Name ________________________________**Chem 162, Section**: _______**Team Number:** ______

ALE 7. Ionization Energies & Electron Affinities

(Reference: Sections 8.4 - *Silberberg 5th edition*)

How can one use the Periodic Table to make predictions of atomic properties?

The Model: First Ionization Energies

The first ionization energy (IE_1) is the amount of energy that must be added to 1 mole of gas-phase atoms (X) to yield 1 mole of gas-phase cations and 1 mole of gas-phase electrons:

$$\mathbf{X}(g) + IE_1 \rightarrow \mathbf{X}^+(g) + e^-(g)$$

We can understand the periodic trends in ionization energy through the use of Coulomb's Law and what we already know (*e.g.*, relative atomic radii) about the atoms we're comparing. Any deviations in the overall periodic trend in ionization energy can usually be explained in terms of the electron configurations of the atoms we're comparing.

Key Questions

1. Suppose we're comparing two atoms, A and B. The force of attraction between the nucleus of A and A's outermost electron is stronger than the force of attraction between the nucleus of B and B's outermost electron. Which element, is going to have the greater first ionization energy (*i.e.*, which element requires more energy to ionize 1 mole of gas-phase atoms): A or B? *Circle the correct answer and then briefly justify your answer*.

2 a. When comparing elements within the same group, we've already said that the atoms will have basically the same effective nuclear charge. But the atomic radii of two elements in the same group will not be the same. Which element will have the smaller atomic radius: an element toward the top or one toward the bottom of a column of the Periodic Table? (Circle your answer.)

b. According to Coulomb's Law, what happens to the force of attraction between the outermost electron and the nucleus when the distance between the nucleus and that electron decreases? Does the force decrease or increase in strength? (Circle your answer.)

c. Which element will have the greater first ionization energy: an element toward the top or one toward the bottom of a column of the Periodic Table? (Circle your answer.)

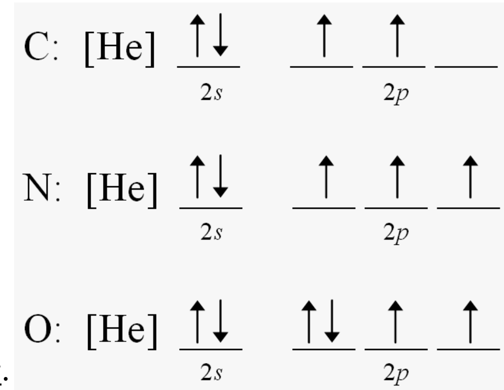
3 a. According to Coulomb's Law, does the force of attraction between the outermost electron and the nucleus decrease or increase when the effective nuclear charge increases? (Circle your answer.)

b. Which element will have the smaller atomic radius: an element toward the left or one toward the right of a period of the Periodic Table? (Circle your answer.)

c. Which element will have a greater effective nuclear charge: an element toward the left or one toward the right of a period of the Periodic Table? (Circle your answer.)

d. Which element will have the greater first ionization energy: an element toward the left or one toward the right of a period of the Periodic Table? (Hint: Look at your answers to Questions 2b and 3a-c.) (Circle your answer.)

4a. **Hund's Rule** says that when there is more than one equal-energy orbital into which an electron may go, the electrons should be placed in their own orbital first before being paired up—i.e. the most stable arrangement of electrons occurs when they're all unpaired within a sublevel. Therefore, the electron configurations of Carbon, Nitrogen, and Oxygen expressed as **abbreviated orbital diagrams** are shown to the right.



Circle the highest-energy electron (i.e., the one that is removed when IE_1 is added) in each of the orbital diagrams.

b. The 1st ionization energies of Carbon, Nitrogen, and Oxygen are 1086 kJ/mol, 1400 kJ/mol, and 1314 kJ/mol, respectively. We can think of the deviation in the periodic trend being that "Nitrogen has too great" (rather than "Oxygen has too small") an ionization energy. What does this say about the stability of an atom having a p subshell that is half-filled? (Such can also be said about atoms that have a half-filled d or f subshell.)

