Statistics:
- **Average:** 73 pts (73%);
- **Highest:** 99 pts (99%); **Lowest:** 27 pts (27%)
- Number of students performing at or above average: 58 (62%)
- Number of students performing at or below 55%: 13 (14%)

PART I: MULTIPLE CHOICE (Each multiple choice question has a 2-point value).

1. What is the phenomenon that occurs when certain metals emit electrons when illuminated by particular wavelengths of light?
   a. Emission spectrum
   b. Quantum theory
   c. Electromagnetic spectrum
   d. Planck’s constant
   e. Photoelectric effect

2. Determine the energy of a photon that has a wavelength of 645 nm. The speed of light is \(3 \times 10^8\) m/s and \(h = 6.63 \times 10^{-34}\) J.s.
   a. \(3.08 \times 10^{-19}\) J
   b. \(1.43 \times 10^{-19}\) J
   c. \(4.65 \times 10^{14}\) J
   d. \(3.08 \times 10^{-28}\) J
   e. \(1.99 \times 10^{-25}\) J

3. What is a photon?
   a. A high-speed electron that gives off light when it strikes an object
   b. A massless “particle” or bundle of energy that moves at the speed of light
   c. Very high frequency light
   d. Light that comes from a cathode ray tube
   e. Very long wavelength light

4. Which of the following IS NOT a characteristic of the Bohr model of the atom?
   a. An electron is located in an orbit around the nucleus.
   b. Each orbit has a discrete energy associated with it.
   c. Orbits have defined radii.
   d. There are only certain allowed energy levels that an electron can have around a nucleus.
   e. Electrons can produce a continuous spectrum of energy.

5. Which idea did Werner Heisenberg propose?
   a. Energy in the atom is quantized.
   b. Ground state orbits have higher energy than excited orbits.
   c. Electrons have no momentum.
   d. Photons used to determine the location of electrons have no measurable effect on electrons.
   e. It is impossible to simultaneously determine both the exact location and momentum of an electron.

6. Which quantum number describes the orientation in space of an orbital?
   a. \(n\)
   b. \(l\)
   c. \(m_s\)
   d. \(m_l\)
   e. any of these

7. How many electrons can the third principal quantum level hold?
   a. 2
   b. 8
   c. 16
   d. 18
   e. 32

8. How many orbitals are contained in the \(3d\) subshell?
   a. 1
   b. 3
   c. 5
   d. 7
   e. 9
9. Which statement IS FALSE?
   a. The d orbitals occur in groups of 5.
   b. The 3p orbitals have higher energy than the 2p orbitals.
   c. The 3d and 4d orbitals hold the same number of electrons.
   d. Two electrons in the same orbital will have the same spin.
   e. The 1s orbital holds up to 2 electrons.

10. Which of the following sets of quantum numbers refers to a 3d orbital?
    a. n = 2, l = 2, m_l = 2, m_s = +1/2
    b. n = 3, l = 2, m_l = 2, m_s = +1/2
    c. n = 4, l = 2, m_l = 2, m_s = -1/2

11. What is the correct electron configuration for bromine?
    a. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10
    b. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10
    c. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9 4p^6
    d. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10
    e. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10 5s^2

12. Give the element that has the electron configuration:
    1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10
    a. In
    b. Pd
    c. Fe
    d. Ni
    e. Sn

13. Which of the following corresponds to the electron configuration of a noble gas?
    a. 1s^2
    b. 1s^2 2s^2
    c. 1s^2 2s^2 2p^6 3s^2 3p^6
    d. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10
    e. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10 5s^2

14. What is the electron configuration of O^2-?
    a. 1s^2 2s^2 2p^6
    b. 1s^2 2s^2 2p^6 3s^2
    c. 1s^2 2s^2 2p^6 3s^2 3p^6
    d. 1s^2 2s^2 2p^6 3s^2 3p^6
    e. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2

15. Which of the following has the electron configuration 1s^2 2s^2 2p^6 3s^2 3p^6?
    a. Ca^+2
    b. Cl^-1
    c. Ar
    d. K^+1
    e. All of the above

16. From a consideration of electronic configurations, which of the elements indicated below would be classified as a TRANSITION element?
    a. 1s^2 2s^2 2p^2
    b. 1s^2 2s^2 2p^6 3s^2 3p^5
    c. 1s^2 2s^2 2p^6 3s^2 3p^6
    d. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3
    e. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10

17. Which ground-state electron configuration is INCORRECT?
    a. Cr: [Ar] 3d^3
    b. Ca: [Ar] 4s^2
    c. Na: 1s^2 2s^2 2p^6 3s^1
    d. Zn: [Ar] 3d^{10} 4s^2
    e. Kr: [Ar] 3d^{10} 4s^2 4p^6

18. The ground-state electron configuration of a Co^{3+} ion is 1s^2 2s^2 2p^6 3s^2 3p^6 3d^6. Therefore, Co^{3+} is:
    a. diamagnetic.
    b. paramagnetic with one unpaired electron.
    c. paramagnetic with two unpaired electrons.
    d. paramagnetic with four unpaired electrons.
    e. paramagnetic with five unpaired electrons.

