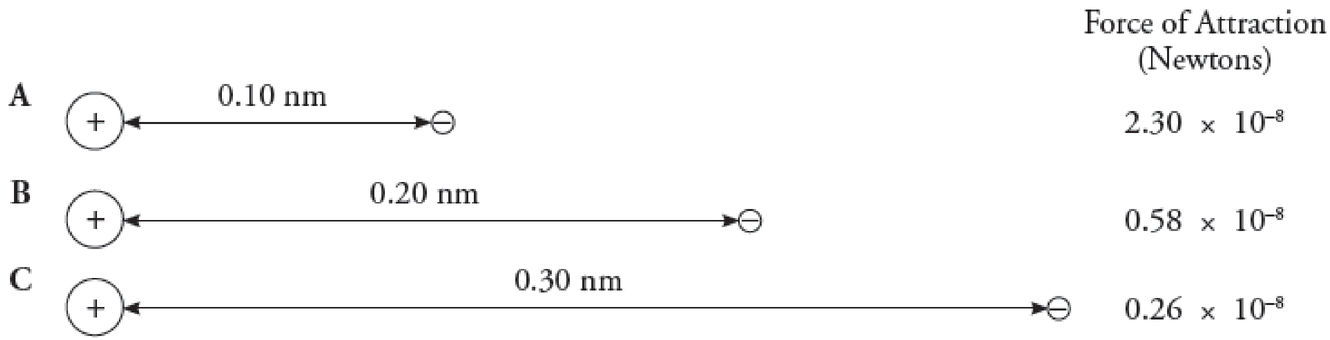
AP Chemistry — Name………………………………………..……..

Unit 9 – Periodic Trends — Hour…….

Coulombic attraction is the attraction between oppositely charged particles. For example, the protons in the nucleus of an atom have an attraction for the electrons surrounding the nucleus. This is because the protons are positive and the electrons are negative. The attractive force can be weak or strong. In this activity, you will explore the strength of attraction between protons and electrons in various atomic structures.

Model 1 – Distance and Attractive Force



1. What subatomic particles do these symbols represent in Model 1?

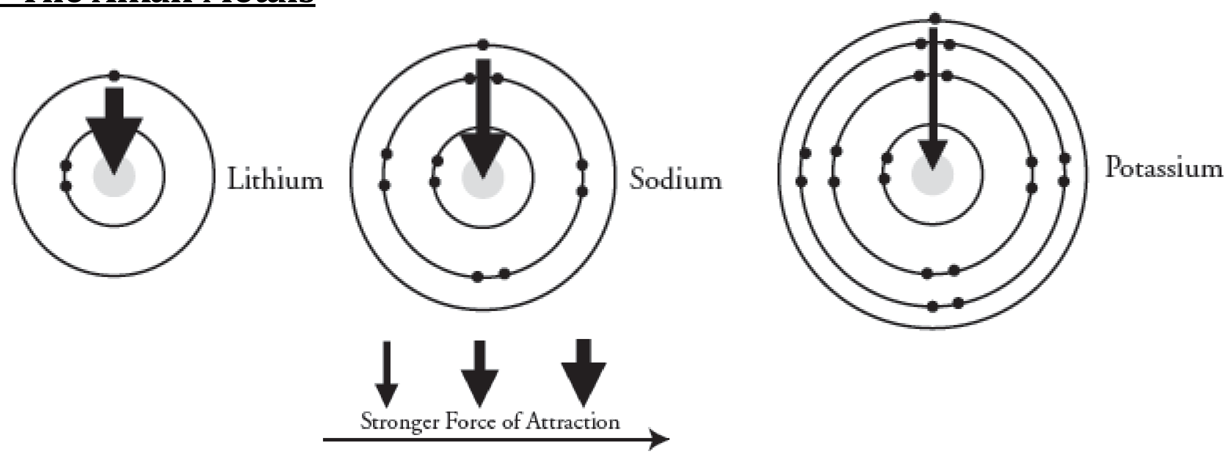
2. Would you expect to observe attraction or repulsion between the subatomic particles in **Model 1**?