5 a. The 1st ionization energies of Copper, Zinc, and Gallium are 745 kJ/mol, 906 kJ/mol, and 579 kJ/mol. Draw arrows to represent electrons (↑ for spin up, ↓ for spin down, ↑↓ for a pair of electrons in the same orbital) to complete the electron configurations (orbital diagrams) of the three neutral atoms. (*Hint*: Because a completely-filled *d* subshell grants an atom a significant amount of stability, the electron configuration of ground state Copperis not what you'd expect it to be based on the Periodic Table.)

Cu: [Ar] ___ ___ ___ ___ ___ ___ ___ ___ ___
4s 3d 4p

Zn: [Ar] ___ ___ ___ ___ ___ ___ ___ ___ ___
4s 3d 4p

Ga: [Ar] ___ ___ ___ ___ ___ ___ ___ ___ ___
4s 3d 4p

b. Circle which electrons are removed when each of the atoms is ionized.

c. Explain the deviation in the trend, bearing in mind that having a completely-filled subshell grants an atom an additional measure of stability.

The Model: Electron Affinity

The electron affinity (*EA*) is the amount of energy that is released when 1 mole of gas-phase atoms (X) accepts 1 mole of gas-phase electrons to become 1 mole of gas-phase anions:

$$\mathbf{X}(g) + e^-(g) \rightarrow \mathbf{X}^-(g) + EA$$

When comparing two elements on the Periodic Table, we will want to keep in mind Coulomb's Law as well as which atom will have the smaller ionic radius and which atom will have the greatest effective nuclear charge once the newly-added electron becomes part of the atom.

Key Questions

6. It is an expectation that electron affinities are *exo*thermic quantities. Explain why, most of the time, heat is released when a gas-phase atom accepts an electron. (*Hint*: The nucleus of the atom has protons. What kind of force, attractive or repulsive, exists between the nucleus of the atom and the newly-added electron? When that electron is added to the atom, will the species be stabilized or destabilized?)

7. Suppose we're comparing two atoms, A and B, which are both accepting electrons. The force of attraction between the nucleus of A and A's newly-added outermost electron is stronger than the force of attraction between the nucleus of B and B's newly-added outermost electron. Which element, is going to have the greater electron affinity (*i.e.,* which element expels more energy when 1 mole of gas-phase atoms accepts 1 mole of gas-phase electrons): <u>A</u> or <u>B</u>? <u>*Circle the correct answer and then briefly justify your answer*</u>.

8. We already know that an atom toward the bottom of a column on the Periodic Table is larger than an atom toward the top of that column. Suppose we're comparing two atoms, A and B, which are both accepting electrons. A is an atom toward the top of a column on the Periodic Table and B is an atom toward the bottom of that column.

   a. Which species, $\underline{A^-}$ or $\underline{B^-}$, is going to have the smaller ionic radius? (Circle your answer.)

   b. According to Coulomb's Law, what happens to the force of attraction between the newly-added outermost electron and the nucleus when the distance between the nucleus and that electron decreases? Does the force <u>decrease</u> or <u>increase</u> in strength? (Circle your answer.)

   c. Which element will have the greater electron affinity: an element <u>toward the top</u> or one <u>toward the bottom</u> of a column of the Periodic Table? (Circle your answer.)

9 a. According to Coulomb's Law, does the force of attraction between the newly-added outermost electron and the nucleus decrease or increase when the effective nuclear charge increases? (Circle your answer.)

b. Which element will have the smaller atomic radius: an element toward the left or one toward the right of a period of the Periodic Table? (Circle your answer.)

c. Which element will have a greater effective nuclear charge: an element toward the left or one toward the right of a period of the Periodic Table? (Circle your answer.)

d. Which element will have the greater electron affinity: an element toward the left or one toward the right of a period of the Periodic Table? (Circle your answer.)

10. As seen in the table of electron affinities below, the electron affinity of *most* elements is exothermic, but the electron affinities for all of the noble gases are endothermic. *Explain why*.

