Name:___________________

SID:_____________________

TA Name:_______________

• This exam has 45 multiple choice questions.
• Fill in the Scantron form AND circle your answer on the exam.
• Each question is worth 3.34 points.

Note:
• The questions on this exam do not depend on each other. They may be answered in any order.
• All the questions are equally weighted. Answer those you can quickly and go back to those that require more thought.
• Some questions may seem obvious or too simple. They are. There are no ‘trick’ questions.
• Questions that contain ‘mark all that apply’ may require you to mark more than one answer to get credit for that question.
• Potentially useful relations:

\[ E = h \nu \]
\[ \lambda \nu = c \]
\[ \lambda_{\text{deBroglie}} = h / p = h / mv \]
\[ p = mv \]
\[ E_{\text{kin}} = \frac{1}{2} mv^2 \]
\[ E_{\text{kin}} (e-) = hv - \Phi = hv - hv_0 \]
\[ E_n = -\frac{Z^2}{n^2} R_\infty \]
\[ PV = nRT \]
\[ E_{\text{kin}} = \frac{3}{2} RT \]
\[ \nu_{\text{min}} = \sqrt{\frac{3RT}{M}} \]

\[ \Delta E = q + w \]
\[ w = -P_{\text{ext}} \Delta V \]
\[ \Delta E = \frac{3}{2} nR \Delta T \]

\[ N_0 = 6.02214 \times 10^{23} \text{ mol}^{-1} \]
\[ R_\infty = 2.179874 \times 10^{-18} \text{ J} \]
\[ R_\infty = 3.28984 \times 10^{15} \text{ Hz} \]
\[ k = 1.38066 \times 10^{-23} \text{ J K}^{-1} \]
\[ h = 6.62608 \times 10^{-34} \text{ J s} \]
\[ m_e = 9.101939 \times 10^{-31} \text{ kg} \]
\[ c = 2.99792 \times 10^8 \text{ m s}^{-1} \]

Gas Constant:
\[ R = 8.31451 \text{ J K}^{-1} \text{ mol}^{-1} \]
\[ R = 8.20578 \times 10^{-2} \text{ L atm K}^{-1} \text{ mol}^{-1} \]
\[ T (K) = T (\text{C}) + 273.15 \]
\[ F = 96,485 \text{ C / mol} \]
\[ 1 \text{ V} = 1 \text{ J / C} \]
\[ 1 \text{ nm} = 10^{-9} \text{ m} \]
\[ 1 \text{ kJ} = 1000 \text{ J} \]

\[ \Delta G^\circ = \Delta H^\circ - T \Delta S^\circ \]
\[ \Delta H^\circ = \sum \Delta H^\circ_i (\text{products}) - \sum \Delta H^\circ_i (\text{reactants}) \]
\[ \Delta S^\circ = \sum S^\circ (\text{products}) - \sum S^\circ (\text{reactants}) \]
\[ \Delta G^\circ = \sum \Delta G^\circ_i (\text{products}) - \sum \Delta G^\circ_i (\text{reactants}) \]
\[ S = k_B \ln W \]

\[ Q = \frac{[C]^a [D]^b}{[A]^c [B]^d} \]

At equilibrium, \( Q = K \)

\[ \Delta G^\circ = -RT \ln K \]
\[ \ln K = -\frac{\Delta H^\circ}{R} \frac{1}{T} + \frac{\Delta S^\circ}{R} \]
\[ \Delta G^\circ = -nF \Delta \varepsilon^o \]

\[ pX = -\log X \]
\[ pH = pK_a + \log \frac{[A^-]}{[HA]} \]

**Color and Wavelength of Light**

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>800</th>
<th>600</th>
<th>400</th>
<th>200</th>
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</thead>
<tbody>
<tr>
<td>IR</td>
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<tr>
<td>Visible</td>
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<tr>
<td>UV</td>
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</tbody>
</table>

**\( \Delta G^\circ \) of Formation**

<table>
<thead>
<tr>
<th>compound</th>
<th>( \Delta G^\circ ) (kJ / mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>-394.36</td>
</tr>
<tr>
<td>H(_2)O (g)</td>
<td>-228.57</td>
</tr>
<tr>
<td>C(_6)H(_12)O(_6)</td>
<td>-910</td>
</tr>
<tr>
<td>O(_2)</td>
<td>0</td>
</tr>
</tbody>
</table>
SECTION 1: PERIODIC TABLE

1.) Why does the ionization energy increase when electrons are consecutively removed from an atom?