3. The relationship between which two variables are tested in **Model 1**? Is the relationship direct or inverse?

4. If the distance between a proton and electron is 0.50 nm, would you expect the force of attraction to be greater than or less than 0.26×10^{-8} N?

5. If two protons are 0.10 nm away from one electron, would you expect the force of attraction to be greater than or less than 2.30×10^{-8} N?

Model 2 – The Alkali Metals



6. Write the complete electron configurations for the three atoms in **Model 2**.

   Li: ____

   Na: ____

   K: ____

7. The diagrams in **Model 2** are sometimes referred to as a **Bohr diagram** of an atom.

   a. What does the central circle represent?

   b. What do the big circles around the central circle represent (hint: look at your answer in Question 6)?

   c. What do the dots on the big circles represent (hint: look at your answer in Question 6)?

8. Consider the diagrams in **Model 2**.

   a. What do the arrows represent?

   b. How does the thickness of the arrows relate to the property given in the answer above?

9. Using the periodic table, locate the elements whose atoms are diagrammed in **Model 2**. Are the elements in the same column or the same row?

10. Circle the valence electron in each of the diagrams in **Model 2**.

    a. As you move from the smallest atom to the largest atom in **Model 2**, how does the distance between the outermost electron and the nucleus change?

    b. As you move from the smallest atom to the largest atom in **Model 2**, how does the attractive force between the outermost electron and the nucleus change?

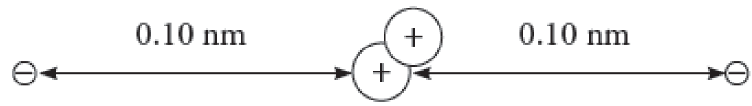
    c. Are your answers to the questions above consistent with the information in **Model 1**?

Model 3 – Number of Protons and Attractive Force

11. The relationship between which two variables are tested in **Model 3**? Is the relationship direct or inverse?

12. What would be the attractive force on a single electron if five protons were in the nucleus of an atom? Show mathematical work to support your answer.

The attractive and repulsive forces in another are rather complex. An electron is attracted to the protons in the nucleus, but it is repelled by the other electrons in the atom. It is important to note however that the attractive force of the nucleus is NOT divided up among the electrons in the atom. Each electron gets approximately the full attractive force of the nucleus (minus the repulsive effects of other electrons. Compare the diagram below to set D in **Model 3**. Notice the similarity in attractive force.



The periodic table is often considered to be the "best friend" of chemists and chemistry students alike. It includes information about atomic masses and element symbols, but it can also be used to make predictions about atomic size, electronegativity, ionization energy, bonding, solubility and reactivity. In this activity you will look at a few periodic trends that can help you make those predictions.

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13. Consider the data in **Model 4** on the following page.

    a. Write a complete sentence to convey your understanding of atomic radius. *Note:* You may not use the word "radius" in your definition.

    ____

    ____

    b. In general, what is the trend in atomic radius as atomic number increases in a vertical column on the periodic table? *Note:* Columns on the periodic table are often called "families" or "groups".

    ____

    c. Using your knowledge of Coulombic attraction and the structure of the atom, **explain** the trend in atomic radius that you identified above. *Hint:* You should discuss either a change in distance between the nucleus and valence electrons or a change in the number of protons in the nucleus.

    ____

    ____

    d. In general, what is the trend in atomic radius as atomic number increases in a period on the periodic table? *Note:* Rows on the periodic table are called "periods".

    ____

e. Using your knowledge of Coulombic attraction and the structure of the atom, **explain** the trend in atomic radius that you identified above. *Hint:* You should discuss either a change in distance between the nucleus and valence electrons or a change in the number of protons in the nucleus.