11. A general trend in electron affinity is that as one goes from the left to the right on a period of the Periodic Table the electron affinity increases as illustrated in the table to the right. However, it is consistently seen in the 2nd through the 5th periods that as one goes from Group 3A to Group 4A the electron affinity increases dramatically, then electron affinity decreases in going from Group 4A to Group 5A. *Use orbital diagrams to explain this apparent deviation in the general trend*.

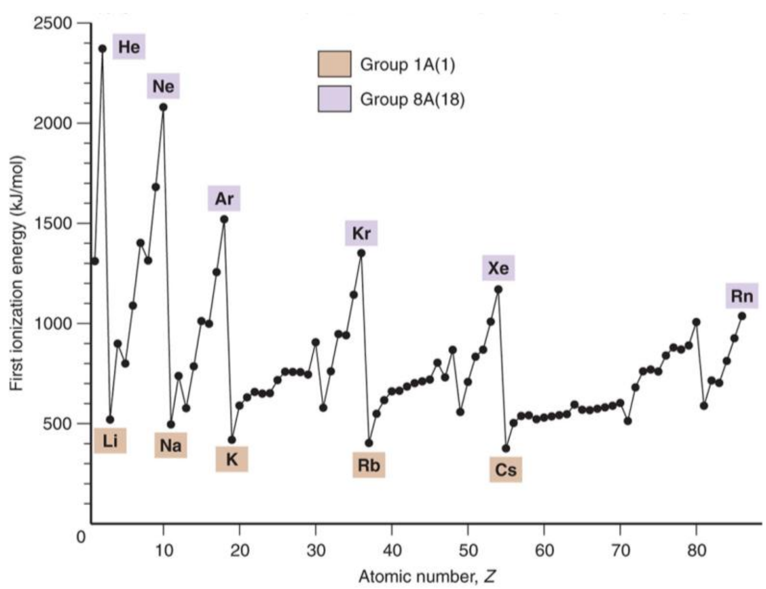
	1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	H −72.8							He (0.0)
2	Li −59.6	Be ≤0	B −26.7	C −122	N +7	O −141	F −328	Ne (+29)
3	Na −52.9	Mg ≤0	Al −42.5	Si −134	P −72.0	S −200	Cl −349	Ar (+35)
4	K −48.4	Ca −2.37	Ga −28.9	Ge −119	As −78.2	Se −195	Br −325	Kr (+39)
5	Rb −46.9	Sr −5.03	In −28.9	Sn −107	Sb −103	Te −190	I −295	Xe (+41)
6	Cs −45.5	Ba −13.95	Tl −19.3	Pb −35.1	Bi −91.3	Po −183	At −270	Rn (+41)

Electron affinities (in kJ/mol) of the main group elements.

12. Another general trend in electron affinity is that as one goes from the top to the bottom of a column of the Periodic Table the electron affinity decreases. However, it is consistently seen in Group 3A through Group 7A that as one goes from the 2nd to the 3rd period the electron affinity increases (see the table of electron affinities on page 4). *Explain this apparent deviation in the general trend*, *taking into account that elements in the same group are isoelectronic and also that an element in the 3rd period is considerably larger than the corresponding 2nd-period element of the same group*. (Hint: think of the electron – electron repulsion and the relative sizes (volumes) of the atomic orbitals involved.)

Exercises

13. Problem 8.49 (modified): In a plot of IE_1 for the Period 2 and Period 3 elements (see the figure to the right), why do the values for elements in Groups 3A and 6A drop slightly below the generally increasing trend? *Explain in terms of the electronic structure of the relevant elements.*
(i.e. For period 2: Be vs. B and O vs. N *or* for period 3: Mg vs. Al and P vs. S).



Periodicity of first ionization energy, IE_1

14. Problem 8.51:
   a.) The EA_2 of an oxygen atom is positive, even though its EA_1 is negative. *Explain why this change in sign occurs*.

   b.) Which other elements exhibit a positive EA_2. *Explain*.

15. Problem 8.60: *Circle* the element in each of the following sets would you expect to have the *lowest third ionization energy*, IE_3? *Use your knowledge of electronic configurations to briefly* explain your reasoning.
   a.) Na, Mg, Al   Reasoning:

   b.) K, Ca, Sc   Reasoning:

   c.) Li, Al, B   Reasoning: