

Last Name: _____ First Name _____ NetID _____
Discussion Section: _____ Discussion TA Name: _____

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. 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 block.
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 11 **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 **114** 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.

1. A hermetically sealed box has a mixture of two gases in it, namely nitrogen gas and helium gas. The numbers of molecules of each gas is equal. The initial temperature is 300 K. The temperature of the box is reduced to 10 K. At this temperature He remains in the gaseous phase while nitrogen becomes solid, so that all nitrogen molecules stick to the walls permanently. Assume the volume of the box does not change. How does the pressure in the box change?

- a. The pressure increases by a factor of 30.
- b. The pressure drops by a factor of 30.
- c. The pressure drops by a factor of 60.

2. Radon is a radioactive gas with atomic weight 0.222 kg/mole. Assume that some amount of this gas is absorbed on a flat, perfectly polished surface. Thus the atoms can freely move on the surface forward and backward, or to the right and left. But the atoms stick to the surface so they cannot move up or down. (Such molecules are said to be effectively two dimensional.) Compute the average translational kinetic energy of a single radon molecule that is absorbed on the surface at room temperature (20° C)?

- a. 1.13×10^{-20} J
- b. 4.05×10^{-21} J
- c. 2.75×10^{-22} J
- d. 6.08×10^{-21} J
- e. Cannot be determined with the information given.

The next two questions pertain to the following situation:

A diatomic ideal gas is confined to a closed container of volume 0.1 m^3 . (Assume that the volume remains constant.) Initially, the pressure of the gas is 2 atm and its temperature is 300 K.

3. If the internal energy of the gas is doubled, which one of the following is true?

- a. The ratio between the kinetic and rotational energies increases.
- b. The pressure increases by a factor of 2.
- c. The density increases.
- d. The pressure increase by a factor of $\sqrt{2}$.
- e. The pressure does not change.

4. Approximately, how much heat is required to raise the temperature of this gas by 4 K?

- a. 25 J
- b. 147 J
- c. 272 J
- d. 340 J
- e. 675 J

The next two questions pertain to the following situation:

2.4×10^{24} atoms of an ideal monoatomic gas are at an initial temperature of $T=250$ K and an initial pressure of $P=1.5$ atm.

5. What is the initial volume V of the gas?

- a. $V = 1 \times 10^{20}$ liters
- b. $V = 27.4$ liters
- c. $V = 54.5$ liters
- d. $V = 89.3$ liters
- e. $V = 1.75 \times 10^{-14}$ liters

6. Suppose now all atoms of the gas form pairs, so that the gas becomes diatomic. Note that in such a case the number of molecules is half as many as the initial number of atoms. Assume also that no energy escapes from the system. What is the new temperature of the diatomic gas, T_2 ?

- a. $T_2 = T/2$
- b. $T_2 = 2T$
- c. $T_2 = T$
- d. $T_2 = 6T/5$
- e. $T_2 = 3T/5$

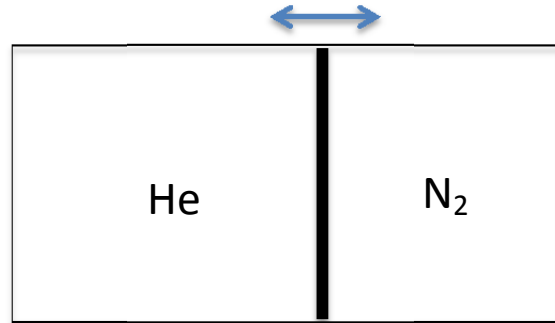
7. Water, having a temperature of 10°C , is placed into a pot made of stainless steel. The volume of water is 1 L. The diameter of the bottom of the pot is 20 cm. The thickness of the bottom is 5 mm. The thermal conductivity of the stainless steel is $16 \text{ W m}^{-1} \text{ K}^{-1}$. Specific heat of water is $4187 \text{ J kg}^{-1} \text{ K}^{-1}$. Take the density of water to be 1000 kg/m^3 .

We now place the pot on a hot plate of temperature 300°C . How long do we have to wait for the temperature to change from 10°C to 11°C ?

