AP® CHEMISTRY
2006 SCORING GUIDELINES

Question 8

8. Suppose that a stable element with atomic number 119, symbol Q, has been discovered.

(a) Write the ground-state electron configuration for Q, showing only the valence-shell electrons.

$8s^1$	One point is earned for the electron configuration.

(b) Would Q be a metal or a nonmetal? Explain in terms of electron configuration.

It would be a metal (**OR** an alkali metal). The valence electron would be held only loosely.	One point is earned for the correct answer and explanation, which must include reference to the valence electron.

(c) On the basis of periodic trends, would Q have the largest atomic radius in its group or would it have the smallest? Explain in terms of electronic structure.

It would have the largest atomic radius in its group because its valence electron is in a higher principal shell.	One point is earned for the correct answer and explanation; the size must refer to number of electron shells.

(d) What would be the most likely charge of the Q ion in stable ionic compounds?

+1	One point is earned for the correct charge. (Must be consistent with configuration in part (a).)

(e) Write a balanced equation that would represent the reaction of Q with water.

$2\ Q(s) + 2\ H_2O(l) \rightarrow 2\ Q^+(aq) + 2\ OH^-(aq) + H_2(g)$	One point is earned for H_2 as a product. One point is earned for balancing the equation.

(f) Assume that Q reacts to form a carbonate compound.

(i) Write the formula for the compound formed between Q and the carbonate ion, CO_3^{2-}.

Q_2CO_3	One point is earned for the formula consistent with the charge given in part (d).

(ii) Predict whether or not the compound would be soluble in water. Explain your reasoning.

It would be soluble in water because all alkali metal carbonates are soluble.	One point is earned for the answer consistent with the identification of Q.

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Question 7

7. Account for each of the following observations in terms of atomic theory and/or quantum theory.

(a) Atomic size decreases from Na to Cl in the periodic table.

Across the periodic table from Na to Cl, the number of electrons in the *s*- and *p*- orbitals of the valence shell increases, as does the number of protons in the nucleus. The added electrons only partially shield the added protons, resulting in an increased effective nuclear charge. This results in a greater attraction for the electrons, drawing them closer to the nucleus, making the atom smaller.	One point is earned for indicating the increase in nuclear charge. One point is earned for attributing the size decrease to the greater attraction of the nucleus for the electrons caused by the increase in nuclear charge.

(b) Boron commonly forms molecules of the type BX_3. These molecules have a trigonal planar structure.

Boron has three valence electrons, each of which can form a single covalent bond with X. The three single covalent bonds of the boron atom orient to minimize electron-pair interaction, resulting in bond angles of 120° and a trigonal planar structure.	One point is earned for describing the valence electrons and the bonds. One point is earned for a correct VSEPR argument.

(c) The first ionization energy of K is less than that of Na.

Both Na and K have an s^1 valence-shell electron configuration (Na: [Ne] $3s^1$; K: [Ar] $4s^1$). The K atom valence electron has a higher *n* quantum number, placing it farther from the nucleus than the Na atom valence electron. The greater distance results in less attraction to the nucleus. Because its valence electron is less attracted to its nucleus, the K atom has the lower ionization energy.	One point is earned for the size explanation. One point is earned for describing the attraction to the nucleus.

(d) Each element displays a unique gas-phase emission spectrum.

Each element has a unique set of quantized energy states for its electrons (because of its unique nuclear charge and unique electron configuration). As the electrons of an element absorb quanta of energy, they change to higher energy states (are excited) – during de-excitation, energy is released as EM radiation as the electrons cascade to lower energy states. Each photon of the EM radiation is associated with a specific wavelength ($\lambda = hc/E$), a flux of which produces the lines of the emission spectrum.	One point is earned for describing the quantized energy states and emission phenomenon. One point is earned for describing the effect of the uniqueness of the nucleus and/or electron configuration.

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Question 8

8. Use chemical and physical principles to account for each of the following.

(a) An aluminum container filled with an aqueous solution of $CuSO_4$ eventually developed a leak. Include a chemical equation with your answer.

$Al(s) + Cu^{2+}(aq) \rightarrow Al^{3+}(aq) + Cu(s)$ Cu^{2+} has a higher reduction potential than does Al^{3+}, which results in the oxidation and eventual disappearance of the Al metal (depending upon the amount of Cu^{2+}).	One point is earned for the correct equation (phases not required). One point is earned for the explanation of relative reactivity.

(b) The inside of a metal container was cleaned with steam and immediately sealed. Later, the container imploded.

The high temperature of the steam causes the air/water mixture in the container to be at an elevated temperature. When the container is sealed and the temperature decreases, the pressure of the residual gases decreases below the external pressure, causing the implosion. The decrease in pressure occurs because pressure is proportional to temperature and/or vapor pressure of water decrease with temperature, which means that condensation occurs upon cooling with a resultant pressure drop.	One point is earned for explaining the implosion in terms of internal pressure decrease. One point is earned for the explanation of the change of pressure (either cause is accepted).

(c) Skin feels cooler after rubbing alcohol has been applied to it.

Rubbing alcohol evaporates rapidly. Evaporation is endothermic so heat energy is absorbed from the skin in the process, which causes the cooling sensation.	One point is earned for reference to the volatility of the alcohol. One point is earned for discussing the endothermic nature of the process.

(d) The redness and itching of the skin caused by ant bites (injections of methanoic acid, HCO_2H) can be relieved by applying a paste made from water and baking soda (solid sodium hydrogen carbonate). Include a chemical equation with your answer.

$HCO_2H + NaHCO_3 \rightarrow NaHCO_2 + H_2O + CO_2$ Methanoic acid is neutralized by the HCO_3^- ion; with the neutralization of the acid; the redness and itching of the ant bites subside.	One point is earned for the equation. One point is earned for the explanation.

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Question 6

	First Ionization Energy ($kJ\ mol^{-1}$)	Second Ionization Energy ($kJ\ mol^{-1}$)	Third Ionization Energy ($kJ\ mol^{-1}$)
Element 1	1,251	2,300	3,820
Element 2	496	4,560	6,910
Element 3	738	1,450	7,730
Element 4	1,000	2,250	3,360

The table above shows the first three ionization energies for atoms of four elements from the third period of the periodic table. The elements are numbered randomly. Use the information in the table to answer the following questions.

(a) Which element is most metallic in character? Explain your reasoning.

Element 2. It has the lowest first-ionization energy. Metallic elements lose electron(s) when they become ions, and element 2 requires the least amount of energy to remove an electron.	One point is earned for the identification. One point is earned for the justification.

(b) Identify element 3. Explain your reasoning.

Magnesium. Element 3 has low first and second ionization energies relative to the third ionization energy, indicating that the element has two valence electrons, which is true for magnesium. (The third ionization of element 3 is dramatically higher, indicating the removal of an electron from a noble gas core.)	One point is earned for the identification. One point is earned for the justification.

(c) Write the complete electron configuration for an atom of element 3.

$1s^2\ 2s^2\ 2p^6\ 3s^2$	One point is earned for the correct electron configuration.

(d) What is the expected oxidation state for the most common ion of element 2?

1+	One point is earned for the correct oxidation state.

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Question 6 (continued)

(e) What is the chemical symbol for element 2?

Na	One point is earned for the correct symbol.

(f) A neutral atom of which of the four elements has the smallest radius?

Element 1	One point is earned for the correct identification of the element.

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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., $1s^2\ 2s^2$ . . .) 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, $3p$) 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.