Last Name:________________First Name_________________NetID_______________
Discussion Section:________Discussion TA Name:______________________________

Instructions—
Turn off your cell phone and put it away. This is a closed book exam.
You have 2 hours (120 minutes) to complete it. This is a multiple choice exam.
Use the bubble sheet to record your answers. Do not write on your formula sheet.
All written work should be confined to your exam booklet.

1. Use a #2 pencil; do **not** use a mechanical pencil or a pen. Fill in completely (until there is no white space visible) the circle for each intended input – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner.

2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.

3. Print your NetID in the **NETWORK ID** boxes, and then mark the corresponding circle below each of the letters or numerals. Note that there are different circles for the letter "I" and the numeral "1" and for the letter "O" and the numeral "0". **Do not** mark the hyphen circle at the bottom of any of these columns.

4. You may find the version of t**his Exam Booklet at the top of page 2**. Mark the version circle in the **TEST FORM** box in the bottom right of your answer sheet. **DO THIS NOW!**

5. Print your UIN# in the **STUDENT NUMBER** designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.

6. Write in your course on the **COURSE LINE** and on the **SECTION** *line*, print your **DISCUSSION SECTION**. (You need not fill in the INSTRUCTOR line.)

7. Sign **(DO NOT PRINT)** your name on the **STUDENT SIGNATURE** *line*.

8. At the end of this exam, you must return this Exam Booklet complete with all pages, including the formula sheet, along with your answer sheet. Note that this is a different policy than the one applying to midterm exams.

9. If you do not turn in a complete Exam Booklet, including the formula sheet, your Answer Sheet will not be graded, and you will receive the grade AB (Absent) for this exam.

*Before starting work, check to make sure that your test booklet is complete. You should have **14 numbered pages** plus 1 Formula Sheet at the end.*

*Academic Integrity—***Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including expulsion.**

$$\frac{6.14}{33} = \frac{x}{33}$$

This Exam Booklet is Version A. Mark the **A** circle in the **TEST FORM** box in the bottom right of your answer sheet. **DO THIS NOW**

Exam Grading Policy—

The exam is worth a total of 147 points, composed of three types of questions.

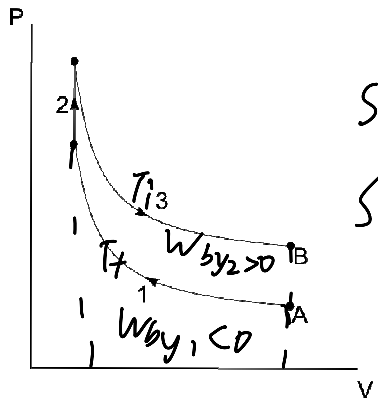
MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

The next two problems refer to the following situation:



$S_1 = C_v \ln\left(\frac{T_f}{T_i}\right)$, $Q = \alpha N k \Delta T$

$S_2 = C_v \ln\left(\frac{T_i}{T_f}\right)$, $Q = \alpha n k \Delta T$

A system is brought from point A to point B along the indicated path on the P-V diagram above.

b. 1. In order for the system to go from point A to point B

a. Net work must be done *on* the system *by* the environment.
b. Net work must be done *by* the system *on* the environment.
c. Cannot be determined with the information given.

ΔU

$\Delta S_1 = 0 = \Delta S_2$ 恒温

2. Suppose the system is then put in a closed cycle where the final step takes the system from point B to point A on the diagram. What is the total change in the entropy S of the system plus environment after one complete cycle?

a.

a. S > 0
b. S = 0
c. Cannot be determined with the information given.

C.

3. A brick of unknown heat capacity C, which we wish to determine, is heated up to temperature T. The brick is then used as the hot reservoir of a Carnot engine and produces maximum total work W. Given that the cold reservoir is at room temperature $T_R < T$

a. $C = \frac{W}{T - T_R}$

b. $C < \frac{W}{T - T_R}$

c. $C > \frac{W}{T - T_R}$

$$\frac{W}{C(T-T_R)} = 1 - \frac{T_R}{T}$$

$$\frac{W}{1-\frac{T_R}{T}} = C(T-T_R)$$

$$C = \frac{W}{T-T_R} \cdot \frac{1}{1-\frac{T_R}{T}}$$

a:

4. Argon, a monatomic ideal gas, is contained in a special balloon that is a perfect thermal insulator at 300 K and 1 atm. The balloon is free to compress as the environment pressure is raised to 2 atm. What is the final temperature of the gas?

a. 396 K
b. 227 K
c. 300 K
d. 476 K
e. Cannot be determined with the information given.

$V_1 = 1$ $\quad 1\cdot 1 = V^{\frac{5}{3}}\cdot 2$ $\quad V^{\frac{5}{3}} = \frac{1}{2}$

$1\cdot 1 = nR\cdot 300$ $\quad V = (\frac{1}{2})^{\frac{3}{5}}$

$PV = nkT$ $\quad PV = nTR$

$2\cdot(\frac{1}{2})^{\frac{3}{5}} = \frac{T_1}{300}$

a.

5. Two moles of an ideal gas are contained in a box of volume V and temperature T. The temperature is then decreased to T/2 and two more moles of gas are added to the container. Which of the following is true for the pressure p and the average collision rate r of a particular molecule with the walls of the container?

a. p remains the same and r decreases
b. p increases and r increases
c. p decreases and r remains the same
d. p remains the same and r remains the same
e. p decreases and r decreases

$PV = nkT$

$2 \quad \frac{1}{2}$

The next two problems refer to the following situation:

3 moles of an ideal gas are prepared at 0° C in a 1-m^3 container.

d.

6. If that gas is in contact with a heat bath at the same initial temperature and then compressed very slowly to 0.5 m^3, what is the total work <u>on</u> the gas <u>by</u> the environment?

a. 0 J
b. 3410 J
c. -3410 J
d. 4720 J
e. -4720 J

273.15°

$PV = nTR$

$\int P\,dV$

$\int \frac{nTR}{V} dV = nTR \ln\left(\frac{V_2}{V_1}\right)$

b.

7. If instead the gas is isolated from the environment and then compressed to 0.5 m^3, then how does the total work change?

a. Less work must be done by the environment.
b. More work must be done by the environment.
c. There is no change in the total work done.

$PV^{\frac{5}{3}} = C_1 = C_2$

$\int \frac{C_1}{V^{\frac{5}{3}}} dV = -\frac{3}{2} C_1 V^{-\frac{2}{3}} \Big|_1^{0.5}$

b.

8. Suppose that N particles of a monatomic ideal gas at a temperature T_i are placed in a sealed container and put in contact with a heat reservoir. When it equilibrates it has experienced a temperature increase of 5K. If we replace the monatomic gas by N/2 molecules of a diatomic gas initially at the same temperature T_i and then put into contact with the same reservoir, how much will its temperature change by when it equilibrates?

a. 2.5K
b. 5K
c. 10K

$Q_1 = \frac{3}{2} \cdot N \cdot k \cdot 5$

$Q_2 = \frac{5}{2} \cdot \frac{N}{2} \cdot k \cdot$

a.

9. Suppose we are given a brick at temperature 400 K with a heat capacity of 245 J/K. Compare the amount of work that can be extracted from the brick while in contact with a particular environment if the temperature of the environment is either (i) 300 K or (ii) 500 K.

$\frac{C_V \Delta T}{T}$

a. The available of work that can be extracted is greater for case (i)
b. The available of work that can be extracted is greater for case (ii)
c. The available of work that can be extracted is the same in both cases

$\Delta F_1 = \Delta U_1 - T_1 \cdot C_V \ln\left(\frac{T_f}{T_i}\right) = -245 \cdot 100 - 300 \cdot 245 \ln\left(\frac{300}{400}\right) \approx -3355.36$

$\Delta F_2 = \Delta U_2 - T_2 \cdot C_V \ln\left(\frac{T_f}{T_i}\right) = 245 \cdot 100 - 500 \cdot 245 \ln\left(\frac{500}{400}\right) \approx -2835085$

The next two problems refer to the following situation:

Suppose that you wish to use an ideal heat pump to heat your home and you would like your house to be held at a constant temperature of 20 °C. Although the walls are almost perfect thermal insulators, heat can still leak out through the 10 windows. Assume each of the windows has an area of 2 m^2 and each window has a thermal resistance of 6x10^{-3} K•s/J.

10. On a spring day the temperature outside reaches 17 °C. Calculate the power needed to keep the house at 20 °C.

C.

a. 0.812 J/s
b. 7.5 J/s
c. 51.2 J/s
d. 102 J/s
e. 750 J/s

~~b.~~ ?

11. At what outside temperature would the power needed to run the heat pump exactly match the rate at which the heat is leaking?
a. 0 K
b. 293 K
c. Infinity

a

The next two problems refer to the following situation:

Take a single, stationary electron with two spin states ("up" and "down") in a magnetic field of 2 Tesla. Recall that the energy states of the resulting electron magnetic moment in a magnetic field are E =± μ_BB where μ_B = 5.79x10^{-5} eV/Tesla. The average energy of the electron is <E> = -μ_BBtanh(μ_BB/kT).

E_1

U =

12. Suppose the electron is in thermal equilibrium with a heat reservoir at temperature 1000 K. Calculate the free energy of the electron ~~assuming that~~ kT >> |μ_BB|. Hint: what is the entropy of a spin in a magnetic field at very large temperatures?

d.

a. 6x10^{-7} eV
b. -6x10^{-7} eV
c. -6x10^{-5} eV
d. -6x10^{-2} eV
e. 6x10^{-2} eV

1
2
$\frac{2!}{1!\cdot 1!}$

$\langle E\rangle = -\mu_B B \cdot \frac{e^{\frac{\mu_B B}{kT}} - e^{-\frac{\mu_B B}{kT}}}{e^{\frac{\mu_B B}{kT}} + e^{-\frac{\mu_B B}{kT}}}$

$F = U - TS \qquad -1000 \cdot k\ln(2) \qquad = -\mu_B B \cdot \frac{1-1}{2} = 0$

13. Calculate the free energy of the electron if it is in thermal equilibrium with a reservoir at approximately T = 0 K instead, still with the 2 T field applied.

a.

a. -1.16x10^{-4} eV
b. 0 eV
c. 1.16x10^{-4} eV

$-\mu_B B$

14. Suppose that we have an ideal gas made up of large dust particles that each have mass 1.0x10^{-6} kg. At room temperature essentially all of the dust particles are lying on the ground. Compare the temperatures at which will half of the dust particles (on average) have a chance of spontaneously rising to a height of 3-m if they are on Earth (g_{Earth}=9.8 m/s^2) or Mars (g_{Mars}=3.8 m/s^2)? That is, calculate T_{Earth}/T_{Mars}.

d.

C_{V_1}

a. 0.388
b. 0.559
c. 1.79
d. 2.58
e. 5.16

$U_1 = mgh_1$

$U_2 = mgh_2$

$-\frac{E}{kT} +$

$\Delta T_1 = \frac{mgh_1}{C_1}$

$\Delta T_2 = \frac{mgh_2}{C_2}$

$\frac{P_1}{P_2} = e^{-\frac{mgh}{kT}} = e^{-\frac{mg_2h}{kT}} = 0.5$

$\frac{T_E}{T_n} = \frac{20 - \frac{mgh_1}{C_1}}{20 - \frac{mgh_2}{C_1}}$

$\frac{y_1}{T}$

The next two problems refer to the following situation:

H_2 (an ideal gas) can come in two forms, ortho-hydrogen and para-hydrogen, which are distinguishable from each other.

b.

15. Consider a 2-m^3 box at T=300 K, which has a fixed semi-permeable membrane that splits the box into two halves and only transmits ortho-hydrogen molecules. The left half of the box starts with 1 mole of ortho-hydrogen and the right half of the box starts with 1 mole of para-hydrogen. After the system equilibrates the amount of ortho-hydrogen on the left half of the box is

a. 1 mole
b. ½ mole
c. 0 moles

b.

16. Now assume that ortho-hydrogen and para-hydrogen can freely convert back and forth between each other and that each of the ortho-hydrogen molecules are 0.01 eV less energy then the para-hydrogen molecules. n_Q for both types of hydrogen is 10^{30} m^3. Now you remove the semi-permeable membrane. The temperature stays at T=300 K. After the system equilibrates, what is the ratio of para-hydrogen to ortho-hydrogen in the box?

a. $n_{para}/n_{ortho} = 1.0$
b. $n_{para}/n_{ortho} = 0.68$
c. $n_{para}/n_{ortho} = 0.50$
d. $n_{para}/n_{ortho} = 10^{-30}$
e. $n_{para}/n_{ortho} = 0.46$

$$\frac{n}{n_Q} = e^{-\frac{\Delta}{kT}}$$

$$\frac{n_{para}}{n_{or}} = e^{-\frac{0.01 \cdot 1.6\times10^{-19}}{1.381\times10^{-23}\cdot 300}} \approx 0.68$$

a.

17. A protein in your body has two configurational macrostates A and B. In macrostate A, there is only one folded configuration. In macrostate B there are 1000 folded configurations of equal energy (to each other but not macrostate A). When your temperature rises to having a bad fever, 105 degrees Fahrenheit (313.7 Kelvin), 50% of the proteins are misfolded into macrostate B. What is the difference in energy between macrostate A and B?

a. 3.0×10^{-20} J
b. 5.1×10^{-23} J
c. 5.1×10^{-20} J
d. 1.0×10^{-17} J
e. 1.5×10^{-5} J

273.15
37
313.7
310.15
3.55 K

$$1 = e^{-\frac{\Delta}{1.381\times10^{-3}\cdot 313.7}}$$

$$\frac{e^{-\frac{E_0}{kT}}}{e^{-\frac{E_0}{kT}} + 1000e^{-\frac{E_0-\Delta}{kT}}} = 0.5$$

$$\frac{e^{-\frac{E_0}{kT}}}{e^{-\frac{E_0}{kT}} + 1000e^{-\frac{E_0-\Delta}{kT}}} = 0.5$$

$$\frac{1}{1+1000e^{-\frac{\Delta}{kT}}} = 0.5$$

$2 = 1 + 1000\, e^{-\frac{\Delta}{kT}}$ $\Delta = 3\times10^{-20}$

$\frac{1}{1000} = e^{\frac{\Delta}{kT}}$

a. 18. The boiling temperature of liquid helium at 1 atm is 4.2 K. If the latent heat of evaporation is 92 J/mol, estimate the gain in the number of microstates for each helium atom when it transitions from liquid to gas.

a. × 14
b. × 22
c. × 90
d. × 122
e. × 530

1 mol 92 J

$\Delta S = \frac{92}{4.2} = 6.02\times10^{23} \cdot 1.381\times10^{-23} \ln(\Omega)$

$\Omega \approx 14$

The next two problems refer to the following situation:

a. 19. The temperature of interstellar space is 2.7K. Consider a spaceship whose silicon semiconductors (band gap=1.14 eV) have an intrinsic carrier density of 5.2 x 10^{15}/m^3 on the Earth (T=300K). What is the expected intrinsic carrier density in interstellar space?