19. Species that have the same electron configuration are:
    a. Isoelectronic
    b. Paramagnetic
    c. Diamagnetic
    d. Ferromagnetic
    e. Lanthanides
20. Which element has the largest atomic radius?
   a. F  d. H
   b. C  e. N
   c. O

21. Which of the following has the largest ionic radius?
   a. S
      d. Li
      b. Na
      e. F
      c. Cl

22. Which element has the largest first ionization energy?
   a. Sr  d. Ca
   b. Ba  e. Mg
   c. Be

23. Arrange the following elements in order of increasing ionization energy.
   Ar  Cl  Li  Na  P
   a. Ar < Cl < Na < Li < P
   b. Cl < Ar < Na < Li < P
   c. P < Cl < Ar < Na < Li
   d. P < Cl < Ar < Li < Na
   e. Na < Li < P < Cl < Ar

24. Which of the following atoms designated by electronic configurations has the highest ionization energy?
   a. [Ne] 3s^2 3p^2
   b. [Ne] 3s^2 3p^3
   c. [Ar] 3d^{10} 4s^2 4p^3
   d. [Kr] 4d^{10} 5s^2 5p^3
   e. [Xe] 4f^{14} 5d^{10} 6s^2 6p^3

25. Which molecule DOES NOT contain a double bond?
   a. CO_2  d. O_3
   b. CH_2O  e. HCOOH
   c. N_2

26. Which molecule DOES NOT contain a multiple bond?
   a. O_3  d. F
   b. CO  e. HCN
   c. SO_2

27. Which bond is longest?
   a. C-H  d. C-O
   b. C-C  e. C-P
   c. C-N

28. From the data given below, calculate the enthalpy change for the reaction below.

   \[ 2 \text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{H}_2\text{O} (g) \]

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-H</td>
<td>414</td>
</tr>
<tr>
<td>C-C</td>
<td>347</td>
</tr>
<tr>
<td>C=O</td>
<td>611</td>
</tr>
<tr>
<td>O=O</td>
<td>351</td>
</tr>
<tr>
<td>C=O</td>
<td>803</td>
</tr>
<tr>
<td>O=H</td>
<td>463</td>
</tr>
<tr>
<td>O=O</td>
<td>498</td>
</tr>
<tr>
<td>H-H</td>
<td>436</td>
</tr>
</tbody>
</table>

   a. 471 kJ
   b. 486 kJ
   c. -471 kJ
   d. -482 kJ
   e. 444 kJ

29. Which bond is most polar?
a. C-C
b. C-N
c. N-N
d. C-F
e. C-O

30. Which element is the least electronegative?
   a. Iron
e. Cesium
   b. Barium
c. Potassium
d. Calcium

PART II: SHORT ANSWERS (Each short answer question has a 1-point value).

31. The energy change associated with addition of an electron to an atom in the gas phase is called **electron affinity**.

32. Each valid combination of \( n, l \) and \( m_l \) defines a(n) **atomic orbital**.

33. According to Pauli’s exclusion principle, an atom can have no more than **two** electron(s) with identical \( n, l \) and \( m_l \).

34. According to their polarity, bonds are classified as **nonpolar covalent**, **polar covalent** and **ionic**.

35. Two or more valid **Lewis** structure representations of the same molecule are known as **resonance structures**.

PART III: LEWIS STRUCTURES AND VSEPR THEORY.

36. For each of the following molecules (or ions), draw the complete **Lewis** structure and determine electron-pair and molecular geometry.

   a. (5 pts) Oxygen difluoride, \( \text{OF}_2 \);

   **Solution:**
   \[
   A = 6 + 2 \times 7 = 20 \\
   B = 3 \times 8 = 24 \\
   (B - A)/2 = 2 \text{ bonds} \\
   \text{Remaining: } (20 - 4)/2 = 8 \text{ lone pairs}
   \]

   Molecule is: \( \text{AX}_2 \text{E}_2 \)

   Lewis structure

   Electron-pair geometry: Tetrahedral

   Molecular geometry: Bent

   b. (5 pts) Xenon pentafluoride cation, \( \text{XeF}_5^+ \);

   **Solution:**
   \[
   A = 8 + 5 \times 7 - 1 = 42 \\
   B = 6 \times 8 = 48 \\
   (B - A)/2 = 3 \text{ bonds} - \text{impossible! Expanded octet molecule. Construct a structure with five Xe – F bonds} \\
   \text{Remaining: } (42 - 10)/2 = 16 \text{ lone pairs}
   \]

   Molecule is \( \text{AX}_5 \text{E}_1 \)

   Lewis structure

   Electron-pair geometry: Octahedral

   Molecular geometry: Square pyramidal

PART IV: LEWIS STRUCTURES AND RESONANCE.

37. For each of the following molecules (or ions), draw **TWO** valid resonance structures.
a. (5 pts) Hydrazoic acid, $\text{HN}_3$;

\[
\begin{align*}
\text{H} & \quad \text{N} \quad \text{N} \quad \text{N} \quad \text{H} \\
\text{H} & \quad \text{N} \quad \text{N} \quad \text{N} \\
\end{align*}
\]

b. (5 pts) Nitronium cation, $\text{NO}_2^+$;

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{O} \\
\text{O} & \quad \text{N} \quad \text{O} \\
\end{align*}
\]

PART V: LEWIS STRUCTURES AND HYBRIDIZATION.

38. (10 pts) In each of the following structures, indicate the hybridization of ALL non-hydrogen atoms.

\[
\begin{align*}
\text{H} & \quad \text{O} & \quad \text{H} \\
\text{H} & \quad \text{O} & \quad \text{H} \\
\text{H} & \quad \text{O} & \quad \text{H} \\
\text{H} & \quad \text{O} & \quad \text{H} \\
\end{align*}
\]

PART VI: MOLECULAR POLARITY

39. (5 pts) Identify (circle) the polar molecules among the structures below. Do not explain!

\[
\begin{align*}
\text{SO}_2 & \quad \text{SO}_3 & \quad \text{PCl}_3 & \quad \text{SiBr}_4 & \quad \text{CCl}_4
\end{align*}
\]