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Model 4 – Main Group Elements

1 H							2 He
37							31
1312							2372
2.1							N/A
3 Li	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne
152	112	83	77	71	66	71	70
520	900	801	1086	1402	1314	1681	2081
1.0	1.5	2.0	2.5	3.0	3.5	4.0	N/A
11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
186	160	143	117	115	104	99	98
496	738	578	786	1011	1000	1251	1521
0.9	1.2	1.5	1.8	2.1	2.5	3.0	N/A
19 K	20 Ca	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
227	197	122	123	125	117	114	112
404	550	558	709	834	869	1008	1170
0.8	1.0	1.7	1.8	1.9	2.1	2.5	N/A

Atomic Number
Element Symbol
Electron Shell Diagram
Atomic Radius (pm)
1st Ionization Energy (kJ/mol)
Electronegativity

Note: The transition elements and f-block elements have been removed from the periodic table here to ease the analysis of the trends.

14. Locate the numbers in **Model 4** that represents the ionization energy. The **ionization energy** is the amount of energy needed to remove a **valence** electron from an atom in its gaseous state. The **first ionization energy, IE_1,** refers to the energy required to remove the **first valence electron** from an atom.

$$Mg(g) \rightarrow Mg^{1+}(g) + 1e^- \qquad IE_1 = 738 \text{ kJ/mol}$$

a. Using your knowledge of Coulombic attraction, explain why ionization – removing an electron from an atom – takes energy.

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b. Which takes more energy, removing an electron from an atom where the nucleus has a tight hold on its electrons, or a weak hold on its electrons? Explain.

____

____

c. In general, what is the trend in ionization energy as atomic number increases in a family/group on the periodic table?

____

d. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified above. *Hint:* You should discuss either a change in distance between the nucleus and valence electrons or a change in the number of protons in the nucleus.

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____

e. In general, what is the trend in ionization energy as atomic number increases in a period on the periodic table?

____

f. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified above. *Hint:* You should discuss either a change in distance between the nucleus and valence electrons or a change in the number of protons in the nucleus.

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15. Atoms with loosely held electrons are usually classified as **metals**. They will exhibit high conductivity, ductility (ability to be pulled into a thin wire) and malleability (bendable) because of their atomic structure.

    a. Would you expect metals to have high ionization energies or low ionization energies?

    ____

    b. Would you expect metals to be more on the left side or right side of the periodic table?

    ____

Electronegativity is a measure of the atom's nucleus to attract electrons from a different atom within a covalent bond (a bond between non-metal atoms). A higher electronegativity value correlates to a stronger pull on the electrons in a bond.

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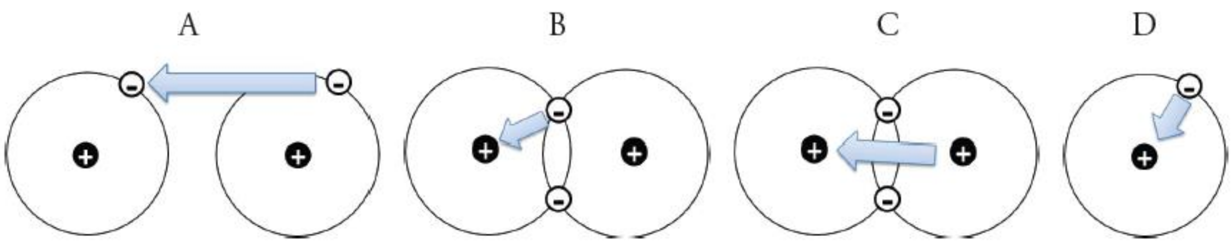
16. Circle the letter of the best visual representation of electronegativity.



17. Locate the electronegativity values in **Model 4**.

    a. What is the trend in electronegativity as atomic number increases in a family/group?

    ____

    b. Explain the existence of the trend described above in terms of atomic structure and Coulombic attraction.

    ____

    ____

    c. What is the trend in electronegativity as atomic number increases in a period?

    ____

    d. Explain the existence of the trend described above in terms of atomic structure and Coulombic attraction.

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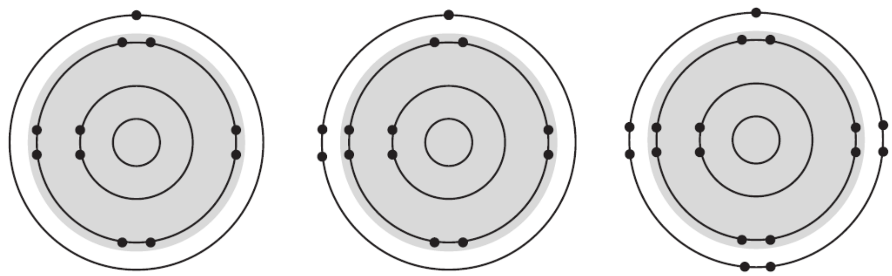
Previously you have learned about Coulombic attraction and how it governs the trends in properties among the elements of the periodic table. For example, as you move across a period, atoms have more protons in the nucleus, which pulls the electrons in tighter making smaller, more electronegative atoms. As atomic number increases in a group/family of the periodic table, the valence electrons get farther away, and the atoms get larger and less electronegative. Inquisitive students may ask, “If more protons in the nucleus pull electrons in tighter, then why don’t atoms get smaller when atomic number increases in a group/family?” That is a good question, and one that you will investigate in this activity.

Model 5 – Period 3 Elements



Atomic Number (Z)			
Number of valence electrons			
Number of shielding electrons			
Effective nuclear charge (Z*)	1+		
Atomic radius	186 pm	143 pm	99 pm
1st ionization energy	496 kJ/mole	578 kJ/mole	1251 kJ/mole
Electronegativity	0.9	1.5	3.0

18. Describe the relationship of the three elements in **Model 5** with regard to their relative positions on the periodic table. Are they in the same family, the same period or neither?

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19. Refer to a periodic table to complete the first two rows of the table in **Model 5**.

20. Consider the charge and location of the protons in an atom.

   a. Indicate on the atomic drawings in **Model 5** a total charge provided by the protons in the proper location for each atom.

   b. The number you just added to the diagrams in **Model 5** is called the **nuclear charge, Z**. Explain why this is an appropriate name for this value.

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21. Circle the valence electron(s) in each of the atoms in **Model 5**.

22. In **Model 5**, the shaded circle in each atom indicates the core of the atom – the nucleus and the non-valence **shielding electrons**. Complete the third row in **Model 5**.

The valence electrons in an atom are influenced not only by the attractive power of the nucleus but also by the repulsive power of neighboring and non-valence electrons. The shielding effect of the non-valence electrons reduces the attractive power of the nucleus. The pulling force that a valence electron actually feels, the **effective nuclear charge (Z^*)**, is much less than the nuclear charge because of this **shielding effect** from non-valence electrons. Although this effective nuclear charge is difficult to calculate directly due to complex quantum effects within the atom, **it is approximately equal to the difference between the nuclear charge and the number of shielding electrons.**

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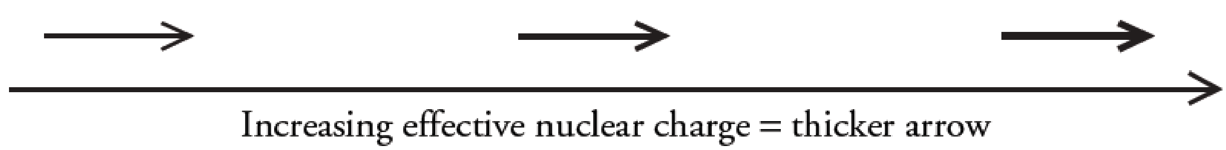
23. Complete the fourth row in **Model 5**.

24. Use arrows like those below to illustrate the relative strength of the effective nuclear charge on the valence electrons in the atoms of **Model 1**.



25. According to **Model 5**, what happens to the effective nuclear charge of atoms as atomic number increases in a period?

