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., $1s^2\ 2s^2 \ldots$) of each species.

S : $1s^2 2s^2 2p^6 3s^2 3p^4$ S^{2-} : $1s^2 2s^2 2p^6 3s^2 3p^6$ Note: Replacement of $1s^2 2s^2 2p^6$ by [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 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.

Question 6 (continued)

(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?

The atomic orbitals involved in bonding with the H atoms in H_2S 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 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.

The strength of the London forces in liquid H_2S is greater than that of the London forces in liquid H_2O. The electron cloud of H_2S has more electrons and is thus more polarizable than the electron cloud of the H_2O molecule.	One point is earned for the correct answer with a correct explanation.

(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.

The strength of the dipole-dipole forces in liquid H_2S is weaker than that of the dipole-dipole forces in liquid H_2O. The net dipole moment of the H_2S molecule is less than that of the H_2O 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) i) $S = 1s^2 2s^2 2p^6 3s^2 3p^4$
$S^{2-} = 1s^2 2s^2 2p^6 3s^2 3p^6$

ii) Because S^{2-} has 2 more electrons than S, there are more repulsions, and therefore the radius is larger

iii) $\boxed{S}$ would because it has 2 unpaired electrons, making it paramagnetic and S^{2-} has none, making it diamagnetic & not attracted to a magnetic field
(Para = ~~[illegible]~~ exhibits magnetism)

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

c) The p-orbitals because p-orbitals are perpendicular to each other

d) i) The LDF's are stronger in H_2S because it has a greater mass & therefore more electrons,

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

so there is a stronger attraction.
ii) H_2O exhibits Hydrogen bonding, so its dipole-dipole forces would be greater than those in H_2S.

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

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(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.

6. a. i. S: $1s^2 2s^2 2p^6 3s^2 3p^4$

S^{2-}: $1s^2 2s^2 2p^6 3s^2 3p^6$

ii. S has the same # of p^+ and e^- (16 of ea); S^{2-} has 2 extra e^-, which are shielded from the (+) nucleus by the inner e^-, allowing them to orbit farther out, increasing the radius.

iii. S, it is paramagnetic (unpaired e^-), making it attracted to mag. fields.

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

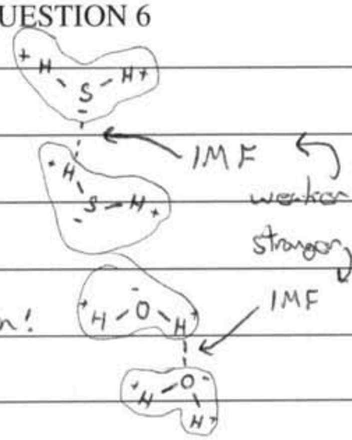
c. 3p orbitals

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

ii. Dipole forces are stronger in H_2O than in H_2S because H_2O ~~(like H~~ exhibits hydrogen bonding (attraction between hydrogens and either O, F, or N),

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

which is the strongest form of dipole force. dipole:



hydrogen!

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(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)i) S - $1s^2 2s^2 2p^6 3s^2 3p^4$ ii) WHEN AN ATOM GAINS ELECTRONS ITS ATOMIC
S^{-2} - $1s^2 2s^2 2p^6 3s^2 3p^6$ RADIUS INCREASES

iii) S - IT HAS 1 UNPAIRED e^- WHICH WOULD BE ATTRACTED TO THE + CHARGE OF THE MAGNETIC FIELD

b) S^{-2} BECAUSE Ar IS A NOBLE GAS AND IT IS ALMOST IMPOSSIBLE TO REMOVE THEIR ELECTRONS

c) 3p - BECAUSE IT HAS 2 UNPAIRED ELECTRONS AND 2 LONE PAIRS WHICH GIVE THE MOLECULE ITS BENT SHAPE, AS OPPOSED TO LINEAR IF THERE WEREN'T ANY LONE PAIRS

d)i) DISPERSION FORCES OF H_2S > H_2O BECAUSE H_2S HAS A LARGER MASS THEREFORE MORE DISPERSION FORCES

ii) DIPOLE FORCES H_2O > H_2S BECAUSE O HAS GREATER ELECTRONEGATIVITY THAN S THEREFORE CREATING A MORE POLAR BOND WITH H THAN S DOES

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_2S 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_2S and H_2O.

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_2O 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.