A) the outermost electron experiences a higher effective nuclear charge
B) the remaining electrons are held more strongly
C) atomic radius is decreasing
D) all of the above
E) none of the above

For the next two questions consider the ionization energy of sodium is 496 kJ/mol and the electron affinity of Cl is -349 kJ/mol.

2.) What is the approximate net energy change in producing Na⁺ and Cl⁻ from Na and Cl atoms (kJ/mol)?

A) 150  B) 0  C) -323  D) -510  E) -1776

3.) What is the net energy change in making the NaCl molecule (kJ/mol) from the ions?

A) -642  B) 0  C) 323  D) 510  E) 1776

For the next four questions consider the following atoms Br, Sn, Sb, Te, I.

4.) Which has the largest atomic radius?

A) Br  B) Sn  C) Sb  D) Te  E) I

5.) Which is the most paramagnetic?

A) Br  B) Sn  C) Sb  D) Te  E) I

6.) Which has the largest ionization energy?

A) Br  B) Sn  C) Sb  D) Te  E) I

7.) Which has the largest electronegativity?

A) Br  B) Sn  C) Sb  D) Te  E) I
SECTION 1: CHEMICAL BONDING
For the following ten questions, consider the lowest energy Lewis structure for the following molecules/ions: SO₃, PH₃, SCN⁻¹ (you may want to draw the Lewis structures in the space provided, the central atom is highlighted).

8.) Which is transparent to microwaves (mark all that apply)?
A) PH₃  B) SCN⁻¹  C) SO₃  D) all three  E) none

9.) What is the O-S-O bond angle in SO₃?
A) 90  B) 108  C) 110  D) 120  E) 180

10.) What is the H-P-H bond angle in PH₃?
A) 90  B) 108  C) 110  D) 120  E) 180

11.) What is the bond angle in SCN⁻¹?
A) 90  B) 108  C) 110  D) 120  E) 180

12.) What is the oxidation number of S in SO₃?
A) -6  B) -2  C) 0  D) +2  E) +6

13.) What is the SO bond order in SO₃?
A) -2  B) -1  C) 0  D) 1  E) 2
14.) Which is the best description of the orbital overlap in the P-H bond in PH₃ (the ‘z’ axis is the internuclear axis)?

A) pₓ on P with sp² on H
B) pₓ on P with s on H
C) sp² on P with pₓ on H
D) sp³ on P with sp² on H
E) sp³ on P with s on H

15.) Which molecule is chiral?

A) PH₃  B) SCN⁻¹  C) SO₃  D) all three  E) none

16.) If you could connect the atoms in any order, how many different structural isomers are possible for SCN⁻¹?

A) 1  B) 2  C) 3  D) 4  E) 5

17.) What is the shape of PH₃?

A) Linear.
B) Bent.
C) Trigonal pyramidal.
D) Square planar.
E) Tetrahedral.

Continue with the next question:
For the following five questions match the atomic orbitals with the molecular orbital they would form.

<table>
<thead>
<tr>
<th>Question</th>
<th>Atomic Orbitals</th>
<th>Molecular Orbitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.) E</td>
<td><img src="image" alt="E" /></td>
<td>A</td>
</tr>
<tr>
<td>19.) A</td>
<td><img src="image" alt="A" /></td>
<td>B</td>
</tr>
<tr>
<td>20.) B</td>
<td><img src="image" alt="B" /></td>
<td>C</td>
</tr>
<tr>
<td>21.) D</td>
<td><img src="image" alt="D" /></td>
<td>D</td>
</tr>
<tr>
<td>22.) C</td>
<td><img src="image" alt="C" /></td>
<td>E</td>
</tr>
</tbody>
</table>

23.) Which of the molecular orbitals in the preceding table would have the highest energy?

A) A  B) B  C) C  D) D  E) E

24.) If butyric acid (shown right) smells sour, which one of the following compounds is also likely to smell sour?