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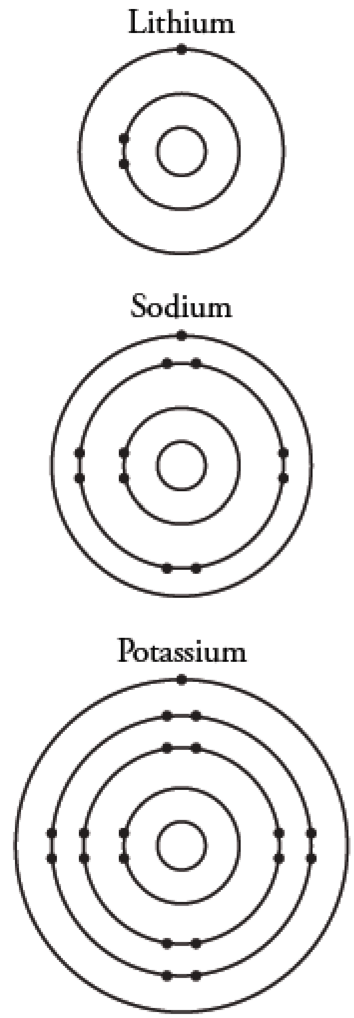
26. Explain how atomic radius, ionization energy and electronegativity change as **<u>atomic number increases in a period</u>** using your understanding of effective nuclear charge, atomic structure and Coulombic attractions. **Submit your answers on the Google form emailed to you.**

<u>Model 6 – The Alkali Metals</u>

	Atomic Number (Z)	Effective Nuclear Charge (Z*)	Atomic Radius	1st Ionization Energy	Electronegativity
Lithium			152 pm	520 kJ/mole	0.91
Sodium			186 pm	496 kJ/mole	0.87
Potassium			227 pm	419 kJ/mole	0.73



27. Are the three elements in **Model 6** in the same period or the same group/family?

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28. Draw a circle and lightly shade the area representing the core of each atom in **Model 6 –** the nucleus and shielding electrons.

29. Refer to a periodic table to complete the table in **Model 6**.

30. According to **Model 6**, what happens to the effective nuclear charge of atoms as atomic number increases in a group/family on the periodic table?

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31. Is effective nuclear charge a factor in how periodic properties change within a group/family? If no, propose another factor that would influence the attractive forces between the nucleus and valence electrons in an atom.

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32. Use arrows like those in **Model 5** to illustrate the relative strength of attraction between the nucleus and the valence electrons in the atoms of **Model 6**.

33. Explain how atomic radius, ionization energy and electronegativity change as **atomic number increases in a family/group** using your understanding of effective nuclear charge, atomic structure and Coulombic attractions. **Submit your answers on the Google form emailed to you.**

34. If more protons in the nucleus pull electrons in tighter, then why don't atoms get smaller as atomic number increases in a group/family?

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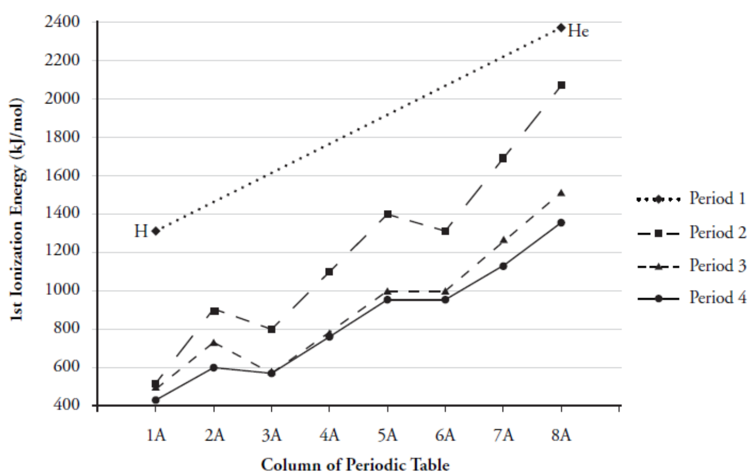
Model 7 – Ionization Energies



35. Two elements, hydrogen and helium, have been labeled on the graph above. Label the remaining elements on the graph. You should finish with krypton.

36. How does the graph in **Model 7** illustrate the periodic trend for ionization energy as atomic number increases in a group/family?

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37. How does the graph in **Model 7** illustrate the periodic trend for ionization energy as atomic number increases in a period? Is this trend an absolute trend (always true) or a general trend?

