 \text{ g/mole}$ .

~~a.  $v_{\text{rms,He}}/v_{\text{rms,NH}_3} = 0.378$~~

~~b.  $v_{\text{rms,He}}/v_{\text{rms,NH}_3} = 1$~~

c. The answer depends on temperature since at high temperature vibrational modes can be excited.

d.  $v_{\text{rms,He}}/v_{\text{rms,NH}_3} = 4.25$

e.  $v_{\text{rms,He}}/v_{\text{rms,NH}_3} = 2.06$

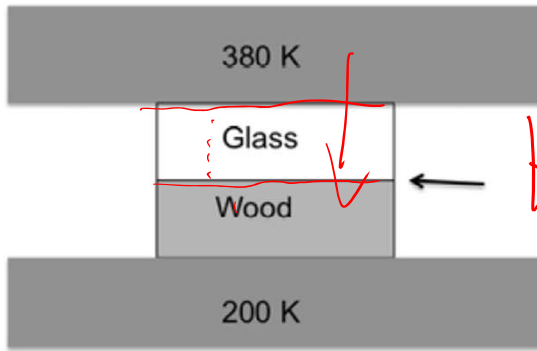
Handwritten derivation:

$$\langle KE_{\text{trans}} \rangle = \frac{1}{2} m \langle v^2 \rangle$$

$$v_{\text{rms}} \sim \sqrt{\frac{3kT}{m}}$$

$$\frac{v_{\text{He}}}{v_{\text{NH}_3}} = \sqrt{\frac{m_{\text{NH}_3}}{m_{\text{He}}}} = \sqrt{\frac{17}{4}}$$

16) A flat piece of glass (thermal conductivity = 1 W/m-K) rests on top of a flat piece of wood (thermal conductivity = 0.1 W/m-K). The glass and wood pieces have identical cross-sectional areas and thickness. The top of the glass is held at 380 K and the bottom of the wood is held at 200 K. What is the temperature at the boundary of the two pieces, marked by the arrow?



In steady state  $Q_{\text{into interface}} = Q_{\text{out of interface}}$

$$H = \frac{\Delta T}{R_{\text{th}}} \quad \frac{380 - T}{R_{\text{th, glass}}} = \frac{T - 200}{R_{\text{th, wood}}}$$

$$380 - T = T \frac{R_{\text{glass}}}{R_{\text{wood}}} - 200 \frac{R_{\text{glass}}}{R_{\text{wood}}}$$

$$T \left(1 + \frac{R_g}{R_w}\right) = 380 + 200 \frac{R_g}{R_w}$$

$$T = \frac{380 + 200(0.1)}{1 + 0.1} = 363.6$$

- a. 288.8 K
- b. 370.2 K
- c. 341.2 K
- d. 305.5 K
- e. 363.6 K

$$\frac{R_g}{R_w} = \frac{d_g \frac{k_w A_w}{l}}{k_g A_g \frac{d_w}{l}} = \frac{k_w}{k_g} = \frac{0.1}{1}$$



Consider a block of iron. The vibrational motion of the iron atoms is characterized by a harmonic frequency  $f$ , and a corresponding energy  $\epsilon = hf = 26 \text{ meV}$ , where  $h = \text{Planck's constant}$ .

17) How does the heat capacity of the block at a temperature  $T_1 = 300 \text{ K}$  compare to the heat capacity of the block at a temperature  $T_2 = 350 \text{ K}$ ?

- a.  $C(T_1) > C(T_2)$
- b.  $C(T_1) < C(T_2)$
- c.  $C(T_1) = C(T_2)$

$C(T \rightarrow \infty) = 3NR$

$\epsilon$   
 $kT \ll \epsilon \quad C \rightarrow 0$



Ans  
 $U = \frac{3}{2} NkT$  for any  $T$   
 $C = \frac{3}{2} NR$

vibrational modes "freeze out"

$N_2 \quad C = \frac{5}{2} NR$  if  $T$  high to allow rotations  
 and  $T$  low enough to not have vibrations

Consider a surface consisting of 100 single-occupancy sites, on which are resting 10 hydrogen atoms, each one initially in a *different* internal energy level, i.e., one is in the ground state, one is in the first excited state, one is in the second excited state, etc. The atoms are free to sample all sites, subject to the single-occupancy constraint.

18) Find the change in dimensionless entropy from the starting condition to one in which all of the atoms have decayed to the lowest energy state. That is, find  $\Delta\sigma = \sigma(\text{final}) - \sigma(\text{initial})$ . Again, Stirling's approximation is not accurate enough for this calculation.

- a. 0
- b. -4.62
- c. -15.1

Indistinguishable objects have fewer microstates than distinguishable objects

	<u>Single</u>	<u>Dilate</u> ( $M \gg N$ )	
Dist	$\frac{M!}{(M-N)!}$	$M^N$	$100^{10}$
Ident.	$\frac{M!}{(M-N)! N!}$	$\frac{M^N}{N!}$	$\frac{100^{10}}{10!}$

$\sigma_{\text{final}} - \sigma_{\text{init}} = \ln \Omega_f - \ln \Omega_i$   
 $= \ln \frac{\Omega_f}{\Omega_i} = \ln \frac{1}{10!} = -\ln 10!$

19) Compare the change in entropy ( $\Delta S = S_{\text{final}} - S_{\text{initial}}$ ) of an ideal gas when its volume doubles in the following ways (1) isothermal expansion (2) adiabatic expansion (3) free expansion (i.e., not pushing on any piston).

- a.  $\Delta S(\text{iso}) > \Delta S(\text{adiabatic}) = \Delta S(\text{free})$
- b.  $\Delta S(\text{free}) > \Delta S(\text{iso}) > \Delta S(\text{adiabatic})$
- c.  $\Delta S(\text{free}) = \Delta S(\text{iso}) > \Delta S(\text{adiabatic})$
- d.  $\Delta S(\text{iso}) > \Delta S(\text{adiabatic}) > \Delta S(\text{free})$
- e.  $\Delta S(\text{adiabatic}) > \Delta S(\text{free}) > \Delta S(\text{iso})$

$dS = \frac{dq}{T}$  for ~~quasi-static~~ quasi-static process  
 # microstates increase  
 Adiabatic:  $Q = 0$   
 $\Delta S = 0$   
 Not free expansion

$\Delta S_{\text{isothermal}}$   
 $\Delta U = Q - W_{\text{by}}$   
 $Q = \frac{nR V^{\gamma}}{T}$

$\Delta T = 0$   
 $\Rightarrow \Delta U = 0$   
 $Q = W_{\text{by}}$   
 $dS = \frac{dW_{\text{by}}}{T} = \frac{p dV}{T}$   
 $p = \frac{NkT}{V}$   
 $= Nk \frac{dV}{V} = Nk \frac{dV}{V}$   
 1. Volume increasing  $\Delta S$  increases  
 2. Temp decreasing  $\Delta S$  decreases

$\Delta S_{\text{tot, free}} > \Delta S_{\text{tot, iso}} = \Delta S_{\text{tot, adiabatic}} = 0$   
 $\Delta S_{\text{env, free}} < 0$   
 $\Rightarrow$  also free expansion for

$$\Delta S_{\text{env, free}} = 0$$

$$\Delta S_{\text{env, adiabatic}} = 0$$

$$\Delta S_{\text{env, isothermal}} = -\Delta S_{\text{gas, isothermal}}$$

Animal cells are complex. Their survival requires the transport of proteins throughout the cell. For small cells (e.g., bacteria), this transport occurs via diffusion.

20) If the diffusion constant for a protein in the cell is  $20 \mu\text{m}^2/\text{s}$ , approximately how long will it take a protein to diffuse from the center of the cell to any point on the cell wall? Assume the cell is spherical with a radius of  $1 \mu\text{m}$ .

- a. 16.7 milliseconds
- b. 25 milliseconds
- c. 50 milliseconds
- d. 8.33 milliseconds**
- e. 4.17 milliseconds

$$\langle r^2 \rangle = \langle x^2 \rangle + \langle y^2 \rangle + \langle z^2 \rangle$$

$$= 6Dt$$

$$r_{rms} = 1 \mu\text{m} \quad t = \frac{(1 \mu\text{m})^2}{6 \cdot 20 \mu\text{m}^2/\text{s}}$$

21) Suppose we decrease the temperature of the cell from  $30^\circ\text{C}$  to  $12^\circ\text{C}$ . Find the ratio  $t(T=12^\circ\text{C})/t(T=30^\circ\text{C})$  where  $t$  is the time for the protein to diffuse from the center to the cell wall. Assume that the mean free path of the protein remains the same.