- a. 0.0014 s
- b. 2.4 s
- c. 13 s
- d. 0.14 s
- e. 66 s

The next three problems refer to the following situation:

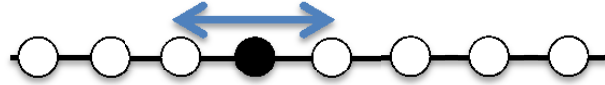
Consider a box that is split in two by a freely moving piston. The left side of the partition is filled with Helium gas and has a volume of 3 m^3 . The right side is filled with Nitrogen gas and has a volume of 2 m^3 . The two gases are in equilibrium at a temperature of 300K . There are 130 moles of Nitrogen gas. The barrier/piston is then removed.



8. What is the partial pressure due to the Nitrogen gas of the final mixture?
- a. 64.8 kPa
 - b. 162 kPa
 - c. 108 kPa
9. How much does the total entropy of the combined system increase due to the mixing? (assume this is a dilute ideal gas)
- a. Cannot be determined with the information given
 - b. 12.24 J/K
 - c. 9820 J/K
 - d. 1818 J/K
 - e. 990.1 J/K
10. What is the probability that all the nitrogen gas returns to the side of the partition that it started in?
- a. $(3/5)^{783 \times 10^{23}}$
 - b. $(2/5)^{783 \times 10^{23}}$
 - c. 4.04×10^{-27}
 - d. 1.27×10^{-26}
 - e. $(5/2)^{783 \times 10^{23}}$

The next two problems refer to the following situation:

A particle is randomly hopping on a 1 dimensional lattice with spacing 3×10^{-2} m. Every 2.5×10^{-2} seconds it hops either to the left or to the right with equal probability.



11. After exactly 1 second what is the probability the particle will be at the same location that it started?

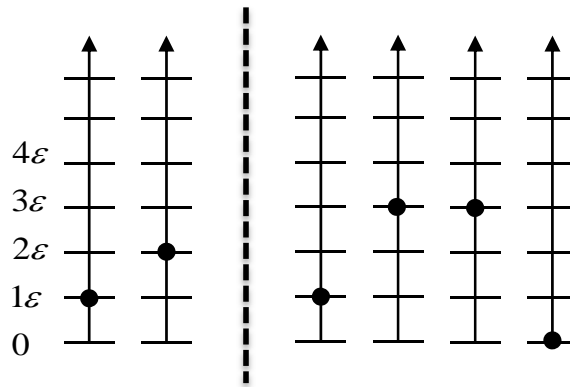
- a. 0.0157
- b. 2.14×10^{-3}
- c. 0.125
- d. 0.063
- e. 1.37×10^{-5}

12. Roughly estimate how long we would have to wait until the particle reaches the edge of the lattice whose total size is 2m assuming that the particle is released from the center.

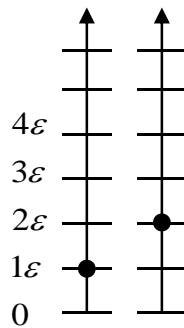
- a. 0.8 seconds
- b. 30 seconds
- c. 600 seconds

The next three problems refer to the following situation:

A “small” system (S) of 2 harmonic oscillator is allowed to exchange energy with a “large” reservoir (R) of 4 harmonic oscillators. Each oscillator has the same energy spacing ε . The total combined system + reservoir has an energy 10ε .



13. Consider the following state for the small system:



What is the probability for the small system to be in this state?

- a. 0.00133
- b. 0.1598
- c. 0.09524
- d. 0.00666
- e. 0.03996

14. What is the probability to find the small system in a macrostate with fixed energy $E_S = 3 \epsilon$?

- a. 0.03996
- b. 0.00666
- c. 0.1598
- d. 0.3201
- e. 1

15. The most probable macrostate with a fixed energy E_S for the small system S is determined in this problem via: (Definition: Ω_S is the multiplicity of the system microstates and Ω_R is the multiplicity of the reservoir microstates.)

