1) Light irradiates a metal surface and ejects an electron. Compare the energy $E_{\text{photon}}$ of the incoming photon to the kinetic energy $K_{\text{electron}}$ of the ejected electron.

- $E_{\text{photon}} > K_{\text{electron}}$
- $E_{\text{photon}} = K_{\text{electron}}$
- $E_{\text{photon}} < K_{\text{electron}}$
- Not enough information

2) Select the appropriate number of nodes for a 3d orbital.

- 1 radial, 1 angular
- 2 radial, 0 angular
- 0 radial, 2 angular
- No nodes

3) A compound strongly absorbs light between 300-650 nm. Light is transmitted between 650-750 nm. What color is the compound?

- Blue
- Green
- Yellow
- Red

4) Rank the following objects in order of their de Broglie wavelength (smallest to greatest).

- 3 m/s baseball < 30 m/s baseball < $10^2$ m/s electron < $10^4$ m/s electron
- $30$ m/s baseball < 3 m/s baseball < $10^4$ m/s electron < $10^2$ m/s electron
- $10^2$ m/s electron < $10^4$ m/s electron < 3 m/s baseball < 30 m/s baseball
- 3 m/s baseball < $10^2$ m/s electron < 30 m/s baseball < $10^4$ m/s electron

5) Select the appropriate electron configuration for Cl$^-$

- [Ar] 3s$^2$ 3p$^5$
- [Ne] 3s$^2$ 3p$^6$
- [Ne] 3s$^2$ 3p$^5$
- [Ar] 3s$^2$ 3p$^6$
6) Ozone molecules ($O_3$) can react with oxygen atoms ($O$) to produce diatomic oxygen ($O_2$).
   i. Write a balanced reaction equation for this process.

   \[ O_3 + O \rightarrow 2O_2 \]

   The destruction of ozone is much more rapid in the presence of chlorine atoms, through a sequence of reactions

   \[ Cl + O_3 \rightarrow ClO + O_2 \]
   \[ ClO + O \rightarrow Cl + O_2 \]

   Consider a mixture that initially contains no $O_2$, no ClO, and the following masses of Cl, $O_3$, and O:

   18 g Cl
   48 g $O_3$
   32 g O

   ii. How many moles of Cl, $O_3$, and O are initially present? (Only one significant figure is needed for each species.)

   \[
   \begin{align*}
   18 \text{ g Cl} & \cdot \frac{1 \text{ mol Cl}}{35.46 \text{ g Cl}} = 0.5 \text{ mol Cl} \\
   48 \text{ g } O_3 & \cdot \frac{1 \text{ mol } O_3}{48 \text{ g } O_3} = 1 \text{ mol } O_3 \\
   32 \text{ g O} & \cdot \frac{1 \text{ mol O}}{16 \text{ g O}} = 2 \text{ mol O}
   \end{align*}
   \]

   Final Answer
   \[
   \begin{align*}
   0.5 \text{ mol Cl} \\
   1 \text{ mol } O_3 \\
   2 \text{ mol O}
   \end{align*}
   \]
iii. How many oxygen nuclei are initially present? (Your answer should be a number with no units.)

\[
1 \text{ mol } O_3 \rightarrow 5 \text{ mol oxygen nuclei} \\
2 \text{ mol } O \\
5 \cdot 6.02 \cdot 10^{23} = 30.1 \cdot 10^{23}
\]

Final Answer: \(3.01 \cdot 10^{24}\)

iv. If the sequence of reactions proceeds as far as possible, which molecule or atom is the limiting reagent? Explain your reasoning.

\[
\begin{align*}
0.5 \text{ mol } Cl &+ 1 \text{ mol } O_3 \rightarrow 0.5 \text{ mol } ClO + 0.5 \text{ mol } O_2 + 0.5 \text{ mol } O_3 \\
0.5 \text{ mol } ClO &+ 2 \text{ mol } O \rightarrow 0.5 \text{ mol } Cl + 1 \text{ mol } O_2 + 1 \text{ mol } O
\end{align*}
\]

O_3 is the limiting reagent. Cl product after the 2nd reaction can react w/ O_3 left over in 1st run. There is excess O compared to O_3 - more moles of O and 1:1 stoichiometry.

v. What is the system's total mass at the end of the reaction?

\[
\text{Mass is conserved} \\
18g + 48g + 32g
\]

Final Answer: 98g
7) The diagram below shows the allowed energy levels of a certain molecule.