a. < 10^{-100}/m^3
b. 4.6 x 10^{13}/m^3
c. 9.2 x 10^{13} /m^3

$\frac{x}{5.2\times10^{15}} = e^{\frac{1.14\times1.6\times10^{-19}}{2k\cdot T}}$

$\frac{x_1}{x_2} = e^{-\frac{\Delta}{2kT_1} + \frac{\Delta}{2kT_2}}$

A 20. Consider adding a drop of food coloring to water. The food coloring proceeds to diffuse throughout the water, coloring it. Comparing the free energy immediately after and long after the drop has been added, the free energy is

a. higher immediately after the drop has been added.
b. higher long after the drop has been added.
c. the same.

C.

21. A disc-shaped interstellar spacecraft faces a star such that the cross-section toward the star is 1 m^2 . It absorbs 2 x 10^{-7} W from the star which is 9.4 x 10^{12} km away and whose radius r_{star} = 700,000 km. What is the peak wavelength from the star?

a. **λ=**25 nm
b. **λ=**200 nm
c. **λ=**580 nm
d. **λ=**820 nm
e. **λ=**2300 nm

$4\pi r_{star}^2 \sigma_{AB} \cdot T^4 \cdot \frac{1}{4\pi d^2} = 2\times10^{-7}$

$\Rightarrow T = \sqrt[4]{\frac{2 d^2 \times 10^{-7}}{r_{star}^2 \sigma_{AB}}}$

$\lambda = \frac{0.0029}{T}$

a.

22. There are two separate boxes of (potentially different) ideal gas. The dimensionless entropy in box 1 is 10 and the dimensionless entropy in box 2 is 20. What is the total dimensionless entropy of the combined system of box 1 and box 2 (where they stay separate)?

a. 30
b. 200
c. 15

The next two problems refer to the following situation:

a.

23. Suppose you randomly put four indistinguishable balls in four bins (each bin can hold multiple balls) so that all microstates are equally likely. What is the probability that all the balls are in the first bin?

C

a. 0.004
b. 0.042
c. 0.028
d. 0.25
e. 1.0

4 $\quad \frac{7!}{4!\cdot 3!} \quad \frac{7\cdot 6\cdot 5}{} \quad$ 35

24. Now suppose that the balls are turned to distinguishable balls. The probability that all four balls are in the first bin

a.

a. is higher then when they were indistinguishable.
b. is the same as when they were indistinguishable.
c. is lower then when they were indistinguishable.

C

The next three questions pertain to the following situation

Consider a collection of N non-interacting 'quantum dots'. In each of these, the electron can either be in the ground state, with energy E_g or in the excited state, with energy $E_e = E_g + 0.01$ eV. The electron can have precisely two values of the z-component of angular momentum, i.e., 'spin up' or 'spin down'; thus, the degeneracy of the ground state is 2, as is the degeneracy of the excited state. There is no extended magnetic field for this problem.

C.

25. At T = 200 K what is the likelihood P(e) to find the electron in a particular quantum dot in the excited state?

a. 0.04
b. 0.18
c. 0.36
d. 0.50
e. 0.72

$$P(e) = \frac{2e^{-\frac{0.01}{KT}}}{2e^{-\frac{0.01}{KT}} + 2}$$

C.

26. At very high temperature, what is the entropy S of this collection of quantum dots?

a. kN ln 2
b. 2k lnN
c. kN ln4

C4

kN ln 4

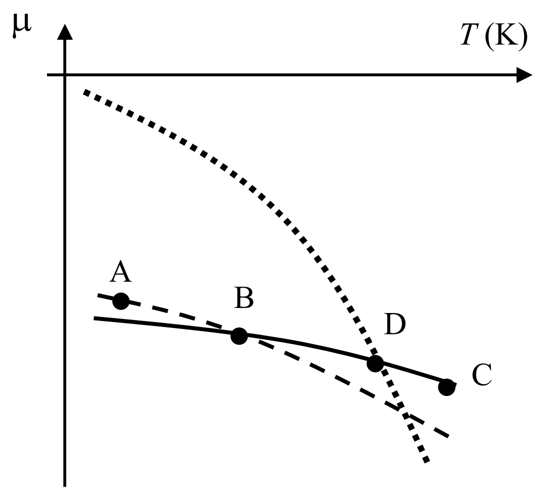
a.