- a. Finding the maximum of: $\Omega_S(E_S) \times \Omega_R(10\epsilon - E_S)$
- b. Finding E_S such that the following equation is satisfied:

$$\frac{\partial \ln \Omega_S}{\partial V_S} = \frac{\partial \ln \Omega_R}{\partial V_S}$$

- c. Finding the maximum of: $\Omega_S(E_S)$

The next two problems refer to the following situation:

Two 100 meter tall airtight cylinders each contain N-molecules of gas are placed vertically on the surface of the earth. The gravitational constant is $g = 9.8 \text{ m/s}^2$. They are in thermal equilibrium with their surroundings at 300 K. The molecular species in column A has a mass of $M_A = 1000 \text{ AMU} = 1.673 \times 10^{-24} \text{ kg}$, while the molecular species in column B has a mass of $M_B = 2000 \text{ AMU} = 3.346 \times 10^{-24} \text{ kg}$. You may treat the two gas species as though they are ideal, although the densities and the partial pressures are a function of elevation.

16. What is the ratio of the density at zero elevation, $N(0)$ to the density at 100 meters, $N(100)$ in the two columns?

- a. $N_A(0)/N_A(100) = 2.638$ and $N_B(0)/N_B(100) = 3.861$
- b. $N_A(0)/N_A(100) = 2.449$ and $N_B(0)/N_B(100) = 2.975$
- c. $N_A(0)/N_A(100) = 2.018$ and $N_B(0)/N_B(100) = 2.714$
- d. $N_A(0)/N_A(100) = 1.837$ and $N_B(0)/N_B(100) = 2.533$
- e. $N_A(0)/N_A(100) = 1.485$ and $N_B(0)/N_B(100) = 2.207$

17. An asteroid crashes into the earth raising the temperature of the atmosphere to 400°C for a long enough period of time that the cylinders equilibrate at that temperature. Which statement is true?

- a. The ratio of the density at the top and the density at the bottom of the cylinders increases.
- b. The ratio of the density at the top and the density at the bottom of the cylinders remains the same.
- c. The ratio of the density at the top and the density at the bottom of the cylinders decreases.

The next two problems are closely related:

18. Consider a gas of N spin $\frac{1}{2}$ atoms, each with magnetic moment $\mu_e = 9.285 \times 10^{-24} \text{ J/T}$, pointing in the direction of the spin. In a magnetic field the spins can point either in the same or opposite direction of the magnetic field. When they point in the same direction the magnetic energy is $-\mu_e B$ and if they point in the opposite direction the magnetic energy is $+\mu_e B$. If the magnetic field is 10 Tesla, at what temperature does the net magnetic moment of the gas (in the direction of the applied magnetic field) equal $+N\mu_e/2$?

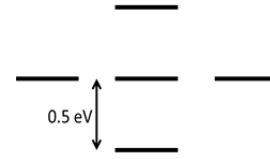
- a. 0.173 K.
- b. 5.250 K.
- c. 7.772 K.
- d. 12.24 K.
- e. 23.77 K.

19. If the temperature and the size of the magnetic field are both doubled, what happens to the magnetic moment?

- a. The magnetic moment is increased by a factor of $\sqrt{2}$.
- b. The magnetic moment remains unchanged.
- c. The magnetic moment is reduced by a factor of $\sqrt{2}$.

The next two problems are closely related:

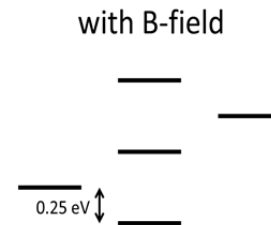
An atomic system has three energy levels where the middle one is triply degenerate while the ground state and the most excited level are non-degenerate. The energy spacing between the ground state and the triply degenerate level is 0.5 eV, and the energy spacing between the triply degenerate level and the most excited state is also 0.5 eV. The atom is in thermal equilibrium at 3000 K. (Note: This is 10 times room temperature.)



20. What is the probability ratio of occupancy of the triply degenerate level (including all three states) to the occupancy of the ground state?

- a. 1.235×10^{-7}
- b. 0.4340
- c. 3.000
- d. 0.0394
- e. 9.593

21. A magnetic field is applied which causes the triply degenerate energy level to split. One state is increased in energy by 0.25 eV, one state has its energy decreased by 0.25 eV, while the energy of one state is unchanged. What happens to the probability of being in the ground state $P(1)$?



- a. $P(1)$ is reduced.
- b. $P(1)$ remains the same.
- c. $P(1)$ is increased.

