Consider the following data for first ionization energy \( (IE_1) \) as a function of atomic number \( (Z) \).

1. Provide a definition for first ionization energy \( (IE_1) \).
2. Within each row of the periodic table, the general trend is for \( IE_1 \) to increase from left to right. For example, F and Ne have larger \( IE_1 \) values than Li and Be. Explain this trend.
3. Within each column of the periodic table, the general trend is for \( IE_1 \) to decrease from top to bottom. For example, He and Ne have larger \( IE_1 \) values than Ar and Kr. Explain this trend.
4. There are certain anomalies that break these trends. For example, explain why the Group 13 elements (e.g. B, Al, Ga) have lower \( IE_1 \) values than the elements immediately to their left in each row.
5. Similarly, explain why the Group 15 elements (e.g. N, P, As) have higher \( IE_1 \) values than the corresponding Group 16 elements (e.g. O, S, Se) in each row.
7. Similarly, atomic radii for each element have clear trends vs. charge. Rank the following ions in order of atomic radius: Mn\(^{2+}\), Mn\(^{3+}\), Mn\(^{4+}\). Explain the trend.

Consider the following data for ammonia (NH\(_3\)) and phosphine (PH\(_3\)).

<table>
<thead>
<tr>
<th>Property</th>
<th>Boiling point</th>
<th>H-E-H bond angle</th>
<th>Inversion barrier</th>
<th>pK(_a) of EH(_4^+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH(_3)</td>
<td>-33°C</td>
<td>107°</td>
<td>155 kJ/mol</td>
<td>9.25</td>
</tr>
<tr>
<td>PH(_3)</td>
<td>-83°C</td>
<td>93°</td>
<td>25 kJ/mol</td>
<td>-14</td>
</tr>
</tbody>
</table>

8. Explain why PH\(_3\) has a lower boiling point than NH\(_3\)
9. Explain why PH\(_3\) has a smaller bond angle than NH\(_3\)
10. Explain why PH\(_3\) has a lower inversion barrier than NH\(_3\).
11. Explain why PH\(_4^+\) has a significantly lower pK\(_a\) than NH\(_4^+\), i.e. why NH\(_3\) is a Brønsted base and PH\(_3\) is not.

12. Use MO analysis to provide S-S bond orders for the following molecules/ions: S\(_2\), S\(_2^+\), S\(_2^{2-}\). Show your work.