Instructions—

Turn off your cell phone and put it away.
Keep your calculator on your own desk. Calculators may not be shared.
This is a closed book exam. You have ninety (90) minutes to complete it.

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 This Exam Booklet at the top of page 2. Mark the version circle in the TEST FORM box near the middle of your answer sheet. DO THIS NOW!

5. Stop now and double-check that you have bubbled-in all the information requested in 2 through 4 above and that your marks meet the criteria in 1 above. Check that you do not have more than one circle marked in any of the columns.

6. Do not write in or mark any of the circles in the STUDENT NUMBER or SECTION boxes.

7. On the SECTION line, print your DISCUSSION SECTION. (You need not fill in the COURSE or INSTRUCTOR lines.)

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

Before starting work, check to make sure that your test booklet is complete. You should have 10 numbered pages plus one 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.
This Exam Booklet is Version A. Mark the A circle in the TEST FORM box near the middle of your answer sheet. DO THIS NOW!

Exam Grading Policy—

The exam is worth a total of 120 points, composed of two 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 4 problems are related:

A 30 kg weight lies on top of a massless piston of area $A = 0.01 \text{ m}^2$. The exterior air is at a (constant) $p = 1 \text{ atm}$ and $T = 27 \text{ C}$. The interior gas is 0.4 moles of (ideal) $\text{N}_2$ and it has initial temperature 27.00 degrees C.

1. What is the initial pressure in the interior?
   a. 29.4 kPa
   b. 130.7 kPa
   c. 101.3 kPa

The next three questions concern what happens when an amount of heat $Q$ is slowly added to the interior, raising the piston by 1 mm and raising the interior temperature to 27.40 C

2. How much work is done by the gas?
   a. 1.3 J
   b. 0 J
   c. $-1.3$ J

3. A $pV$ diagram is shown here, where the initial state is at point W (isotherms are drawn for reference.) At which of the labeled points does the system end up?
   a. point X
   b. point Y
   c. point Z

4. What was the amount of heat added?
   a. $Q = 4.6$ J
   b. $Q = 1.2$ J
   c. $Q = 2.5$ J
5. A square window of area 0.5 x 0.5 meters and glass thickness of 7 mm separates the interior of a home at 24 C from the exterior at –10 C. The thermal conductivity of the glass is 1.8 W/mK; its heat capacity is 1 Joule/ K kg; its mass density is 2.4 g/cm³. The heat conductivity of air is 0.03 W/mK. At what rate does heat escape through this window?

a. 2.2 kW
b. 1.1 kW
c. 0.55 kW

The next two problems pertain to this box with 5 bins containing 9 identical indistinguishable particles separated by a partition shown with a dark line. Particles can move between bins but they cannot cross the partition. One possible microstate is shown in the figure.

6. With the partition fixed in the indicated position between the 3rd and 4th bins (and 4 particles on the left and 5 on the right), what is the total entropy?

a. $\sigma = 7.9$
b. $\sigma = 6.1$
c. $\sigma = 4.5$
d. $\sigma = 3.9$
e. $\sigma = 2.8$

7. If the partition is now free to move (but we continue to demand that there are 4 particles on the left and 5 on the right), then at which of these positions is the partition most likely to be found?

a. between 1st and 2nd bins
b. between 2nd and 3rd bins
c. between 3rd and 4th bins
d. between 4th and 5th bins
e. equally likely at all four positions.
8. Compare the room temperature heat capacities at constant volume of 1 kg Helium gas, 1/2 kg Hydrogen gas, and 4 kg Aluminum solid.

a. \( C_{He} > C_{H2} > C_{Al} \)
b. \( C_{H2} > C_{He} > C_{Al} \)
c. \( C_{H2} > C_{Al} > C_{He} \)
d. \( C_{Al} > C_{He} > C_{H2} \)
e. \( C_{He} > C_{Al} > C_{H2} \)

9. What is the root-mean-square speed of oxygen molecules \( O_2 \) at temperature \( T = 332 \) K.

a. 251 m/s  
b. 358 m/s  
c. 508 m/s  
d. 759 m/s  
e. The answer depends on the gas pressure, which is not given.

10. It is observed that Helium impurity atoms placed on the surface of a 1 \( \mu \)m thick piece of a certain material slowly diffuse through the thickness. At 300K, the typical time to diffuse is 1 day. How much time would it take to diffuse through a sample of thickness 4 \( \mu \)m ?

a. 32 days  
b. 16 days  
c. 8 days  
d. 4 days  
e. 2 days

11. Consider a mixture of 5 moles of the gas \( O_2 \) and 30 moles of He at 288 K in a volume of 900 m\(^3\). What fraction of the total internal energy is in the rotations of the \( O_2 \) molecules?

a. 8.7%  
b. 14.1%  
c. 22.3%

12. Consider a set of 9 distinguishable atoms, each of which can be in one of three equally probable states, all of the same energy. What is the entropy \( \sigma \) of this system?

a. 9.9  
b. 6.6  
c. 6.2
The next three questions pertain to 43 moles of \( \text{H}_2 \) gas in a volume of 1 m\(^3\) at an initial pressure of 1 atm and initial temperature 283 K. It is compressed adiabatically to 0.5 m\(^3\).

13. What is the final pressure?

a. 2.64 atm  
b. 2.00 atm  
c. 1.51 atm

14. What is the final temperature?

a. 283 K  
b. 325 K  
c. 373 K

15. In this process, the entropy of the gas …

a. increased  
b. decreased  
c. remained the same

The next two problems are related.

