1. The four quantum numbers needed to define the energy state of an atom are:
   - the principal quantum number, \( n \). This can have integer, non-zero values and describes the size and energy of the orbital.
   - the angular momentum quantum number, \( l \). For each value of \( n \), \( l \) takes every value from 0 to \((n - 1)\). It describes the shape of the orbital. For historic reasons, orbitals with \( l = 0 \) are called \( s \)-orbitals, orbitals with \( l = 1 \) are called \( p \)-orbitals and orbitals with \( l = 2 \) are called \( d \)-orbitals.
   - the magnetic quantum number, \( m_l \). For each value of \( l \), \( m_l \) takes every value from \(-l\) to \(+l\). It describes the orientation of the orbital.
   - the spin quantum number, \( m_s \). For an electron, \( m_s = +\frac{1}{2} \) or \(-\frac{1}{2} \). It describes the spin of the electron.

2. The rows of the Periodic Table correspond to different values of \( n \).

   The lowest value of \( n \) is 1. For \( n = 1 \), \( l \) can only be equal to 0. For \( l = 0 \), \( m_l \) can only be 0. As \( m_s \) can take two values \((+\frac{1}{2} \text{ and } -\frac{1}{2})\), there are two elements only in the first row: H and He.

   The next value of \( n \) is 2. For \( n = 2 \), \( l \) can be equal to 0 or 1. Because there are two values, the \( n = 2 \) shell is made up of two subshells.
   - For \( l = 0 \), \( m_l \) can again only be zero and as \( m_s \) can take two values, there are two elements in the first subshell (Li and Be).
   - For \( l = 1 \), \( m_l \) can take three values: \(-1 \), 0 and \(+1 \). For each of these, \( m_s \) can take two values so that there are six elements in the second subshell (B, C, N, O, F and Ne).

   As \( n \) increases, these subshells form blocks of elements. Those with the outer electrons having \( l = 0 \) are called \( s \)-block elements. Those with the outer electrons having \( l = 1 \) are called the \( p \)-block elements.

   For \( n = 3 \), \( l \) can be 0, 1 and 2 and this leads to a new subshell and ultimately to a new block of elements called the \( d \)-block elements.

3. |   | 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^1\) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) S</td>
<td>1s(^2) 2s(^2) 2p(^6) 3s(^2) 3p(^4)</td>
</tr>
<tr>
<td>(b) Br(^-)</td>
<td>1s(^2) 2s(^2) 2p(^6) 3s(^2) 3p(^6) 4s(^2) 3d(^10) 4p(^6)</td>
</tr>
<tr>
<td>(c) Ca(^{2+})</td>
<td>1s(^2) 2s(^2) 2p(^6) 3s(^2) 3p(^6)</td>
</tr>
</tbody>
</table>
4. (a) O
\[ \text{O}^2-: 1s^2 \ 2s^2 \ 2p^4 \]

(b) Mg
\[ \text{Mg}^{2+}: 1s^2 \ 2s^2 \ 2p^6 \]

(c) Al
\[ \text{Al}^{3+}: 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^1 \]

(d) Sr
\[ \text{Sr}^{2+}: 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^2 \ 3d^{10} \ 4p^6 \ 5s^2 \]

5. Atomic and ionic radii increase down groups as the \( n \)-shell increases. They decrease across periods as the nuclear charge increases. Positive charge decreases the radius due to lower \( e^-/e^- \) repulsion whereas negative charge increases the radius due to higher \( e^-/e^- \) repulsion.

6. (a) P, As, Sb
Radii increases down the group: \( \text{P} < \text{As} < \text{Sb} \).

(b) S, Cl, K
Radii decrease across each period so Cl < S. K is in the next period so is the largest.

Overall, the radii increases in the order \( \text{Cl} < \text{S} < \text{K} \)

(c) \( \text{O}^+, \text{O}, \text{O}^- \)
Positive charge contracts the atom and negative charge expands the atom.

Overall, the radii increase in the order \( \text{O}^+ < \text{O} < \text{O}^- \)

(d) Pd, Ni, Pt
Radii increase down the group: \( \text{Ni} < \text{Pd} < \text{Pt} \)

7. (a) O
\[ 1s^2 \ 2s^2 \ 2p^4 \] or \( [\text{He}] \ 2s^2 \ 2p^4 \). Two unpaired electrons:

\[
\begin{array}{c|c}
2s & 2p \\
\hline
\uparrow \downarrow & \uparrow \downarrow \uparrow \uparrow \\
\end{array}
\]

(b) \( \text{O}^+ \)
\[ 1s^2 \ 2s^2 \ 2p^3 \] or \( [\text{He}] \ 2s^2 \ 2p^3 \). Three unpaired electrons:

\[
\begin{array}{c|c|c|c}
2s & 2p \\
\hline
\uparrow \downarrow & \uparrow & \uparrow & \uparrow \\
\end{array}
\]

