Statistics:
• **Average:** 68 p (68%);
• **Highest:** 91 p (91%); **Lowest:** 37 p (37%)
• Number of students performing at or above average: 58 (53%)
• Number of students performing below 55%: 19 (17%)

**PART I: MULTIPLE CHOICE** (32 questions, each multiple choice question has a 2-point value, 64 points total).

1. Pressure is
   A. defined as the mass that an object exerts when at rest
   B. measured in Newtons
   C. defined as the number of moles of substance divided by the mass of the substance
   D. **defined as the force per unit area**
   E. measured in grams

2. Which of the following correctly describes the relationship between the pressure of a gas and the volume of a gas at constant temperature?
   A. as one increases the other increases
   B. unrelated
   C. directly proportional
   D. **irreversibly proportional**
   E. inversely proportional

3. For an ideal gas, which two variables are *directly* proportional to each other (if all other conditions remain constant)?
   1. \( P \) and \( V \)
   2. \( V \) and \( n \)
   3. \( V \) and \( T \)
   A. 1 only
   B. 2 only
   C. 3 only
   D. 1 and 2
   E. 2 and 3

4. A sample of \( N_2 \) gas occupies 2.40 L at 20°C. If the gas is in a container that can contract or expand at constant pressure, at what temperature will the \( N_2 \) occupy 4.80 L?
   A. 10°C
   B. 40°C
   C. 146°C
   D. **313°C**
   E. 685°C

5. If the pressure on a gas sample is tripled and the absolute temperature is quadrupled, by what factor will the volume of the sample change?
   A. 12
   B. \( \frac{1}{4} \)
   C. 3/4
   D. **1/3**
   E. 4

6. At what temperature will a fixed amount of gas with a volume of 175 L at 15°C and 760 mmHg occupy a volume of 198 L at a pressure of 640 mm Hg?
   A. 274°C
   B. 214°C
   C. **114°C**
   D. **1°C**
   E. -59°C

7. You are holding two balloons, an orange balloon and a blue balloon. The orange balloon is filled with neon (Ne) gas and the blue balloon is filled with argon (Ar) gas. The orange balloon has twice the volume of the blue balloon. Which of the following best represents the mass ratio of Ne:Ar in the balloons?
   A. 1:1
   B. 1:2
   C. 2:1
   D. **1:3**
   E. 3:1

8. Calculate the volume occupied by 35.2 g of methane gas (\( CH_4 \)) at 25°C and 1.0 atm (\( R = 0.0821 \text{ L.atm/mol.K} \))
   A. 0.0186 L
   B. 4.5 L
   C. 11.2 L
   D. **49.2 L**
   E. **53.7 L**
9. Calculate the density, in g/L, of CO\(_2\) gas at 27°C and 0.50 atm pressure.
   A. 0.89 g/L  
   B. 1.12 g/L  
   C. 9.93 g/L  
   D. 46.0 g/L  
   E. 2.17 kg/L

10. Which of the following gases will have the greatest density at the same specified temperature and pressure?
   A. H\(_2\)  
   B. CClF\(_3\)  
   C. CO\(_2\)  
   D. C\(_2\)H\(_6\)  
   E. CF\(_4\)

11. Two moles of chlorine gas at 20.0°C are heated to 350°C while the volume is kept constant. The density of the gas:
   A. increases.  
   B. decreases.  
   C. remains the same.

12. You have two samples of the same gas in the same size container, with the same pressure. The gas in the first container has a Kelvin temperature four times that of the gas in the other container. The ratio of the number of moles of gas in the first container compared to that in the second is:
   A. 1:1  
   B. 4:1  
   C. 1:4  
   D. 2:1  
   E. 1:2

13. How many liters of chlorine gas at 200°C and 0.500 atm can be produced by the reaction of 12.0 g of MnO\(_2\) with HCl as follows?
   \[
   \text{MnO}_2(s) + 4\text{HCl}(aq) \rightarrow \text{MnCl}_2(aq) + 2\text{H}_2\text{O}(l) + \text{Cl}_2(g)
   \]
   A. 10.7 L  
   B. 3.09 L  
   C. 4.53 L  
   D. 0.138 L  
   E. 0.093 L

14. If equal masses of O\(_2\)(g) and HBr(g) are in separate containers of equal volume and temperature, which one of the following statements is true?
   A. The pressure in the O\(_2\) container is greater than that in the HBr container.  
   B. There are more HBr molecules than O\(_2\) molecules.  
   C. The average velocity of the O\(_2\) molecules is less than that of the HBr molecules.  
   D. The average kinetic energy of HBr molecules is greater than that of O\(_2\) molecules.  
   E. The pressures of both gases are the same.