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38. The 1st ionization energy of oxygen is __**lower**__ than its anticipated value based on the general trend of ionization energy in a period. The same is true of sulfur. Write the full electron configurations for both oxygen and sulfur. Propose an explanation for this discrepancy, based on what you know about attractive and repulsive forces in the atom.

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39. The 1st ionization energy of boron is __**lower**__ than its anticipated value based on the general of ionization energy in a group/family. The same is true of aluminum. Write the full electron configurations for both boron and aluminum. Propose an explanation for this discrepancy, based on what you know about attractive and repulsive forces in the atom.

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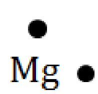
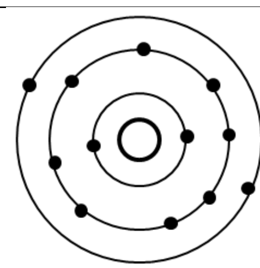
By definition, an atom is a particle where the number of positive protons in the nucleus are equal to the number of negative electrons surrounding the nucleus. The Coulombic forces in the atom consist of ***favorable attractions*** between negative electrons and positive protons and ***unfavorable repulsions*** between electrons. An ion forms when an atom either gains or loses one or more electrons. A ***cation*** is a positive ion formed when an atom loses an electron. An ***anion*** is a negative ion where an atom gains an electron. How does the radius of an ion compare to its atomic radius? Can we use the Periodic Table to predict which elements form cations and which form anions?

__Model 8 – The element magnesium and the magnesium ion__.

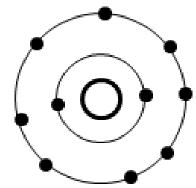
The table below for the element magnesium is shown below.

Elemental Symbol	Electron configuration	Lewis dot structure	Bohr diagram	Atomic radius
Mg	$1s^22s^22p^63s^2$			130pm

40. How many valence electrons are in the element magnesium? ___________

41. The Lewis dot structure of the element magnesium shows two dots. What do you think the dots represent? ____

The table for the magnesium ion is shown below.

Ion Symbol	Electron configuration	Lewis dot structure	Bohr diagram	Ionic radius
Mg^{+2}	$1s^2 2s^2 2p^6$	Mg^{+2}		86 pm

42. In forming the magnesium ion, did the element magnesium gain or lose electrons? ___________

43. How many electrons did the element magnesium gain or lose? ___________

44. The atomic radius of magnesium is larger than the ionic radius of the magnesium ion. Explain this observation. *Hint:* You should discuss either a change in distance between the nucleus and valence electrons or Coulombic affects in the atom.

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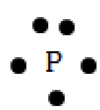
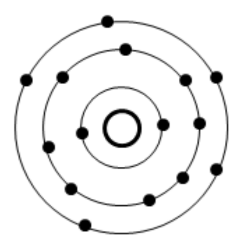
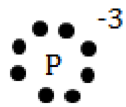
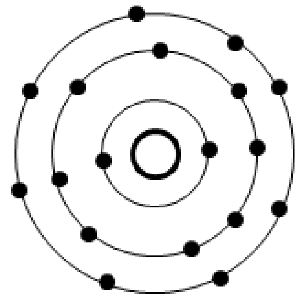
Model 9 – The element phosphorus and the phosphide ion.

Tables for the element phosphorus and the phosphide ion are shown below.

Elemental Symbol	Electron configuration	Lewis dot structure	Bohr diagram	Atomic radius
P	$1s^2 2s^2 2p^6 3s^2 3p^3$			84 pm

Ion Symbol	Electron configuration	Lewis dot structure	Bohr diagram	Ionic radius
P^{-3}	$1s^2 2s^2 2p^6 3s^2 3p^6$			212 pm

45. In forming the phosphide ion, did the phosphorus atom gain or lose electrons? ___________

46. How many electrons did the phosphorous atom gain or lose? ___________

47. The ionic radius of phosphide is larger than the atomic radius of phosphorous. Explain this observation. *Hint:* Re-read the introductory paragraph and discuss Coulombic affects in the atom.

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