(c) \( \text{O}^- \)
\[ 1s^2 \ 2s^2 \ 2p^5 \] or \( [\text{He}] \ 2s^2 \ 2p^5 \). One unpaired electron:

\[
\begin{array}{c|c|c|c}
2s & 2p \\
\hline
\uparrow \downarrow & \uparrow \uparrow & \uparrow \\
\end{array}
\]
(d) Fe

\begin{align*}
1s^2 & 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6 \text{ or } [Ar] 4s^2 3d^6.
\end{align*}

Four unpaired electrons:

\begin{align*}
\begin{array}{c}
\uparrow \downarrow \\
3d
\end{array}
\quad
\begin{array}{cccc}
\uparrow & \uparrow & \uparrow & \uparrow \\
4s
\end{array}
\end{align*}

(e) S

\begin{align*}
1s^2 2s^2 2p^6 3s^2 3p^4 \text{ or } [Ne] 3s^2 3p^4.
\end{align*}

Two unpaired electrons:

\begin{align*}
\begin{array}{c}
\uparrow \downarrow \\
3p
\end{array}
\quad
\begin{array}{c}
\uparrow \\
3s
\end{array}
\end{align*}

(f) F

\begin{align*}
1s^2 2s^2 2p^5 \text{ or } [He] 2s^2 2p^5.
\end{align*}

One unpaired electron:

\begin{align*}
\begin{array}{c}
\uparrow \downarrow \\
2p
\end{array}
\quad
\begin{array}{c}
\uparrow \uparrow \uparrow \uparrow \\
2s
\end{array}
\end{align*}

8. (a) nitrous acid HNO₂
    (b) nitric acid HNO₃
    (c) sulfurous acid H₂SO₃
    (d) sulfuric acid H₂SO₄
    (e) sodium hydrogenphosphate Na₂HPO₄

(“Hydrogenphosphate” corresponds to HPO₄²⁻ so the compound must have two Na⁺ ions. “Dihydrogenphosphate” is H₂PO₄⁻ so sodium dihydrogenphosphate is NaH₂PO₄).

9. (a) \[3\text{PO}_4^{3-}(aq) + 5\text{Ca}^{2+}(aq) + 2\text{H}_2\text{O}(l) \rightarrow \text{Ca}_5(\text{PO}_4)_3(\text{OH})(s) + \text{H}_3\text{O}^+(aq)\]
    (b) The number of moles \((n)\) is related to the concentration \((c)\) and the volume \((V)\):

\[n = c \times V\]

As each mole of Na₃PO₄ contains one mole of PO₄³⁻, 0.20 L of a 0.090 M solution contains:

\[\text{number of moles of PO}_4^{3-} = 0.090 \text{ mol L}^{-1} \times 0.20 \text{ L} = 0.018 \text{ mol}\]

As each mole of CaCl₂ contains one mole of Ca²⁺, 0.40 L of a 0.10 M solution contains:

\[\text{number of moles of Ca}^{2+} = 0.10 \text{ mol L}^{-1} \times 0.40 \text{ L} = 0.040 \text{ mol}\]

From the chemical equation, each mole of Ca₅(PO₄)₃(OH) requires 3 moles of PO₄³⁻(aq) and 5 moles of Ca²⁺(aq).
To use all of the PO$_4^{3-}$ present would require $\frac{5}{3} \times 0.018 \text{ mol} = 0.030 \text{ mol}$ of Ca$^{2+}$. There is more than enough Ca$^{2+}$ present to do this.

To use all of the Ca$^{2+}$ present would require $\frac{3}{5} \times 0.040 \text{ mol} = 0.024 \text{ mol}$ of PO$_4^{3-}$. There is not enough PO$_4^{3-}$ present to do this and so the amount of PO$_4^{3-}$ determines the possible yield. Unreacted Ca$^{2+}$(aq) will be left.

From the chemical equation, one mole of hydroxyapatite is made from every three moles of PO$_4^{3-}$. As 0.018 mol is available:

$$\text{maximum possible yield of hydroxyapatite} = \frac{1}{3} \times 0.018 \text{ mol} = 0.0060 \text{ mol}$$

(c) As the chloride ions do not take part in the reaction, the number of moles of Cl$^-$ (aq) remaining in solution is equal to the number of moles present in 400 mL of a 0.10 M solution of calcium chloride. As each mole of CaCl$_2$ yields two moles of Cl$^-$ ions,

$$\text{number of moles of Cl}^- = 2 \times c \times V = 2 \times 0.10 \text{ mol L}^{-1} \times \frac{400}{1000} \text{ L} = 0.080 \text{ mol}$$

After the two solutions are mixed, the total volume is 200 + 400 = 600 mL. The concentration is thus:

$$\text{concentration of Cl}^- = \frac{n}{V} = \frac{0.080 \text{ mol}}{(600/1000) \text{ L}} = \frac{0.080}{(600/1000)} = 0.13 \text{ M}$$