Please print your name on this cover page and sign your name on this cover sheet as indicated below. Turn ONLY this sheet and your Scantron in after the exam. Good luck!

On my honor as a University of Colorado at Boulder student I have neither given nor received unauthorized assistance on this work.

Name

Signature
Answer all questions on the Scantron answer sheet by filling in the proper bubble with a number 2 pencil. If you change your answer, please erase the previous mark thoroughly.

**You are not permitted to use a programmable calculator; only non-programmable calculators can be used!**

Be sure to fill in the boxes for your SID# and name; then fill in the corresponding bubbles beneath them correctly. A periodic table with atomic numbers and masses is attached to the back of this exam.

Be sure to fill out the Scantron sheet with your name and SID#.

\[
K = \text{°C} + 273.15 \quad R = 0.08206 \frac{\text{L-atm}}{\text{mol-K}} = 8.314 \frac{\text{J}}{\text{mol-K}}
\]

\[
1 \text{ atm} = 760 \text{ mmHg} = 101325 \text{ Pascal}
\]

**Zeroth order reactant:**

\[
[A] = [A]_o - kt
\]

**First order reactant:**

\[
\ln[A] = \ln[A]_o - kt \quad t_{\frac{1}{2}} = \frac{0.693}{k}
\]

**Second order reactant:**

\[
\frac{1}{[A]} = \frac{1}{[A]_o} + kt
\]

\[
\ln \left( \frac{k_1}{k_2} \right) = \frac{E_a}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)
\]

\[
\ln \left( \frac{P_1}{P_2} \right) = \frac{H_{wp}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)
\]

Avogadro's Number: \(6.022 \times 10^{23}\) things/mol

STP is 1.0 atm and 0 °C \(\Delta E = q + w\) \(w = -P\Delta V\)

\[H = E + PV \quad \Delta G = \Delta H - T\Delta S \quad q = mC_p\Delta T \quad P = \frac{nRT}{V-nb} = \frac{a}{V^2}\]

\[\Delta H^o_{rxn} = \sum \Delta H^o_f(\text{products}) - \sum \Delta H^o_f(\text{reactants})\]

\[\Delta H^o_{rxn} \approx \sum D(\text{bonds broken}) - \sum D(\text{bonds formed})\]
1. Choose the true statement
   a. Entropy is a form of energy that can be converted to useful work
   b. According to the laws of thermodynamics, the total energy and entropy of the universe do not change over time
   c. The development of living things is the only known exception to the 2nd law of thermodynamics
   d. The entropy of the universe increase for all spontaneous processes, so the universe must have started in a much lower entropy state then it is in today
   e. The entropy of the universe decreases for all spontaneous processes, so the universe must have started in a much higher entropy state than it is in today

2. In a chemical reaction, the value of $\Delta H$ is approximately the same as $\Delta E$ when
   a. The ionization energy of at least one reactant is positive
   b. The reaction produces no heat and is endothermic
   c. There is a change in volume in going from reactants to products so that PV work is involved
   d. A hydrocarbon undergoes incomplete combustion
   e. There are no gases among the reactants or products

3. Given the phase diagram, what is the lowest temperature at which a liquid can exist for this material?

   ![Phase Diagram]

   a. 140°C
   b. 310°C
   c. 30°C
   d. 150°C
   e. A liquid can exist at any temperature at the right pressure
4. I have two balloons of volume 22.4 L at STP. One contains nitrogen gas, the other helium gas. Which statement about the balloons is true we assume both gases behave ideally?
   a. The density of the gases in the balloons is the same
   b. If I heat up both balloons keeping the pressure constant, the volume of both balloons will decrease, and by the same amount
   c. Each balloon contains 2 moles of gas
   d. The number of molecules in the two balloons is the same
   e. Both gases will explode when lighted, giving off a large quantity of heat

5. In the diagram below, the quantity that is indicated by the double-headed arrow B is best described as the

   ![Diagram](image)

   a. Activation energy
   b. Energy of reaction
   c. Reaction state
   d. Production state
   e. Heat of formation