27. What is the heat capacity of this collection of quantum dots, as the temperature goes to infinity?

a. 0
b. Nk
c. 2Nk

The next two questions are related.

A substance has three phases: gas, liquid, and solid. The chemical potentials of various phases are illustrated below.



b.

28. If the substance starts out in state D and is held at constant temperature, what happens if it is allowed to reach equilibrium?

a. Nothing will happen.
b. The solid component will melt, while the gas component condenses.
c. The substance will evaporate.
d. The substance will melt and evaporate.
e. The substance will sublime.

a.

29. If the substance starts out in any of the states (A – C), and is held at constant temperature, for which initial state(s) will the entropy of the *environment* decrease as the system reaches thermal equilibrium?

a. C
b. B
c. A
d. A or C
e. none of the above

30. Consider the methane reaction: $CH_4 + 2O_2 \leftrightarrow CO_2 + 2H_2O$
Assuming the reactants and products can be considered ideal gases, which of the following formulas describe the equilibrium conditions for this reaction? (Here K(T) is a function that does not depend upon the concentration of either products or reactants.)

a. $n_{CO_2} n_{H_2O} = K(T) n_{CH_4} n_{O_2}$ and $\mu_{CO_2} \mu_{H_2O}^2 = \mu_{CH_4} \mu_{O_2}^2$

b. $\dfrac{n_{CO_2} n_{H_2O}^2}{n_{CH_4} n_{O_2}^2} = K(T)$ and $2\mu_{CO_2} + \mu_{H_2O} = 2\mu_{CH_4} + \mu_{O_2}$

c. $n_{CO_2} n_{H_2O} = K(T) n_{CH_4} n_{O_2}$ and $\mu_{CO_2} + 2\mu_{H_2O} = \mu_{CH_4} + 2\mu_{O_2}$

d. $n_{CO_2} + 2n_{H_2O} = n_{CH_4} + 2n_{O_2}$ and $\mu_{CO_2} + 2\mu_{H_2O} = \mu_{CH_4} + 2\mu_{O_2}$

e. None of the other options.

31. The measured value of the latent heat of vaporization of helium (at 1 atm) is 84 J/mol. Use this to estimate the binding energy of helium atoms in the liquid.

a. 2.6×10^{-6} eV
b. 3.6×10^{-4} eV
c. 5.1×10^{-4} eV
d. 8.6×10^{-3} eV
e. 3.6×10^{-2} eV

The next two questions are related.

Consider the reaction $2CO + O_2 \leftrightarrow 2CO_2$. Define n_{CO}, n_{O2}, and n_{CO2} as the equilibrium number densities of the three species at temperature T.

32. If we wish to increase the density of CO_2, what should we do to the temperature?

a.

a. increase the temperature
b. decrease the temperature
c. we cannot change the CO_2 density by changing the temperature.

33. Again starting with n_{CO}, n_{O2}, and n_{CO2}. If we now remove half of the O_2, what will happen to the ratio n_{CO}/n_{CO2}, after the system has come back to equilibrium? Assume that the temperature (and volume) remains constant during this process.

C.

?

a. n_{CO}/n_{CO2} will double.
b. n_{CO}/n_{CO2} will half.
c. n_{CO}/n_{CO2} will increase by a factor of $\sqrt{2}$.
d. n_{CO}/n_{CO2} will quadruple.
e. n_{CO}/n_{CO2} will decrease by a factor of 0.71 (i.e., $1/\sqrt{2}$).

$\leftarrow$

$\frac{n_{CO}}{n_{CO_2}}$