The chemical formula for molecular Iodine is I_2 . It is a linear molecular with a vibrational frequency of 6.45×10^{12} Hz. Consider a volume that contains N such molecules in equilibrium at various temperatures.

22. Recalling that the partition function for a simple harmonic oscillator with level spacing ε is $Z = 1 / (1 - e^{-\varepsilon/kT})$, what is the probability of the iodine molecule being in the first excited state at 300 K and at 1000 K?

- a. $P_1(300K) = 0.229$ and $P_1(1000K) = 0.195$
- b. $P_1(300K) = 0.368$ and $P_1(1000K) = 0.539$
- c. $P_1(300K) = 0.178$ and $P_1(1000K) = 0.308$
- d. $P_1(300K) = 0.208$ and $P_1(1000K) = 0.792$
- e. $P_1(300K) = 0.547$ and $P_1(1000K) = 0.326$

23. For a gas of diatomic molecule like I_2 , treating it as ideal

- a. as the temperature goes to zero, the constant volume heat capacity is $1.5kT$
- b. as the temperature goes to zero, the constant volume heat capacity is $2.5kT$
- c. as the temperature goes to zero, the constant volume heat capacity is $3.5kT$

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

Physics 213 Formula Sheet

Constants, Data, Definitions

$$0 \text{ K} = -273.15 \text{ }^{\circ}\text{C} = -459.67 \text{ }^{\circ}\text{F}$$

$$N_A = 6.022 \times 10^{23} / \text{mole}$$

$$k = 1.381 \times 10^{-23} \text{ J/K} = 8.617 \times 10^{-5} \text{ eV/K}$$

$$R = kN_A = 8.314 \text{ J/mol}\cdot\text{K} = 8.206 \times 10^{-2} \text{ l}\cdot\text{atm/mol}\cdot\text{K}$$

$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} \quad 1 \text{ liter} = 10^{-3} \text{ m}^3$$

$$\text{STP} \rightarrow T = 0^{\circ}\text{C}; p = 1 \text{ atm}$$

$$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} = 4.136 \times 10^{-15} \text{ eV}\cdot\text{s}$$

$$\hbar = h/2\pi = 1.055 \times 10^{-34} \text{ J}\cdot\text{s}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

$$c = 2.998 \times 10^8 \text{ m/s}$$

$$\mu_e = 9.2848 \times 10^{-24} \text{ J/T}$$

$$m_e = 9.109 \times 10^{-31} \text{ kg}$$

$$g = 9.8 \text{ m/s}^2$$

$$\mu_p = 1.4106 \times 10^{-26} \text{ J/T}$$

$$m_p = 1836 m_e$$

$$= 1.673 \times 10^{-27} \text{ kg}$$

Fundamental Laws/Principles:

$$\text{First law: } dU = dQ + dW$$

$$\text{Second Law: } d\sigma/dt \geq 0$$

$$P_i \propto \Omega_i \equiv e^{\sigma_i}$$

$$\text{Classical equipartition } \langle \text{energy} \rangle = \frac{1}{2} kT \text{ per quadratic term}$$

$$\text{Entropy \& Temperature: } S = k\sigma = k \ln \Omega; \quad \frac{1}{T} \equiv \left(\frac{\partial S}{\partial U} \right)_{V,N}$$

$$\text{Heat Capacities: } C_V \equiv (\partial U / \partial T)_V; \quad C_p \equiv (\partial (U + pV) / \partial T)_p$$

Special properties of α -ideal gases

$$U = \alpha NkT = \alpha nRT \quad pV = NkT \quad p_{\text{tot}} = p_1 + p_2 + \dots$$

$$C_V = \alpha Nk = \alpha nR \quad C_p = C_V + Nk \quad n = \# \text{ moles} = N/N_A$$

$$c_p/c_V = (\alpha + 1)/\alpha = \gamma \quad W_{\text{by}} = NkT \ln(V_f/V_i)$$

$$VT^\alpha = \text{const.}, \text{ or } pV^\gamma = \text{const.}, \gamma = (\alpha + 1)/\alpha$$