6. If we take into account the molecular attraction between molecules, but not their size, then the pressure at a given volume would be
   a. Significantly lower than the pressure predicated by the ideal gas law
   b. Slightly lower than the pressure predicted by the ideal gas law
   c. The same as the pressure predicted by the ideal gas law
   d. Slightly higher than the pressure predicted by the ideal gas law
   e. Significantly higher than the pressure predicted by the ideal gas law

7. Two 1 L bulbs are connected by a stopcock. On the left side, initially, there is a 1 atm nitrogen gas (N₂) and on the right side there is a vacuum. The apparatus is also thermally insulated. Find ΔE of the left bulb when we open the stopcock.
   a. 101.3 J
   b. 0J
   c. -101.3 J
8. Which is the proper ordering of the heats of vaporization?
   a. \( \text{NaCl} > \text{NH}_3 > \text{HCl} > \text{C}_2\text{H}_6 \)
   b. \( \text{HCl} > \text{NH}_3 > \text{NaCl} > \text{C}_2\text{H}_6 \)
   c. \( \text{NaCl} > \text{HCl} > \text{NH}_3 > \text{C}_2\text{H}_6 \)
   d. \( \text{NH}_3 > \text{NaCl} > \text{HCl} > \text{C}_2\text{H}_6 \)
   e. \( \text{C}_2\text{H}_6 > \text{NH}_3 > \text{HCl} > \text{NaCl} \)

9. A tank of He gas with volume 2.0 L is pressurized to \( 7.6 \times 10^4 \text{ mm Hg} \). How many 4.0 L balloons at 1.0 atm pressure could you fill at the same temperature with the He in this tank?
   a. 20
   b. 50
   c. 100
   d. 200
   e. 400

10. What orbital hybridizations are expected for the central nitrogen and oxygen atom in a \( \text{N}_2\text{O} \) molecule?
    a. \( sp, sp \)
    b. \( sp, sp^3 \)
    c. \( sp^2, sp \)
    d. \( sp^3, sp \)
    e. \( sp^2, sp \)

11. A reaction is first order in \( \text{H}_2\text{O}_2 \). The rate constant is \( 1.4 \times 10^{-5} \text{s}^{-1} \) and the initial concentration is 0.2M. How many hours does it take to reach a concentration of 0.01M?
    a. 59.5 hours
    b. \( 1.88 \times 10^4 \) hours
    c. 3.77 hours
    d. 397 hours
    e. 21.2 hours

12. You get into your car on a chilly morning (\( T = -5^\circ C \)) and notice that the tire pressure is 28 psi (pounds per square inch). As you drive down the freeway to Veil for some well-deserved skiing after a tough chemistry exam, your tires heat up to \( 20^\circ C \). What does the pressure gauge read now?
    a. 12.2 psi
    b. 25.6 psi
13. A sample of gold was cooled from 100°C to 25°C in water. In the process, 1.94 kJ of heat transferred from the metal to the water. If the mass of the metal sample was 200.0g what is the molar heat capacity of the metal?
   a. 0.129 \text{ J mol}^{-1}\text{K}^{-1}
   b. 0.129 \text{ kJ mol}^{-1}\text{K}^{-1}
   c. 0.255 \text{ J mol}^{-1}\text{K}^{-1}
   d. 10.06 \text{ kJ mol}^{-1}\text{K}^{-1}
   e. 25.47 \text{ J mol}^{-1}\text{K}^{-1}

14. Which of the following molecules is polar?
   a. Methane
   b. Acetylene (C\_2H\_2)
   c. Carbon tetrachloride
   d. Boron trifluoride
   e. Sulfur dichloride

15. Find \( \Delta H_{rxn} \) for the reaction \( 4\text{NH}_3(g) + 5\text{O}_2(g) \rightarrow 4\text{NO}(g) + 6\text{H}_2\text{O}(g) \), given the heats of formation found on the page at the back of the exam
   a. -1627 \text{ kJ/mol}
   b. -905 \text{ kJ/mol}
   c. 905 \text{ kJ/mol}
   d. 1627 \text{ kJ/mol}
   e. -1189 \text{ kJ/mol}

