AP® Chemistry
2003 Sample Student Responses
Form B

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Answer EITHER Question 7 below OR Question 8 printed on page 26. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.

7. Account for the following observations using principles of atomic structure and/or chemical bonding. In each part, your answer must include specific information about both substances.

(a) The Ca\(^{2+}\) and Cl\(^{-}\) ions are isoelectronic, but their radii are not the same. Which ion has the larger radius? Explain.

(b) Carbon and lead are in the same group of elements, but carbon is classified as a nonmetal and lead is classified as a metal.

(c) Compounds containing Kr have been synthesized, but there are no known compounds that contain He.

(d) The first ionization energy of Be is 900 kJ mol\(^{-1}\), but the first ionization energy of B is 800 kJ mol\(^{-1}\).

F) Both ions have the same number of electrons. Therefore, both ions are identical in size. However, the sizes are not the same as the values for Z\(_{\text{effective}}\). The amount of attraction between the nucleus and electrons is different. Ca\(^{2+}\) has 20 protons in the nucleus, whilst Cl\(^{-}\) has 17.

For this reason, Ca\(^{2+}\) is a smaller ion. It has a smaller ionic radius than Cl\(^{-}\). This is because the increased positive charge in the nucleus of Ca\(^{2+}\) attracts the electrons more strongly than in the Cl\(^{-}\) ion. Z\(_{\text{effective}}\) is proportional to the amount of proton in the nucleus, and since Z\(_{\text{effective}}\) is greater in Ca\(^{2+}\), and since the shielding is identical, the Ca\(^{2+}\) is a smaller ion.

B) Carbon is in period 2 of the periodic table. Lead is in period 6 of the periodic table. Both are in the same group (II) however, lead is a metal because it has a lower Z\(_{\text{effective}}\) than carbon. The added electron shells as you move down a group increase shielding of the Z\(_{\text{effective}}\). Also, as shells are added, the size of the atoms increase. Thus, the outer electrons are able to be removed easily in Pb. In C, however, electrons are close to the nucleus, and they feel a larger Z\(_{\text{effective}}\). Pb is a metal as the low Z\(_{\text{effective}}\) causes it some valence electrons to be more easily removed.
This allows electricity to be conducted. In C, electrons must be added, as the C will not readily give up its electrons.

C) Kr is in period 4, whilst He is in period 1. Kr compounds have been synthesized because Kr atoms contain empty 3d orbitals. Although both atoms have completely filled 5s and 6p orbitals, Kr has empty 3d orbitals which can be used to form bonds. Bonding electrons can be placed in the empty 3d orbitals, allowing bonds to be formed. He, however, has no such empty d orbitals. Thus, bonds cannot be formed due to the lack of space for bonding electrons. Thus, Kr can form molecules, whilst He is a lone atom which is stable.

D) Be has a higher first ionization energy than B. Be has a full 2s orbital, B has a full 2s orbital, and one electron in one of the 2p orbitals. The first ionization energy deals with removing the electron with the greatest energy.
In Be, the full 2s orbital shields the electron in the 2p orbital. This electron thus feels a smaller effective nuclear charge and feels less attracted to the nucleus. This allows the electron to be pulled off more easily. Thus, ionization energy for this electron is lower than in B, where no such extra shielding exists. In B, the shielding is greater than the change in Z-effective from Be to B.
7. Account for the following observations using principles of atomic structure and/or chemical bonding. In each part, your answer must include specific information about both substances.

(a) The Ca\(^{2+}\) and Cl\(^-\) ions are isoelectronic, but their radii are not the same. Which ion has the larger radius? Explain.

(b) Carbon and lead are in the same group of elements, but carbon is classified as a nonmetal and lead is classified as a metal.

(c) Compounds containing Kr have been synthesized, but there are no known compounds that contain He.

(d) The first ionization energy of Be is 900 kJ mol\(^{-1}\), but the first ionization energy of B is 800 kJ mol\(^{-1}\).

A) Cl\(^-\) has a larger radius than Ca\(^{2+}\). This is because, in Ca\(^{2+}\), the effective nuclear charge is increased with the loss of 2 valence electrons; this draws the remaining electrons closer to the nucleus, decreasing the radius. In Cl\(^-\), the addition of one outer electron lowers the effective nuclear charge, allowing the electrons to spread out more, increasing the radius.

B) Carbon is classified as a non-metal because it tends to form covalent rather than ionic bonds; carbon also does not show the characteristics of metals such as being malleable or conducting electricity well. Lead tends to form ionic bonds and has variable oxidation states; these are characteristics of other transition metals so lead is classified as a metal.
C) While He and Kr are both noble gases, the relative sizes of the two atoms are very different. Helium is very small and has a full valence shell of 2, which pairs with its 2 protons in the nucleus. Since the distance between the electrons and nucleus is so small, the effective nuclear charge is strong, it is very difficult to pull an electron off a Helium atom to allow it to react. Krypton is much larger than Helium so therefore, it is much easier to pull electrons off the atom than it is to do so with Helium.

D) Since Be and B have different nuclear charges and numbers of electrons, the effective nuclear charge in a Be is greater than that of a B atom. This makes it more difficult to separate electrons from the Be atom than a B atom, thus Be has a higher first ionization energy than B.