15. Which of the following IS NOT a postulate of the kinetic-molecular theory of gases?
   A. All gases consist of atoms and molecules moving randomly in all directions at various speeds.  
   B. The average kinetic energy of gas molecules increases as the temperature increases.  
   C. The volume of a gas molecule is negligible when compared to the space that separates it from other gas molecules.  
   D. Gas molecules will eventually stop colliding due to the energy lost in each collision.  
   E. There are no attractive or repulsive forces between gas molecules.

16. Which of the following gas molecules have the highest average kinetic energy at 25°C?
   A. H\(_2\)  
   B. O\(_2\)  
   C. N\(_2\)  
   D. Cl\(_2\)  
   E. All the gases have the same average kinetic energy

17. Oxygen gas at 1.000 atm, placed in a container having a pinhole opening in its side, leaks from the container 2.14 times faster than does and unknown gas at 1.000 atm, placed in this same apparatus. Which of the following species could be the unknown gas?
   A. Cl\(_2\)  
   B. SF\(_6\)  
   C. Kr  
   D. UF\(_6\)  
   E. Xe

18. The van der Waals equation, \(nRT = [P + a(n/V)^2] \cdot (V - nb)\), incorporates corrections to the ideal gas law in order to account for the properties of real gases. Which of the following properties of a real gas is related to the \(b\) coefficient in the van der Waals equation?
A. Real gases consist of molecules or atoms that have volume.
B. The average speed of the molecules of a real gas increases with temperature.
C. There are attractive forces between atoms or molecules of a real gas.
D. The rate of effusion of a gas is inversely proportional to the square root of the molecular weight of the gas.
E. None of these.

19. Which of the following is not an example of kinetic energy?
A. The motion of a molecule
B. The motion of a golf ball
C. The vibration of an object
D. A loosely held brick on the top of a building
E. The motion of electrons through a wire

20. An exothermic reaction causes the surroundings to
A. warm up
B. become acidic
C. expand
D. decrease its temperature
E. release CO₂

21. Which statement is true?
A. A positive change in enthalpy occurs with endothermic processes.
B. A positive change in enthalpy occurs with exothermic processes.
C. A positive change in enthalpy occurs when work is done on the surroundings.
D. A positive change in enthalpy occurs when work is done on the system.
E. A positive change in enthalpy occurs when a process is endothermic and does work on the surroundings.

22. For a particular process \( q = 20 \text{ kJ} \) and \( w = 15 \text{ kJ} \). Which of the following statements is true?
A. Heat flows from the system to the surroundings.
B. The system does work on the surroundings.
C. \( \Delta E = 35 \text{ kJ} \)
D. All of the above are true.
E. None of the above are true.

23. Two metals of equal mass with different heat capacities are subjected to the same amount of heat. Which undergoes the smallest change in temperature?
A. The metal with the higher heat capacity
B. The metal with the lower heat capacity
C. Both undergo the same change in temperature.
D. You need to know the initial temperatures of the metals.
E. You need to know which metals you have.

24. How many degrees of temperature rise will occur when a 25.0 g block of aluminum absorbs 10.0 kJ of heat? The specific heat of Al is 0.900 J/g °C.
A. 0.44°C
B. 22.5°C
C. 225°C
D. 360°C
E. 444°C

25. To which one of these reactions occurring at 25°C does the symbol \( \Delta H_f^0 \) [HNO₃(l)] refer?
A. \( \text{H}_2(g) + \text{N}_2(g) + \text{O}_3(g) \rightarrow \text{HNO}_3(l) \)
B. \( \frac{1}{2}\text{H}_2(g) + (1/2)\text{N}_2(g) + (3/2)\text{O}_2(g) \rightarrow \text{HNO}_3(l) \)
C. \( \text{HNO}_3(l) \rightarrow (1/2)\text{H}_2(g) + (1/2)\text{N}_2(g) + (3/2)\text{O}_2(g) \)
D. \( \text{HNO}_3(l) \rightarrow \text{H}(g) + \text{N}(g) + 3\text{O}(g) \)
E. \( \text{H}_2(g) + \text{N}_2(g) + \text{O}_3(g) \rightarrow \text{HNO}_3(l) \)

