Question 6 (8 points)

Answer the following questions related to sulfur and one of its compounds.

(a) Consider the two chemical species S and $S^{2-}$.

(i) Write the electron configuration (e.g., $1\text{s}^2 \ 2\text{s}^2 \ldots$) of each species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Electron Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>$1\text{s}^2 \ 2\text{s}^2 \ 2\text{p}^6 \ 3\text{s}^2 \ 3\text{p}^4$</td>
</tr>
<tr>
<td>$S^{2-}$</td>
<td>$1\text{s}^2 \ 2\text{s}^2 \ 2\text{p}^6 \ 3\text{s}^2 \ 3\text{p}^6$</td>
</tr>
</tbody>
</table>

Note: Replacement of $1\text{s}^2 \ 2\text{s}^2 \ 2\text{p}^6$ by $[\text{Ne}]$ is acceptable.

One point is earned for the correct configuration for S. One point is earned for the correct configuration for $S^{2-}$.

(ii) Explain why the radius of the $S^{2-}$ ion is larger than the radius of the S atom.

The nuclear charge is the same for both species, but the eight valence electrons in the sulfide ion experience a greater amount of electron-electron repulsion than do the six valence electrons in the neutral sulfur atom. This extra repulsion in the sulfide ion increases the average distance between the valence electrons, so the electron cloud around the sulfide ion has the greater radius.

One point is earned for a correct explanation.

(iii) Which of the two species would be attracted into a magnetic field? Explain.

The sulfur atom would be attracted into a magnetic field. Sulfur has two unpaired $p$ electrons, which results in a net magnetic moment for the atom. This net magnetic moment would interact with an external magnetic field, causing a net attraction into the field. The sulfide ion would not be attracted into a magnetic field because all the electrons in the species are paired, meaning that their individual magnetic moments would cancel each other.

One point is earned for the correct answer with a correct explanation.

(b) The $S^{2-}$ ion is isoelectronic with the $\text{Ar}$ atom. From which species, $S^{2-}$ or Ar, is it easier to remove an electron? Explain.

It requires less energy to remove an electron from a sulfide ion than from an argon atom. A valence electron in the sulfide ion is less attracted to the nucleus (charge +16) than is a valence electron in the argon atom (charge +18).

One point is earned for the correct answer with a correct explanation.
(c) In the H₂S molecule, the H–S–H bond angle is close to 90°. On the basis of this information, which atomic orbitals of the S atom are involved in bonding with the H atoms?

The atomic orbitals involved in bonding with the H atoms in H₂S are \( p \) (specifically, 3\( p \)) orbitals. The three \( p \) orbitals are mutually perpendicular (i.e., at 90°) to one another.

One point is earned for the correct answer.

(d) Two types of intermolecular forces present in liquid H₂S are London (dispersion) forces and dipole-dipole forces.

(i) Compare the strength of the London (dispersion) forces in liquid H₂S to the strength of the London (dispersion) forces in liquid H₂O. Explain.

The strength of the London forces in liquid H₂S is greater than that of the London forces in liquid H₂O. The electron cloud of H₂S has more electrons and is thus more polarizable than the electron cloud of the H₂O molecule.

One point is earned for the correct answer with a correct explanation.

(ii) Compare the strength of the dipole-dipole forces in liquid H₂S to the strength of the dipole-dipole forces in liquid H₂O. Explain.

The strength of the dipole-dipole forces in liquid H₂S is weaker than that of the dipole-dipole forces in liquid H₂O. The net dipole moment of the H₂S molecule is less than that of the H₂O molecule. This results from the lesser polarity of the H–S bond compared with that of the H–O bond (S is less electronegative than O).

One point is earned for the correct answer with a correct explanation.
6. Answer the following questions related to sulfur and one of its compounds.

(a) Consider the two chemical species \( S \) and \( S^{2-} \).

   (i) Write the electron configuration (e.g., \( 1s^2 2s^2 \ldots \)) of each species.

   (ii) Explain why the radius of the \( S^{2-} \) ion is larger than the radius of the \( S \) atom.

   (iii) Which of the two species would be attracted into a magnetic field? Explain.

(b) The \( S^{2-} \) ion is isoelectronic with the \( Ar \) atom. From which species, \( S^{2-} \) or \( Ar \), is it easier to remove an electron? Explain.

(c) In the \( H_2S \) molecule, the \( H-S-H \) bond angle is close to 90°. On the basis of this information, which atomic orbitals of the \( S \) atom are involved in bonding with the \( H \) atoms?

(d) Two types of intermolecular forces present in liquid \( H_2S \) are London (dispersion) forces and dipole-dipole forces.

   (i) Compare the strength of the London (dispersion) forces in liquid \( H_2S \) to the strength of the London (dispersion) forces in liquid \( H_2O \). Explain.

   (ii) Compare the strength of the dipole-dipole forces in liquid \( H_2S \) to the strength of the dipole-dipole forces in liquid \( H_2O \). Explain.

\[ a) \]
\[ \text{i)} \quad S = 1s^2 2s^2 2p^6 3s^2 3p^4 \]
\[ S^{2-} = 1s^2 2s^2 2p^6 3s^2 3p^6 \]
\[ \text{ii)} \quad \text{Because } S^{2-} \text{ has 2 more electrons than } S, \text{ there are more repulsions, and therefore the radius is larger} \]
\[ \text{iii)} \quad \text{[S]} \text{ would because it has 2 unpaired electrons, making it paramagnetic and } S^{2-} \text{ has none, making it diamagnetic and not attracted to a magnetic field} \]
\[ \text{(Para = does not exhibit magnetism)} \]

\[ b) \quad \text{It is easier to remove an } e^- \text{ from } S^{2-} \text{ because it has less protons pulling the } e^- \text{s in} \]
\[ \text{than } Ar. \]

\[ c) \quad \text{The } p \text{-orbitals because } p \text{-orbitals are perpendiculart to each other} \]

\[ d) \]
\[ \text{i)} \quad \text{The LDF's are stronger in } H_2S \text{ because it has a greater mass and therefore more electrons,} \]
ii) H₂O exhibits hydrogen bonding, so its dipole- 

dipole forces would be greater than 
those in H₂S.
6. Answer the following questions related to sulfur and one of its compounds.

(a) Consider the two chemical species $S$ and $S^{2-}$.

(i) Write the electron configuration (e.g., $1s^2\ 2s^2\ldots$) of each species.

(ii) Explain why the radius of the $S^{2-}$ ion is larger than the radius of the $S$ atom.

(iii) Which of the two species would be attracted into a magnetic field? Explain.

(b) The $S^{2-}$ ion is isoelectronic with the Ar atom. From which species, $S^{2-}$ or Ar, is it easier to remove an electron? Explain.

(c) In the $H_2S$ molecule, the $H\cdot S\cdot H$ bond angle is close to $90^\circ$. On the basis of this information, which atomic orbitals of the $S$ atom are involved in bonding with the $H$ atoms?

(d) Two types of intermolecular forces present in liquid $H_2S$ are London (dispersion) forces and dipole-dipole forces.

(i) Compare the strength of the London (dispersion) forces in liquid $H_2S$ to the strength of the London (dispersion) forces in liquid $H_2O$. Explain.

(ii) Compare the strength of the dipole-dipole forces in liquid $H_2S$ to the strength of the dipole-dipole forces in liquid $H_2O$. Explain.

\[6. a. i. \ S: \ 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4 \]

\[S^{2-}: \ 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\]

\[i. \ S \text{ has the same } \# \text{ of } p^+ \text{ and } e^- (16 \text{ of each}); \ S^{2-} \text{ has 2 extra } e^-, \text{ which are shielded from the } (+) \text{ nucl} \text{ by the inner } e^-, \text{ allowing them to orbit further out, increasing the radius.} \]

\[ii. \ S, \text{ it is paramagnetic (unpaired } e^-, \text{ making it attracted to magnetic fields.} \]

\[b. \ S^{2-} \text{ is easier to remove from because } Ar \text{ has } 2 \text{ more } p^+ \text{ pulling on the same } \# \text{ of } e^- \]