![Butyric Acid](image)
25.) In which of the following molecules is the carbon-carbon bond likely to be the strongest?
   A) H₃CCH₃  
   B) H₂CCH₂  
   C) CH₃CH₂F  
   D) HCCH  
   E) H₂CO

26.) Which of the following mixtures of atomic orbitals best describes the σ bonding orbital in H₂?
   A) s + s  
   B) s - s  
   C) p₂ + p₂  
   D) pₓ - p₂  
   E) pₓ + pᵧ

27.) Which of the following mixtures of atomic orbitals best describes the σ bonding orbitals in HeH⁺?
   A) s + s  
   B) s - s  
   C) p₂ + p₂  
   D) pₓ - p₂  
   E) pₓ + pᵧ

28.) Which of the following mixtures of atomic orbitals best describes the σ₂p bonding orbitals in C₂?
   A) s + s  
   B) s + p₂  
   C) p₂ + p₂  
   D) p₂ - p₂  
   E) pₓ + pᵧ

29.) What is the bond order of He₂⁺.
   A) 0  
   B) 1/2  
   C) 1  
   D) 1 1/2  
   E) 2
Use the following molecular orbital energy diagram for the next three questions.

30.) How many unpaired electrons are in \( \text{O}_2^+ \)?

A) 0  B) 1  C) 2  D) 3  E) 4

31.) What is the bond order of \( \text{OF} \)?

A) 0  B) 1/2  C) 1  D) 1 1/2  E) 2

32.) Which of the following is not paramagnetic?

A) \( \text{O}_2^+ \)  B) \( \text{OF} \)  C) \( \text{NO} \)  D) \( \text{OF}^- \)  E) \( \text{CO}^+ \)

**SECTION 3: THE BEHAVIOR OF GASSES**

Unless stated otherwise, the system for the next seven questions is a rigid 22.4 L flask containing an equal number of moles of gaseous \( \text{N}_2 \) molecules and \( \text{Cl} \) atoms at 1.00 atm and 25.0°C.

33.) What is the total number of moles of gas in the flask?

A) 0.25  B) 0.50  C) 1.0  D) 1.50  E) 2.00

34.) What is the partial pressure of \( \text{N}_2 \) (atm)?

A) 0.25  B) 0.50  C) 0.75  D) 1.00  E) 2.00
35.) What is the pressure in the flask if the temperature were raised to 100˚C?

A) 0.26  B) 0.54  C) 1.25  D) 1.36  E) 2.11

36.) What is the total pressure in the flask if one mole of Ar gas were to be added at constant temperature (25˚C)?

A) 0.25  B) 0.50  C) 0.75  D) 1.00  E) 2.00

37.) If all the Cl atoms were to react and form Cl₂ molecules what would be the pressure in the flask containing only N₂ and Cl₂ (constant T and V) (25˚C)?

A) 0.25  B) 0.50  C) 0.75  D) 1.00  E) 2.00

38.) Which has the highest root mean squared velocity when there is a mixture of Cl, Cl₂ and N₂ (25˚C)?

A) Cl  B) N₂  C) Cl₂  D) all are the same

39.) Which has the highest molar kinetic energy when there is a mixture of Cl, Cl₂ and N₂ (25˚C)?

A) Cl  B) N₂  C) Cl₂  D) all are the same

Continue with the next question:
For the next questions, choose the plot that best describes the relationship between the variables listed (y vs. x).

40.) Pressure vs. volume for a real gas below its critical temperature?

A) A  B) B  C) C  D) D  E) E

41.) Pressure vs. volume for a real gas above its critical temperature?

A) A  B) B  C) C  D) D  E) E

42.) Volume vs. temperature for an ideal gas?

A) A  B) B  C) C  D) D  E) E

43.) Particle count (at each velocity) vs. the velocity of a gas?

A) A  B) B  C) C  D) D  E) E

44.) Kinetic energy of a mole of gas particles vs. particle mass at constant temperature?

A) A  B) B  C) C  D) D  E) E

45.) Kinetic energy of a mole of particles vs. temperature.

A) A  B) B  C) C  D) D  E) E