- a. 1
- b. 5.02
- c. 0.324
- d. 1.03**
- e. 1.58

Handwritten notes for question 21:

$$t \propto \frac{1}{D} \propto \frac{1}{\sqrt{T}}$$

$$D = \frac{1}{2} v l \propto \sqrt{T}$$

$$\frac{1}{2} m v^2 = \frac{3}{2} kT$$

$$v \propto \sqrt{T}$$

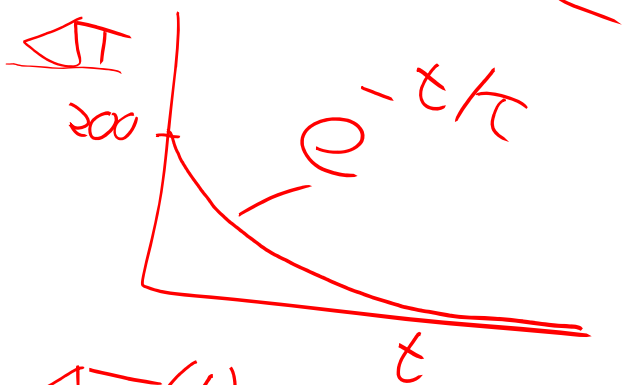
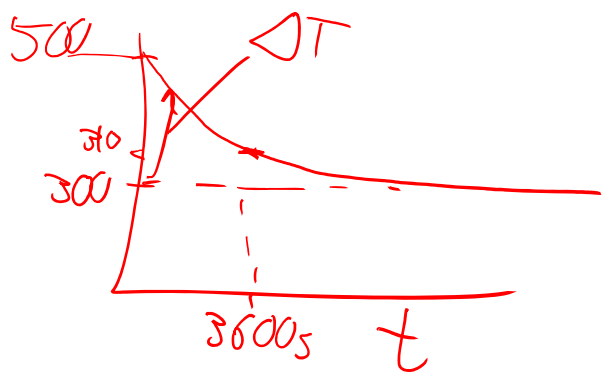
$$\frac{t_{12}}{t_{30}} = \sqrt{\frac{30}{12}} = 1.58$$

~~$T$  must be in K!~~

$$\sqrt{\frac{30+273}{12+273}} = 1.03$$

22) A solid block of aluminum is initially at  $T = 500$  K. The block is inside a room where everything but the block stays at a constant temperature of 300 K. After 1 hour the temperature of the block is 310 K. Assuming that the heat capacity of the block is 25 J/K, independent of temperature, what is the thermal resistance between the room and the block?

- a. 4.8 K/W
- b. 1.6 K/W
- c. 48.1 K/W
- d. 23.7 K/W
- e. 14.4 K/W



$$\Delta T(t) = \Delta T(0) e^{-t/RC}$$

$$\tau = RC$$

$$10 = \Delta T(3600s) = 200 e^{-t/RC}$$

$$\frac{t}{RC} = -\ln \frac{10}{200} = \ln 20$$

$$R = \frac{3600s}{25 J/K} \frac{1}{\ln 20} = 4 \text{ J/K}$$

$$h = \frac{\Delta T}{R} = -\frac{Q}{dt}$$

23) The atmosphere of Venus can be modeled as an ideal gas in thermal equilibrium, with a uniform temperature  $T_{\text{Venus}} = 735 \text{ K}$  and a uniform gravitational acceleration  $g_{\text{Venus}} = 8.9 \text{ m/s}^2$ . At zero altitude, the atmosphere is approximately 4% nitrogen ( $\text{N}_2$ , molar mass = 28 g/mol) and 96% carbon dioxide ( $\text{CO}_2$ , molar mass = 44 g/mol) by composition. As the altitude increases the relative percentage of nitrogen will,

- a. Increase
- b. Decrease
- c. Stay at 4%

Heavy elements fall off more quickly with altitude.

$$n(h) \sim \text{Prob}(h) = \frac{e^{-mgh/kT}}{Z}$$

$$\frac{n(h)}{n(h=0)} = \frac{e^{-mgh/kT}}{e^0/Z} = e^{-mgh/kT}$$

$$= e^{-h/h_c} \quad h_c = \frac{kT}{mg}$$