26. When 0.560 g of Na(s) reacts with excess F₂(g) to form NaF(s), 13.8 kJ of heat is evolved at standard-state conditions. What is the standard enthalpy of formation (\( \Delta H_f^0 \)) of NaF(s)?
A. 24.8 kJ/mol
B. 570 kJ/mol
C. -24.8 kJ/mol
D. -7.8 kJ/mol
E. -570 kJ/mol
27. Glycine, C₂H₅O₂N, is important for biological energy. The combustion reaction of glycine is given by the equation:

$$4\text{C}_2\text{H}_5\text{O}_2\text{N}(s) + 9\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l) + 2\text{N}_2(g) \quad \Delta H_{\text{rxn}}^\circ = -3857 \text{ kJ}.$$  

Given that $$\Delta H_{\text{f}}^\circ [\text{CO}_2(g)] = -393.5 \text{ kJ/mol}$$ and $$\Delta H_{\text{f}}^\circ [\text{H}_2\text{O}(l)] = -285.8 \text{ kJ/mol},$$ calculate the enthalpy of formation of glycine.

A. $$-537.2 \text{ kJ/mol}$$
B. $$-268.2 \text{ kJ/mol}$$
C. $$2,149 \text{ kJ/mol}$$
D. $$-3,178 \text{ kJ/mol}$$
E. $$-964 \text{ kJ/mol}$$

28. Given H₂(g) + (1/2)O₂(g) → H₂O(l), $$\Delta H = -286 \text{ kJ/mol},$$ determine the standard enthalpy change for the reaction

$$2\text{H}_2\text{O}(l) \rightarrow 2\text{H}_2(g) + \text{O}_2(g)$$

A. $$\Delta H = -286 \text{ kJ/mol}$$
B. $$\Delta H = +286 \text{ kJ/mol}$$
C. $$\Delta H = -572 \text{ kJ/mol}$$
D. $$\Delta H = +572 \text{ kJ/mol}$$
E. $$\Delta H = -143 \text{ kJ/mol}$$

29. Pentaborane B₅H₉(s) burns vigorously in O₂ to give B₂O₃(s) and H₂O(l). Calculate $$\Delta H_{\text{rxn}}^\circ$$ for the combustion of 1 mol of B₅H₉.

$$\Delta H_{\text{f}}^\circ [\text{B}_2\text{O}_3(s)] = -1,273.5 \text{ kJ/mol}$$  
$$\Delta H_{\text{f}}^\circ [\text{B}_5\text{H}_9(s)] = 73.2 \text{ kJ/mol}$$  
$$\Delta H_{\text{f}}^\circ [\text{H}_2\text{O}(l)] = -285.8 \text{ kJ/mol}$$

A. $$-1273.5 \text{ kJ/mol}$$
B. $$-4,543 \text{ kJ/mol}$$
C. $$-18,170 \text{ kJ/mol}$$
D. $$-9,086 \text{ kJ/mol}$$
E. $$-8,448 \text{ kJ/mol}$$

30. According to the first law of thermodynamics:

A. Energy is neither lost nor gained in any energy transformations.
B. Perpetual motion is possible.
C. Energy is conserved in quality but not in quantity.
D. Energy is being created as time passes. We have more energy in the universe now than when time began.

31. A calorimeter

A. is equal to the molar enthalpy of a reaction.
B. is a dieting aid.
C. is an indicator of a spontaneous reaction.
D. is a device used to measure the transfer of heat energy.
E. is useful in measuring the amount of heat released by endothermic reactions.

32. For which of these reactions will the difference between $$\Delta H$$ and $$\Delta E$$ be the greatest?

A. $$2\text{H}_2\text{O}(l) \rightarrow 2\text{H}_2(l) + \text{O}_2(g)$$
B. $$\text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g)$$
C. $$\text{NO}(g) + \text{O}_3(g) \rightarrow \text{NO}_2(g) + \text{O}_2(g)$$
D. $$2\text{C}_2\text{H}_6(g) + 7\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 6\text{H}_2\text{O}(l)$$
E. $$4\text{NH}_3(g) + 5\text{O}_2(g) \rightarrow 4\text{NO}(g) + 6\text{H}_2\text{O}(g)$$

PART II: SHORT ANSWER (Each short answer question has a 1-point value, 8 points total)

33. The gas law, which relates pressure and volume for a sample of gas at constant temperature, is known as the Boyle's law.