16. A 2.5 mol of an ideal monatomic gas undergoes a slow isothermal expansion at 360 K until its volume is doubled. What is the increase in entropy \( S \) of the gas?

a. 14.4 J/K  
b. 5.76 J/K  
c. 1.97 J/K  
d. 3.14 J/K  
e. 7.03 J/K

17. The same gas is then slowly heated from the original 360 K to 400 K, at constant volume. What is the increase in entropy \( S \) of the gas due to this second process?

a. 0.87 J/K  
b. 2.18 J/K  
c. 1.31 J/K  
d. 3.28 J/K  
e. 2.62 J/K
18. The absolute pressure of a gas in a piston is measured as its volume is changed isothermally by the indicated plunger. While the volume of the piston $V$ can be measured, the volume of the tubing, $V_{\text{tube}}$, is unknown. The measurement gave the following graph in which the filled circles are the measurements and the line is a straight line fit.

What is the volume of the tubing?

a. 6 ml  
b. 0.5 ml  
c. 12 ml

19. Aluminum and copper rods of the same cross section and same length are connected together with a joint of perfect thermal conductance. One end of the Cu is held at 0 degrees C and one end of the Al is held at 10 degrees C. What is the temperature of the joint? Thermal conductivity of Cu is 401 W/m-K, and that of Al is 235 W/m-K.

a. 2.57 C  
b. 3.69 C  
c. 6.31 C  
d. 0 C  
e. 10 C
20. The following plot shows the entropies of two systems with fixed total energy, as a function of the amount of energy in system number 1. When placed in contact with each other, system number 1 has initial energy \( U_{1i} \) – indicated by the dashed line. Which way does heat then flow?

![Plot of entropies vs energy](image)

a. Heat flows from system 1 to system 2  
b. Heat flows from system 2 to system 1  
c. Their entropies are the same, so heat does not flow

*The next two problems pertain to the following situation*

Initially, a partition separates two equal volumes. Each volume contains \( N \) molecules.

![Diagram of two equal volumes](image)

21. If the molecules in the two volumes are distinct, calculate the change in entropy after the partition is removed.

a. \( \Delta \sigma = 0 \)  
b. \( \Delta \sigma = N \ln(2) \)  
c. \( \Delta \sigma = 2N \ln(2) \)  
d. \( \Delta \sigma = N \ln(2V) \)  
e. \( \Delta \sigma = 2N \ln(2V) \)

22. If the molecules in the two halves are identical, compare the change in entropy to the case when the molecules in the two halves are distinct.

a. \( \Delta \sigma_{\text{distinct}} > \Delta \sigma_{\text{identical}} \)  
b. \( \Delta \sigma_{\text{distinct}} = \Delta \sigma_{\text{identical}} \)  
c. \( \Delta \sigma_{\text{distinct}} < \Delta \sigma_{\text{identical}} \)
The next two problems pertain to the following situation.

A particular molecule has three vibrational modes with energies $E_0 = 0$, $E_1 = \varepsilon$ and $E_2 = 3\varepsilon$ with $\varepsilon = 10^{-20}$ J. The molecule is in contact with a thermal reservoir of temperature 1000 K.

23. What is the average vibrational energy of the molecule?

   a. $\langle E \rangle = 5.2 \times 10^{-21}$ J
   b. $\langle E \rangle = 7.0 \times 10^{-21}$ J
   c. $\langle E \rangle = 1.0 \times 10^{-21}$ J
   d. $\langle E \rangle = 1.4 \times 10^{-21}$ J
   e. $\langle E \rangle = 2.0 \times 10^{-21}$ J

24. For high temperatures, $kT >> \varepsilon$, what is the probability that the molecule's vibrations have energy $E_2$?

   a. $P_2 = 0$
   b. $P_2 = 1/3$
   c. $P_2 = 2/3$

25. How would the average vibrational energy of the molecule be different (at the same temperature) if the energy level $E_0$ were degenerate, with two states, $d_0 = 2$?

   a. $\langle E \rangle$ would be greater if the ground state were doubly degenerate
   b. $\langle E \rangle$ would not depend on the degeneracy of the ground state
   c. $\langle E \rangle$ would be less if the ground state were doubly degenerate

26. A collection of $N$ spins, each with magnetic moment $\mu = 10^{-23}$ J/T, is placed in a 5 Tesla magnetic field. At what temperature will the net polarization (the difference between the number of spins aligned with the field and the number aligned against it) be equal to $N/2$?

   a. $T = 4.2$ K
   b. $T = 5.3$ K
   c. $T = 6.6$ K
   d. $T = 10.4$ K
   e. $T \to \infty$
The following two problems pertain to the following situation

The plot shows the specific heat at constant volume as a function of temperature for H\(_2\).

27. What is the energy corresponding the rotational motion of the H\(_2\) molecule?
   a. \(E_{\text{rot}} = 10^{-22} \text{ J}\)
   b. \(E_{\text{rot}} = 10^{-21} \text{ J}\)
   c. \(E_{\text{rot}} = 10^{-20} \text{ J}\)

28. Estimate the change in the entropy for 1 mole of H\(_2\) between 10 K and 1000 K.
   a. \(\Delta S = 30 \text{ J/K}\)
   b. \(\Delta S = 50 \text{ J/K}\)
   c. \(\Delta S = 80 \text{ J/K}\)
   d. \(\Delta S = 110 \text{ J/K}\)
   e. \(\Delta S = 150 \text{ J/K}\)

Check to make sure you bubbled in all of your answers.
Did you bubble in your name, network-id, and exam version?