![Energy Level Diagram]

i. A transition from $n = 2$ to $n = 1$ is accompanied by emission of a photon with wavelength $\lambda = 600$ nm, as shown in the energy level diagram. Using this information, calculate the value of $E_0$ in units of kJ/mol.

$$
\Delta E = -E_{\text{photon}} = -\frac{hc}{\lambda} = -E_0
$$

$$
- \left( 6.626 \times 10^{-34} \text{ J s} \right) \left( 3.00 \times 10^8 \text{ m/s} \right) = -E_0
$$

$$
E_0 = 3.313 \times 10^{-19} \text{ J per photon}
$$

$$
200 \text{ kJ/mol} \quad \text{Final Answer}
$$

ii. When the molecule is in its ground state ($n = 1$), only certain colors of light can be absorbed. On the graph below sketch its absorption spectrum as a function of wavelength $\lambda$. Consider only transitions that begin from $n = 1$.
iii. A different substance has many more energy levels in the range between $E = -E_0$ and $E = 0$, as shown below.

```
\begin{center}
\begin{tikzpicture}
\draw[->] (0,0) -- (0,4) node[left] {$E$};
\draw[->] (0,0) -- (4,0) node[below] {$\lambda$/nm};
\filldraw[black, fill=gray] (0,0) rectangle (1,4);
\node at (0.5,2) {n = large};
\node at (0.5,-1) {n = 2};
\node at (0.5,-2) {n = 1};
\end{tikzpicture}
\end{center}
```

Considering only transitions that begin from $n = 1$, sketch the absorption spectrum of this substance on the graph below. (You may assume that excited states are so numerous that the spectrum is very smooth.)

```
\begin{center}
\begin{tikzpicture}
\draw[->] (0,0) -- (0,4) node[left] {absorption};
\draw[->] (0,0) -- (4,0) node[below] {$\lambda$/nm};
\filldraw[black, fill=gray] (0,0) rectangle (1,4);
\node at (0.5,2) {n = large};
\node at (0.5,-1) {n = 2};
\node at (0.5,-2) {n = 1};
\end{tikzpicture}
\end{center}
```

iv. Based on the absorption spectrum you drew in part (iii), describe the appearance of this substance to the eye.

Red
8) Consider a model of a hypothetical single-electron atom that is different from the hydrogen atom. This atom has two quantum numbers, \( n \) and \( \ell \). There is one orbital for each combination of \( n \) and \( \ell \).

\( n \) can be any positive integer: \( n = 1, 2, 3, \ldots \)

The possible values of \( \ell \) depend on \( n \): \( \ell = -(n-1), \ldots, 0, \ldots, n-1 \)

The energy of a state depends only on \( n \): \( E_n = -\frac{Ry}{(2n-1)^2} \), where \( Ry \) is Rydberg’s constant.

i. By filling in the table below, indicate the energy and degeneracy of each level, up to \( n = 4 \). (Recall that degeneracy is the number of states with the same energy.)