34. According to kinetic-molecular theory, gas particles undergo elastic collisions.

35. The internal energy of a system is the sum of the kinetic and potential energies of all the particles in the system.

36. According to the First Law of Thermodynamics, the total energy of the universe is constant.

37. Heat involves the transfer of energy between two objects due to a temperature difference.

38. The quantity of energy required to increase the temperature of one gram of a sample by 1°C is called specific heat.

39. In an endothermic reaction, heat is transferred from the surroundings to the system.

40. Enthalpy change is equal to heat transfer at constant pressure.
PART III: CONCEPTS

41. (3 pts) For a sample of gas at constant pressure, what is \( T \) in the table below?

<table>
<thead>
<tr>
<th>( V )</th>
<th>( T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{initial:} 91.8 mL</td>
<td>365 K</td>
</tr>
<tr>
<td>\text{final:} 45.8 mL</td>
<td>( T )</td>
</tr>
</tbody>
</table>

We use Charles’ law to arrive at: \( \frac{V_1}{V_2} = \frac{T_1}{T_2} \)

The final temperature \( T_2 \) = \( \frac{(V_2 \times T_1)}{V_1} \) = \( 182 \) K

42. (5 pts) Below is given a process that results in a change of both volume and temperature.

a. Has any work been done? If so, is the work positive or negative with respect to the system?
   
   **There is a change in volume so work was done.** Since the final volume is greater than the initial, the system has expanded against the surroundings and \( w_{\text{system}} < 0 \) (i.e. the system does work on the surroundings)

b. Has there been an enthalpy change? If so, is the reaction exothermic or endothermic?
   
   **There is a change of temperature, so heat transfer occurred as well.** Since \( T_{\text{final}} > T_{\text{initial}} \), \( q > 0 \). Hence the process is endothermic.

43. (4 pts) A reaction is carried out in a cylinder, fitted with a movable piston (see below). The starting volume is 5.00 L. At constant pressure of 1 atm the changes in enthalpy and energy are: \( \Delta H = -35.0 \) kJ and \( \Delta E = -34.8 \) kJ. Does the volume increase, decrease or remain the same?

![Diagram of volume change](image)

**Solution:** We know that

\[ \Delta E = \Delta H + w = \Delta H - p\Delta V \]

\[ p\Delta V = \Delta H - \Delta E \]

But the pressure is constant and \( p > 0 \). Therefore \( \Delta V < 0 \).

\[ \Delta V = V_f - V_i < 0 \]

\[ V_f < V_i \]

i.e. the volume decreased

44. (4 pts) Consider the following numbered processes:

1. \( A \rightarrow 2B \) \( \Delta H_1 \)
2. \( B \rightarrow C + D \) \( \Delta H_2 \)
3. \( E \rightarrow 2D \) \( \Delta H_3 \)

\( \Delta H \) for the process \( A \rightarrow 2C + E \) is:

A. \( \Delta H_1 + \Delta H_2 + \Delta H_3 \)
B. \( \Delta H_1 + \Delta H_2 \)
C. \( \Delta H_1 + \Delta H_2 - \Delta H_3 \)
D. \( \Delta H_1 + 2\Delta H_2 - \Delta H_3 \)
E. \( \Delta H_1 + 2\Delta H_2 + \Delta H_3 \)

**Solution:** In order to arrive at the equation \( A \rightarrow 2C + E \), we need to retain (1), multiply (2) by a factor of 2, and reverse (3). Thus, \( \Delta H = \Delta H_1 + 2\Delta H_2 - \Delta H_3 \), which corresponds to answer (D).
PART IV: CALCULATION PROBLEMS (Show your work in its entirety. Do not provide just a single number!).