16. Some bacteria like Acetobacter catalyze the oxidation of ethanol to acetic acid when oxygen is present by the following reaction

\[
\text{C}_2\text{H}_5\text{OH} + \text{O}_2 \rightarrow \text{CH}_3\text{COOH} + \text{H}_2\text{O}
\]

Estimate \( \Delta H_{rxn} \) for this reaction from the given average bond dissociation energies found in the table at the back of the exam
a. -48 kJ/mol  
b. -510 kJ/mol  
c. 48 kJ/mol  
d. 510 kJ/mol  
e. -334 kJ/mol

17. Using the experimental data shown below to estimate the rate constant of the reaction: 
\[ 2A + 2B \rightarrow C + D \] in the appropriate units for the rate law:

<table>
<thead>
<tr>
<th>[A] (M)</th>
<th>[B] (M)</th>
<th>Rate (M x hr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.20</td>
<td>0.0214</td>
</tr>
<tr>
<td>0.20</td>
<td>0.50</td>
<td>0.0214</td>
</tr>
<tr>
<td>0.50</td>
<td>0.20</td>
<td>0.1338</td>
</tr>
</tbody>
</table>

a. 0.086  
b. 0.15  
c. 0.21  
d. 0.43  
e. 0.54

18. Given the phase diagram of the right, which of the following is closest to the heat of vaporization of the material?

a. 9 kJ/mol  
b. 19 kJ/mol  
c. 29 kJ/mol  
d. 39 kJ/mol  
e. 49 kJ/mol
19. The activation energy for a given reaction is 33.0 kJ mol\(^{-1}\). The reaction is originally run at 360°C. If the temperature is lowered by 30°C, then the rate at the second temperature is how many times that of the first temperature?
   a. 0.36
   b. 0.73
   c. 0.92
   d. 1.37
   e. 2.79

20. 4.50 L of nitrogen gas reacts with excess hydrogen gas to form ammonia at STP in the reaction listed below. Find \(\Delta E\) for the process (a table of heats of formation is attached to the back of the exam). \(N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)\)
   a. -17.6 kJ
   b. -18.5 kJ
   c. -19.4 kJ
   d. -91.2 kJ
   e. -93.1 kJ

21. The \(ICl_2^-\) ion has ______ valence electrons
   a. 8
   b. 21
   c. 22
   d. 24

22. The geometries around the carbon and the oxygen in methanol \((CH_3OH)\) are, respectively:
   a. Tetrahedral, bent
   b. Linear, tetrahedral
   c. Square planar, linear
   d. Bent, bent

23. The number of atoms with a non zero formal charge in the most stable resonance structure of \(N_3^-\) (the azide ion) is:
   a. 0
   b. 1
   c. 2
   d. 3

24. A nitronium ion \((NO_2^+)\) has how many electrons in lone pairs?
   a. 4
   b. 6
   c. 8
HF needed:

\[
\begin{align*}
\text{NO (g)} & \quad H = -180.5/2 \text{ kJ/mol} \quad \text{(Check numbers)} \\
\text{NH}_3 (g) & \quad H = -91.82/2 \text{ kJ/mol} \\
\text{H}_2\text{O (g)} & \quad H = -483.6/2 \text{ kJ/mol}
\end{align*}
\]

Other questions:

1. \(\Delta H^\circ\) for the reaction \(2 \text{NO}_2(g) \rightarrow 2 \text{NO(g)} + \text{O}_2(g)\) is +110 kJ. The standard molar enthalpy of formation of nitrogen dioxide is 35 kJ/mol. What is the \(\Delta H^\circ\) of nitrogen(II) oxide?

1. Using bond enthalpies from the table at the end of the exam, estimate \(\Delta H^\circ\) for the reaction (CHANGE REACTION)

\[
\text{N}_2\text{H}_4(g) + H_2 (g) \rightarrow 2 \text{NH}_3(g).
\]

(a) -2346 kJ
(b) -619 kJ
(c) -183 kJ
(d) -72 kJ
(e) +72 kJ
(f) +183 kJ
(g) +825 kJ
(h) 2163 kJ