Section I: Multiple Choice. Place the letter of the answer you select to each question on the answer sheet provided. Each question in this section is worth 2 points.

1. Which of the following regions of the electromagnetic spectrum has the longest wavelengths?
   a) microwave  b) infrared  c) x-ray  d) gamma ray  e) visible

2. Which of the following regions of the electromagnetic spectrum has the greatest energy?
   a) radio wave  b) gamma ray  c) microwave  d) x-ray  e) ultraviolet

3. An argon ion laser emits light at 488 nm. What is the frequency of this radiation?
   a) $4.07 \times 10^{-19}$ s$^{-1}$  b) $1.63 \times 10^{-15}$ s$^{-1}$  c) $1.46 \times 10^2$ s$^{-1}$  d) $2.05 \times 10^6$ s$^{-1}$  e) $6.14 \times 10^{14}$ s$^{-1}$

4. A common infrared laser operates at 1060 nm. What is the energy of a photon with this wavelength?
   a) $7.02 \times 10^{-40}$ J  b) $6.25 \times 10^{-28}$ J  c) $3.54 \times 10^{-15}$ J  d) $1.87 \times 10^{-19}$ J  e) $2.83 \times 10^{14}$ J

5. The Schrödinger wave equation
   a) calculates the position and momentum of an electron at any given time.
   b) can be solved to determine the probability of finding an electron in a region of space.
   c) proves that energy is equal to mass times the speed of light squared.
   d) incorrectly predicts circular orbits of electrons around nuclei.
   e) is used to calculate the velocity of an electron.

6. Which of the following statements is INCORRECT?
   a) The location and the energy of an electron in an atom can be simultaneously known with little or no uncertainty.
   b) The energies of an atom’s electrons are quantized.
   c) Quantum numbers define the energy states and the orbitals available to an electron.
   d) The behavior of an atom’s electrons can be described by standing waves.
   e) Electrons have both wave and particle properties.

7. What type of orbital is designated $n = 3$, $l = 1$, $m_l = 0$?
   a) 3s  b) 3p  c) 3d  d) 1d  e) none
8. What type of orbital is designated \( n = 4, \ l = 3, \ m_l = -3 \)?
   a) 4s      b) 4p      c) 4d      d) 4f      e) none

9. What type of orbital is designated \( n = 3, \ l = 2, \ m_l = -2 \)?
   a) 3s     b) 3p     c) 3d     d) 3f     e) none

10. How many orbitals can be described by the quantum numbers \( n = 6, \ l = 3, \ m_l = -2 \)?
    a) 0   b) 1   c) 3   d) 6   e) 7

11. How many orbitals can be described by the quantum numbers \( n = 5, \ l = 3 \)?
    a) 1   b) 3   c) 5   d) 7   e) 9

12. How many orbitals can be described by the quantum numbers \( n = 3, \ l = 3, \ m_l = 2 \)?
    a) 0   b) 1   c) 3   d) 5   e) 5

13. Which one of the following sets of quantum numbers is NOT allowed?
    a) \( n = 6, \ l = 0, \ m_l = +1 \)
    b) \( n = 5, \ l = 4, \ m_l = 0 \)
    c) \( n = 4, \ l = 1, \ m_l = -1 \)
    d) \( n = 3, \ l = 2, \ m_l = +2 \)
    e) \( n = 1, \ l = 0, \ m_l = 0 \)

14. Which one of the following sets of quantum numbers is NOT allowed?
    a) \( n = 6, \ l = 0, \ m_l = 0, m_s = +1/2 \)
    b) \( n = 5, \ l = 3, \ m_l = 1, m_s = +1/2 \)
    c) \( n = 4, \ l = 2, \ m_l = -3, m_s = -1/2 \)
    d) \( n = 3, \ l = 1, \ m_l = -1, m_s = +1/2 \)
    e) \( n = 2, \ l = 0, \ m_l = 0, m_s = -1/2 \)

15. Which one of the following sets of quantum numbers is NOT allowed?
    a) \( n = 7, \ l = 6, \ m_l = 5, m_s = +1/2 \)
    b) \( n = 3, \ l = 3, \ m_l = -3, m_s = -1/2 \)
    c) \( n = 4, \ l = 3, \ m_l = 2, m_s = +1/2 \)
    d) \( n = 3, \ l = 0, \ m_l = 0, m_s = +1/2 \)
    e) \( n = 2, \ l = 1, \ m_l = 0, m_s = -1/2 \)
16. Which of the following properties is associated with the value of the $m_l$ quantum number?

a) the number of electrons in an orbital  
b) the size of an orbital  
c) the shape of an orbital  
d) the energy of an orbital  
**e) the orientation in space of an orbital**

17. Which of the following properties is associated with the value of the $l$ quantum number?

a) the number of electrons in an orbital  
b) the size of an orbital  
**c) the shape of an orbital**  
d) the energy of an orbital  
e) the orientation in space of an orbital

18. Which of the following diagrams represent $p$-orbitals?

(I)  (II)  (III)  (IV)

a) (I) only  
**b) (II) only**  
c) (III) only  
d) (II) and (IV)  
e) (I) and (II)

19. How many electrons can be described by these quantum numbers?

$n = 4, l = 3, m_l = -2, m_s = +1/2$

a) 0  
**b) 1**  
c) 2  
d) 3  
e) 6

20. How many electrons can be described by the quantum numbers $n = 5, l = 3, m_s = -1/2$?

a) 1  
b) 3  
c) 5  
**d) 7**  
e) 9

21. How many electrons can be described by the quantum numbers $n = 3, l = 2, m_l = -1$?

a) 0  
b) 1  
**c) 2**  
d) 3  
e) 5
22. Place the following atoms in order of increasing atomic radii: Ca, Mg, P, and Cl.

   a) Cl < P < Mg < Ca
   b) Mg < P < Cl < Ca
   c) Ca < Mg < P < Cl
   d) P < Cl < Mg < Ca
   e) Ca < Cl < P < Mg

23. Rank K, Li, and Cs in order of increasing first ionization energy.

   a) K < Cs < Li
   b) Cs < K < Li
   c) Cs < Li < K
   d) Li < Cs < K
   e) Li < K < Cs

24. The change in energy for the following reaction is referred to as the ________ for fluorine.

   \[ \text{F(g) } + \text{ e}^- \rightarrow \text{F(g)} \]

   a) oxidation energy
   b) electron affinity
   c) electronegativity energy
   d) first ionization energy
   e) second ionization energy

25. Which of these atomic models is based on assuming the electron can be described as a wave and not a particle?

   a) Bohr model
   b) plum pudding model
   c) Quantum mechanical model
   d) Rutherford model
   e) Heisenberg uncertainty model
Section II: Each question in this section is worth 4 points.

26. What element has this set of quantum numbers for its last electron, assuming the Aufbau Principle has been applied?

\[
\begin{align*}
&\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
&3p \\
\Rightarrow & 3p^5 \\
\Rightarrow & 17 \text{ total electrons} \\
\Rightarrow & Cl \text{ (chlorine)}
\end{align*}
\]

27. What element has this set of quantum numbers for its last electron, assuming the Aufbau Principle has been applied?

\[
\begin{align*}
&\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
&5d \\
\Rightarrow & 5d^4 \\
\Rightarrow & 74 \text{ total electrons} \\
\Rightarrow & W \text{ (tungsten)}
\end{align*}
\]

28. Write the electron configuration of silicon. What term describes the magnetic property of atomic silicon?

\[
\begin{align*}
1s^2 2s^2 2p^6 3s^2 3p^2 \\
\Rightarrow & \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
3p \\
\Rightarrow & \text{paramagnetic (unpaired electrons)}
\end{align*}
\]

29. What are the quantum numbers of the last electron added to phosphorus, assuming the Aufbau Principle has been applied?

\[
\begin{align*}
&\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
&3p \\
\Rightarrow & 3 \ 1 \ 1 \ +\frac{1}{2}
\end{align*}
\]

30. What are the quantum numbers of the last electron added to silver, assuming the Aufbau Principle has been applied?

\[
\begin{align*}
&\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
&5s \ 4d \\
\Rightarrow & 4 \ 2 \ 2 \ -\frac{1}{2}
\end{align*}
\]
Section III: Each question in this section is worth 5 points. You must show work to receive any credit for a question.

31. What is the energy of a mole of photons of red light with a wavelength of 632 nm?

\[ c = \lambda \cdot \nu \]
\[ \nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{632 \times 10^{-9} \text{ m}} = 4.75 \times 10^{14} \frac{1}{s} \]
\[ E = h \nu = (6.626 \times 10^{-34} \text{ J} \cdot \text{s})(4.75 \times 10^{14} \frac{1}{s}) = 3.15 \times 10^{-19} \frac{\text{J}}{\text{photon}} \]
\[ E_{\text{mole}} = \left( 3.15 \times 10^{-19} \frac{\text{J}}{\text{photon}} \right)(6.02 \times 10^{23} \text{ photons/mole}) = 189 \text{ kJ} \]

32. What is the wavelength of radiation emitted, as predicted by the Rydberg equation, when an electron falls from \( n = 7 \) to \( n = 4 \) in the hydrogen atom?

\[ \Delta E = -\frac{Rhc}{n_{\text{final}}^2} \left( \frac{1}{n_{\text{final}}^2} - \frac{1}{n_{\text{initial}}^2} \right) \]
\[ = -(2.18 \times 10^{-18} \text{ J}) \left( \frac{1}{4^2} - \frac{1}{7^2} \right) \]
\[ = -9.18 \times 10^{-20} \text{ J} \]
\[ E = h \nu \]
\[ \nu = \frac{E}{h} = \frac{9.18 \times 10^{-20} \text{ J}}{6.626 \times 10^{-34} \text{ J} \cdot \text{s}} = 1.39 \times 10^{14} \text{ s}^{-1} \]
\[ c = \lambda \cdot \nu \]
\[ \lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/s}}{1.39 \times 10^{14} \text{ s}^{-1}} = 2.16 \times 10^{-6} \text{ m} \]

33. For the element selenium, (i) draw the orbital diagram, (ii) write the electron configuration and (iii) indicate the four quantum numbers of the last electron added to the atom.

\[
\begin{align*}
\text{1s}^2 \text{2s}^2 \text{2p}^6 \text{3s}^2 \text{3p}^6 \text{4s}^2 \text{3d}^{10} \text{4p}^4
\end{align*}
\]
\[ 4 \quad 1 \quad -1 \quad -\frac{1}{2} \]
34. For the strontium $2^+$ ion, Sr$^{2+}$, (i) draw the orbital diagram, (ii) write the electron configuration and (iii) indicate the four quantum numbers of the last electron added to the atom.

\[ 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 \]

35. An electron in the hydrogen atom relaxes to the $n = 2$ energy level, emitting light of 410 nm. What is the value of $n$ for the energy level from which the electron fell?

\[
E = h\nu = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{410 \times 10^{-9} \text{ m}} = 4.848 \times 10^{-19} \text{ J}
\]

\[
\Delta E = -Rhc \left( \frac{1}{n_{\text{final}}^2} - \frac{1}{n_{\text{initial}}^2} \right)
\]

\[
-4.848 \times 10^{-19} \text{ J} = -(2.18 \times 10^{-18} \text{ J}) \left( \frac{1}{2^2} - \frac{1}{n_{\text{initial}}^2} \right)
\]

\[
0.2224 = \left( \frac{1}{2^2} - \frac{1}{n_{\text{initial}}^2} \right)
\]

\[
\frac{1}{n_{\text{initial}}^2} = 0.02760
\]

\[
n_{\text{initial}}^2 = 36.23
\]

\[
n_{\text{initial}} = 6
\]

36. A certain solar cell has a surface area of 2.16 m$^2$. If the solar radiation striking the cell delivers 850 $\frac{\text{J}}{\text{m}^2 \cdot \text{s}}$, how many photons strike the cell every minute? Assume an average wavelength of 504 nm for the solar radiation.

\[
E_{\text{ph}} = h\nu = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{504 \times 10^{-9} \text{ m}} = 3.944 \times 10^{-19} \frac{\text{J}}{\text{photon}}
\]

\[
\frac{1836 \frac{\text{J}}{\text{s}}}{3.944 \times 10^{-19} \frac{\text{J}}{\text{photon}}} = 4.655 \times 10^{21} \frac{\text{photon}}{\text{s}}
\]

\[
4.655 \times 10^{21} \frac{\text{photon}}{\text{s}} \times \frac{60 \text{ s}}{1 \text{ min}} = 2.79 \times 10^{23} \frac{\text{photon}}{\text{min}}
\]