45. (6 pts) When 21.45 g of KNO₃ was dissolved in water in a calorimeter, the temperature fell from 25.00 °C to 14.14 °C. The heat capacity of the calorimeter is 682 J/°C. Write the complete thermochemical equation for the process:

\[
\text{KNO}_3 (s) \rightarrow \text{K}^+ (aq) + \text{NO}_3^- (aq)
\]

**Solution:** It is based on the fact that \( q_{\text{soln}} = - q_{\text{cal}} \)

\[
q_{\text{cal}} = (\text{heat capacity})_{\text{calorimeter}} \times \Delta T = C \times \Delta T = 682 \text{ J/}^\circ \text{C} (14.14 - 25.00) \text{ °C} = 682 \times (-10.86) \text{ °C} = -7407 \text{ J}
\]

Therefore \( q_{\text{soln}} = +7407 \text{ J} \)

This is the amount of heat absorbed by dissolving 21.45 g \times 1 \text{ mol/101.11 g} = 0.2121 \text{ mol of KNO}_3

Per mole: 7407 J/0.2121 mol KNO₃ = 34922 J/mol KNO₃ = 34.92 kJ/mol KNO₃

\[
\text{KNO}_3 (s) \rightarrow \text{K}^+ (aq) + \text{NO}_3^- (aq) \quad \Delta \Delta \Delta \Delta H^\circ = +34.92 \text{ kJ}
\]

46. (6 pts) Determine the enthalpy change for the process:

\[
\text{C}_2\text{H}_4 (g) + 6 \text{ HCl} (g) \rightarrow 2 \text{ CHCl}_3 (g) + 4 \text{ H}_2 (g)
\]

using the information given below:

\[
\begin{align*}
2 \text{ C} (s) + 2 \text{ H}_2 (g) & \rightarrow \text{C}_2\text{H}_4 (g) \quad \Delta H = 52.3 \text{ kJ} \\
\text{H}_2 (g) + \text{Cl}_2 (g) & \rightarrow 2 \text{ HCl} (g) \quad \Delta H = -184.6 \text{ kJ} \\
\text{C} (s) + \frac{1}{2} \text{ H}_2 (g) + 3/2 \text{ Cl}_2 (g) & \rightarrow \text{CHCl}_3 (g) \quad \Delta H = -103.1 \text{ kJ}
\end{align*}
\]

**Solution:** We begin by identifying reactants and products in the equation in question and also where they appear in the set of equations. The following changes/manipulations are necessary:

<table>
<thead>
<tr>
<th>Equation 1: Reverse:</th>
<th>2 C (s) + 2 H₂ (g) → C₂H₄ (g)</th>
<th>ΔH = 52.3 kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation 2: Reverse and multiply by 3:</td>
<td>6 HCl (g) → 3 H₂ (g) + 3 Cl₂ (g)</td>
<td>ΔH° = +553.8 kJ</td>
</tr>
<tr>
<td>Equation 3: Multiply by 2:</td>
<td>2 C (s) + H₂ (g) + 3 Cl₂ (g) → 2 CHCl₃ (g)</td>
<td>ΔH° = -206.2 kJ</td>
</tr>
</tbody>
</table>

Inspection now shows that adding the three new equations gives precisely the process under study. Therefore the summing of the enthalpy changes must give us the enthalpy change for the above process: \( \Delta H^\circ = -52.3 + 553.8 - 206.2 = +295.3 \text{ kJ} \)

47. (3 pts) **BONUS PROBLEM** (In order to receive credit, you have to solve the problem completely!).

A mixture was made form the following: 25.0 g of water at 15.0 °C, 45.0 g of water at 50.0 °C, and 15.0 g of water at 37.0 °C. What is the final temperature of the mixture?

**Solution:** It is based on the fact that \( q_1 + q_2 + q_3 = 0 \), due to the law of conservation of energy

\[
c \times m_1 \times (\Delta T)_1 + c \times m_2 \times (\Delta T)_2 + c \times m_3 \times (\Delta T)_3 = 0
\]

\[
m_1 \times (\Delta T)_1 + m_2 \times (\Delta T)_2 + m_3 \times (\Delta T)_3 = 0
\]
\[ m_1 x (T_i - T_1^i) + m_2 x (T_i - T_2^i) + m_3 x (T_i - T_3^i) = 0 \]

\[(m_1 + m_2 + m_3) x T_i = m_1 x T_1^i + m_2 x T_2^i + m_3 x T_3^i \]

\[ T_i = (m_1 x T_1^i + m_2 x T_2^i + m_3 x T_3^i) / (m_1 + m_2 + m_3) \]

\[ T_i = (25.0 x 15.0 + 45.0 x 50.0 + 15.0 x 37.0) / (25.0 + 45.0 + 15.0) = 37.4 \, ^\circ C \]

\[ T_i = 37.4 \, ^\circ C \]