<table>
<thead>
<tr>
<th>( n )</th>
<th>( E_n/\text{Ry} )</th>
<th>possible ( \ell ) values</th>
<th>degeneracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(-\text{Ry})</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>(-\frac{\text{Ry}}{9})</td>
<td>(-1, 0, 1)</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>(-\frac{\text{Ry}}{25})</td>
<td>(-2, -1, 0, 1, 2)</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>(-\frac{\text{Ry}}{49})</td>
<td>(-3, -2, -1, 0, 1, 2, 3)</td>
<td>7</td>
</tr>
</tbody>
</table>

ii. A certain transition of this atom causes a photon with energy \( \hbar \nu = 0.0196 \text{ Ry} \) to be emitted. The initial state in this transition has \( n_{\text{init}} = 4 \). What is the value of \( n \) in the final state?

\[
\Delta E = E_{f} - E_{i} = E_{\text{photon}} = 0.0196 \text{ Ry}
\]

\[
\frac{\text{Ry}}{1} + \frac{\text{Ry}}{(2n_{f} - 1)^2} = 0.0196 \text{ Ry}
\]

\[
\frac{1}{(2n_{f} - 1)^2} = 0.04
\]

\[
0.04 \cdot (2n_{f} - 1)^2 = 1
\]

\[
(2n_{f} - 1)^2 = 25
\]

\[
2n_{f} - 1 = 5
\]

\[
2n_{f} = 6
\]

\[
n_{f} = 3
\]

\( n_{f} = 3 \) Final Answer
The orbitals of this model can be filled with electrons to make hypothetical multi-electron atoms. Due to screening, the $\ell = 0$ orbitals have slightly lower energy than those with $\ell \neq 0$ for the same value of $n$. The energy level diagram below shows the positioning of these orbitals.

![Energy Level Diagram]

Aufbau, Pauli, and Hund's rules apply to the filling of these orbitals.

iii. Write the electronic configuration of an atom with 6 electrons. By analogy with the hydrogen atom, use "s" to refer to orbitals with $\ell = 0$, and use "p" to refer to orbitals with $\ell = \pm 1$.

\[ 1s^2 2s^2 2p^2 \]

iv. For this model, an atom with 8 electrons is extremely stable and non-reactive. Explain this observation using its electron configuration.

\[ \text{full } n=2 \text{ valence shell: 6 electrons in valence shell and all are paired.} \]
\[ \text{next } e^- \text{ would need to be added to an orbital with principle quantum number } n=3. \]
9) Consider an electron in a potential energy $V(x)$ described by 4 different wavefunctions as shown in panels (a), (b), (c), and (d):

![Wavefunctions and Potential Energy Graphs](image)

Figure 1: The potential energy ($V(x)$) is shown by the dotted curve and the electron wavefunction ($\psi(x)$) by the solid curve.

i. For each panel (b), (c), and (d) in Figure 1, where on the x-axis is the most probable location to find the electron? Explain your answer.

   - (b) $0 \text{ Å}$
   - (c) $1 \text{ Å}$
   - (d) $-1 \text{ Å}$

   $|\psi(x)|^2$ is probability

These are the positions where $\psi(x)$ is at an extreme and $|\psi(x)|^2$ is maximized

ii. Which wavefunction (or wavefunctions) has the highest kinetic energy? Please reason your answer.

   (a) has the most nodes, highest curvature.
iii. Which wavefunction (or wavefunctions) has the lowest kinetic energy? Please reason your answer.

(b), (c), (d) all have the same curvature, no nodes

iv. Which wavefunction (or wavefunctions) has the highest potential energy? Please reason your answer.

(c), (d) $\psi(x)$ has maximum in regions where $V(x)$ is large.

v. Which wavefunction (or wavefunctions) has the lowest potential energy? Please reason your answer.

(b) There is maximal density of the wavefunction at minimal values of $V(x)$

vi. True or false: For panel (a) in Figure 1, the probability of finding the electron in $x < 0$ is smaller than the probability of finding the electron in $x > 0$ because the wavefunction for $x < 0$ is negative. Explain your answer.

Circle True or False: True

Explain:

Probability $= |\psi(x)|^2$

The wave function is odd: $\psi(x) = -\psi(-x)$ for any $x$. $\therefore$ There is equal probability of finding the e$^{-}$ in $x > 0$ and $x < 0$. 