1. (10) In one of Slater’s rules for calculation of effective nuclear charge, the 3s and 3p electrons are grouped together, whereas the 3d electrons are placed in their own group. Provide a brief, qualitative explanation of the rationale for these groupings.

2. (10) Zirconium (Zr) in a 4+ oxidation state has an ionic radius of 86 pm. Hafnium (Hf), the element below zirconium in Group 4, has an ionic radius of 85 pm [i.e. Hf(IV) is slightly smaller than Zr(IV) when it is in the 4+ oxidation state, even though it is 32 atomic mass units heavier than Zr, and occurs in a later period]. Provide a reasonable explanation for the anomalously small ionic radius of Hf(IV).

3. (10) Carbon and silicon have very different first ionization energies (1086 kJ/mol and 786 kJ/mol, respectively, whereas the next group 14 element, germanium, has a first ionization energy (761 kJ/mol) not much different from that of silicon. Provide a reasonable explanation, based on the electronic configurations of Si and Ge, for the unusually small difference in the ionization energies of Si and Ge.

4. (10) Mercury forms an ion, Hg_{2+}^{2+} that has a metal-metal bond and in which the oxidation state of each Hg atom is +1. The other members of the group, zinc and cadmium, do not exhibit similar behavior, even though, other things being equal, one might expect a Hg-Hg bond to be weaker than a Cd-Cd bond or a Zn-Zn bond due to less efficient overlap of the bonding orbitals in Hg (note: other things are obviously not equal). Provide an explanation for this behavior, based on the electronic configuration of Hg(I) and on the nature of the valence atomic orbitals of Hg.

5. (5) The electron affinity of the nitrogen is zero, whereas the electron affinities of all of the other highly electronegative elements except for the noble gases are negative (which means that the attachment of an electron is an exothermic process). Describe the special features of nitrogen that make attachment of an electron less favorable than one might otherwise expect.

6. (15) The first-row elements (lithium through neon) have a number of physico-chemical features that set them apart from the other elements. Briefly outline two of these features and provide a specific example that illustrates each. Comparisons based on compounds and/or reactions of the pairs C/Si, N/P, O/S would be especially useful.

7. (5) Xenon difluoride, XeF₂, reacts as an electrophile with unsaturated organic compounds such as alkenes and arenes. The reactions proceed by a polar mechanism, the first step of which is attack on the π cloud by the electrophilic xenon atom, with displacement of fluoride.

   Suppose that it is discovered that helium will form a kinetically stable compound with fluorine: HeF₂. Would you expect the first step of the mechanism of the reaction of HeF₂ with an unsaturated organic compound to differ from that of XeF₂? If so, in what way? Provide a brief rationale for your answer.

8. (5) Describe the nature of the bonding in potassium hydride (KH).

9. (5) Predict the splitting pattern that would be observed for the ³H (tritium) NMR spectrum of TCD₃ (T = tritium, nuclear spin = ½; D = deuterium, nuclear spin =1). The number of lines is predicted by the expression 2nI + 1, where I = nuclear spin of the neighboring atom, and n = the number of neighboring atoms.

   Assuming a large ³H/¹³C coupling constant, what pattern of lines would you predict for the tritium NMR spectrum of ³H¹³CD₃?

10. (10) Write a balanced equations for: (a) the production of water gas; (b) the reaction of sodium hydride with water.

11. (15) Complete and balance the equations below, and provide a description of observations which one would expect to make upon carrying out the reactions.

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\begin{align*}
\text{Ag(NH₃)₂⁺} + \text{HCl} & \longrightarrow \text{Hg₂²⁺} + \text{NH₃} \\
\text{Cu(H₂O)₄²⁺} + \text{NH₃} & \longrightarrow \text{Cu}^{2+} \quad \text{[note: Cu(H₂O)₄²⁺ = Cuₙaq²⁺]} \\
\end{align*}
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