$$W_{\text{by}} = \alpha Nk (T_1 - T_2) = \alpha (p_1 V_1 - p_2 V_2)$$

$$\Delta S = C_V \ln(T_f/T_i) + Nk \ln(V_f/V_i)$$

	α	γ
●	3/2	5/3
●●	5/2	7/5

Processes, Heat Engines, etc

$$\Delta U = Q - W_{\text{by}} \quad W_{\text{by}} = \int p dV$$

$$\text{Quasistatic: } dS = dQ/T \text{ so } \Delta S = \int (C/T) dT$$

$$dQ = dU + p dV$$

$$\varepsilon_{\text{Carnot}} = 1 - T_C/T_H$$

Diffusion and Heat Conduction

$$D = (\ell^2/3\tau) = v\ell/3 \quad \tau = \ell/v$$

$$\langle x^2 \rangle = 2Dt \quad \langle r^2 \rangle = 6Dt$$

$$J_x = \kappa \Delta T / \Delta x, \quad \kappa = D_{\text{HC}} \text{ where } c = C_V/V$$

$$H_x = J A = \Delta T / R_{\text{th}} \quad R_{\text{th}} = d/\kappa A$$

$$\Delta L/L = \alpha \Delta T$$

$$T_A(t) = T_f + (T_{A0} - T_f) e^{-t/\tau}, \quad \tau = R_{\text{th}} C_A$$

Spins

$$\Omega(N, N_{\text{up}}) = \frac{N!}{N_{\text{up}}! N_{\text{down}}!} = \frac{N!}{N_{\text{up}}! (N - N_{\text{up}})!}; \quad \Omega(m) = 2^N \sqrt{\frac{2}{\pi N}} e^{-m^2/2N}; \quad P(m) = \Omega(m)/2^N$$

$$M = (N_{\text{up}} - N_{\text{down}}) \mu \equiv m\mu, \quad M = N\mu \tanh(\mu B/kT)$$

SHO

$$P_n = (1 - e^{-\varepsilon/kT}) e^{-n\varepsilon/kT}; \quad \langle E \rangle = \varepsilon/(e^{\varepsilon/kT} - 1) \quad \varepsilon = hf; \quad \Omega = \frac{(q + N - 1)!}{q!(N - 1)!}$$

Counting, Bin Statistics, Entropy

	Occupancy (N << M)		
Ω	Unlimited	Single	Dilute
Distinct	M^N	$\frac{M!}{(M-N)!}$	M^N
Identical	$\frac{(N+M-1)!}{N!(M-1)!}$	$\frac{M!}{(M-N)!N!}$	$\frac{M^N}{N!}$

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

Equilibrium

$$\text{Boltzmann: } P_n = \frac{d_n e^{-E_n/kT}}{Z}; \quad Z \equiv \sum_i d_i e^{-E_i/kT}$$

$$\text{Free energies: } F \equiv U - TS \quad G \equiv U - TS + pV$$

$$\text{Chemical potential:}$$

$$\mu = \left(\frac{\partial F}{\partial N} \right)_{V,T} = \left(\frac{\partial G}{\partial N} \right)_{p,T}; \quad \text{equilibrium } \sum_i (\Delta N_i) \mu_i = 0$$

$$\mu_i = kT \ln(n_i/n_{Ti}) - \Delta_i \text{ (ideal gas)}$$

$$n_Q = (2\pi mkT/h^2)^{3/2} = (10^{30} \text{ m}^{-3}) (m/m_p)^{3/2} (T/300\text{K})^{3/2}$$

$$\text{Semiconductors } n_e n_h = n_i^2; \quad n_i = n_Q e^{-\Delta/2kT}$$

Thermal Radiation

$$J = \sigma_B T^4, \quad \sigma_B = 5.670 \times 10^{-8} \text{ W/m}^2 \text{ K}^4 \quad \lambda_{\text{max}} T = 0.0029 \text{ m}\cdot\text{K}$$

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Particle	mass/mol
N ₂	28g
O ₂	32g
He	4g
Ar	40g
CO ₂	44g
H ₂	2g
Si	28g
Ge	73g
Cu	64g
Al	27g
1g	10^{-3} kg

$$aA + bB \leftrightarrow cC \Rightarrow a\mu_A + b\mu_B = c\mu_C$$

$$\frac{n_c^c}{n_a^a n_b^b} = \frac{n_c^c}{n_a^a n_b^b} e^{c\Delta/kT}$$