\[S^{2-} \text{ has fewer } p^+ \text{ pulling on the same } \# \text{ of } e^- \]

\[c. \ 3p \text{ orbitals} \]

\[d. \ i. \ LDF's \text{ are much weaker than dipole-dipole, although of the same nature. Dipole-dipole is based on full differences in charges (ex: } +2 \text{ ion } +2 \text{ ion); whereas LDF is based on only a very slight polarization across the } e^- \text{ cloud of an atom.} \]

\[ii. \ \text{Dipole forces are stronger in } H_2O \text{ than in } H_2S \text{ because } H_2O \text{ exhibits hydrogen bonding (attraction between hydrogens and either } O, F, \text{ or } N). \]
which is the strongest form of dipole force, dipole? 

hydron!
6. Answer the following questions related to sulfur and one of its compounds.

(a) Consider the two chemical species \(S\) and \(S^{2-}\).
   
   (i) Write the electron configuration (e.g., \(1s^2\ 2s^2\ldots\)) of each species.
   
   (ii) Explain why the radius of the \(S^{2-}\) ion is larger than the radius of the \(S\) atom.
   
   (iii) Which of the two species would be attracted into a magnetic field? Explain.

(b) The \(S^{2-}\) ion is isoelectronic with the \(Ar\) atom. From which species, \(S^{2-}\) or \(Ar\), is it easier to remove an electron? Explain.

(c) In the \(H_2S\) molecule, the \(H–S–H\) bond angle is close to 90°. On the basis of this information, which atomic orbitals of the \(S\) atom are involved in bonding with the \(H\) atoms?

(d) Two types of intermolecular forces present in liquid \(H_2S\) are London (dispersion) forces and dipole-dipole forces.
   
   (i) Compare the strength of the London (dispersion) forces in liquid \(H_2S\) to the strength of the London (dispersion) forces in liquid \(H_2O\). Explain.
   
   (ii) Compare the strength of the dipole-dipole forces in liquid \(H_2S\) to the strength of the dipole-dipole forces in liquid \(H_2O\). Explain.
Question 6

Overview

This question tested students’ ability to use principles of atomic structure to predict atomic properties and to explain molecular properties. In part (a) students had to complete the electron configurations for S and S\(^{2-}\) and then use these configurations to predict and explain two property differences. In part (b) students had to predict and explain another atomic property difference for S\(^{2-}\) and Ar. In part (c) they had to use the observed bond angle in H\(_2\)S to identify the orbitals of the S atom that are involved in bonding to the H atoms. In part (d) students had to compare the relative strength of the London dispersion forces and dipole-dipole attractions of H\(_2\)S and H\(_2\)O.

Sample: 6A
Score: 8

This response earned all 8 points: 2 for part (a)(i) (it was common for students to earn these 2 points), 1 for part (a)(ii), 1 for part (a)(iii), 1 for part (b), 1 for part (c), 1 for part (d)(i), and 1 for part (d)(ii).

Sample: 6B
Score: 7

This response earned all the points except for 1 in part (d)(i), where the explanation does not answer the question. Note that the point was earned in part (a)(ii); the response does not specifically need to mention electron-electron repulsions in order to receive credit. In part (d)(ii) the point was earned for indicating that H\(_2\)O has the stronger dipole-dipole forces because it “exhibits hydrogen bonding”; an explanation discussing hydrogen bonding is an acceptable alternative to a discussion of electronegativity differences and molecular dipole moments.

Sample: 6C
Score: 4

In part (a)(ii) the explanation is not sufficient, and the point was not earned; noting the change in the number of electrons is not enough. In part (a)(iii) the answer is correct, but the explanation based on charge is not valid, and the point was not earned. In part (b) the answer is not correct; it was a common misconception that the fact that Ar is a noble gas was relevant to this answer and explanation, even though the two species have the same electron configuration. In part (d)(i) the point was not earned because, although the answer is correct, the explanation is not; mass, like periodic trends, is an indicator of, but not an explanation for, LDF effects. Some reference to size or polarizability was necessary to earn credit.