Chapter 7

Periodic Properties of the Elements

- The periodic table is one of the most useful tools available to chemists.
- Elements are arranged to emphasize the similarities and variations in properties.
- We will examine some of the properties of the elements and see how these properties are related to the electron configurations of the elements.

7.1 Development of the Periodic Table
- There were 114 elements known by 1999.
- The majority of the elements were discovered between 1735 and 1843.
- How do we organize 114 different elements in a meaningful way that will allow us to make predictions about undiscovered elements?
- Arrange elements to reflect the trends in chemical and physical properties.
- First attempt (Mendeleev and Meyer) arranged the elements in order of increasing atomic weight.

Periodic Trends
- KC? Discoverer: investigation of trends (available in the Learning Resource Center)
  - density
  - melting point
  - atomic volume
  - atomic radius

7.2 Electron Shells and the Sizes of Atoms
- As the principal quantum number increases, the size of the orbital increases.
- All s orbitals are spherical and increase in size as n increases.
- The distribution of electrons in an atom can be represented with a radial electron density graph, which shows the probability of finding an electron at a particular distance from the nucleus.

Electron Shells in Atoms
- The ns orbitals all have the same shape, but have different sizes and different numbers of nodes.
- Consider:
  - He: 1s²
  - Ne: 1s² 2s²2p⁶
  - Ar: 1s² 2s²2p⁶ 3s²3p⁶

Radial Electron-Density Graphs
- The radial electron density is the probability of finding an electron at a given distance.
- For He there is only one maximum (for the two 1s electrons).
- For Ne there are two maxima: one largely for the 1s electrons (close to the nucleus) and one largely for the n = 2 electrons (further from the nucleus).
For Ar there are three maxima: one each largely for n = 1, 2, and 3.
The maxima give the distance where it is most likely to find electrons with the
different principal quantum number (shells).
These electron shells are diffuse and overlap a great deal.
These graphs illustrate one of the factors that affect the properties of the elements -
the nuclear charge.

Periodic Properties of the Elements
Properties of atoms correlate with three properties related to electronic configuration:
• Nuclear Charge
• Pairing Energy
• Shielding Effect: effective nuclear charge is essentially the nuclear charge less
  the number of inner electrons

Atomic Sizes
The edges of atoms are fuzzy, so size is difficult to measure. Can measure
interatomic distances in molecules or between molecules during collisions. These
give somewhat different results.
• bonding or covalent radius
• metallic radius
• nonbonding radius

Atomic and Ionic Size
Measure metallic or covalent radii by diffraction of X-rays

Trends in Size
What trends would be expected in atomic or ionic size?
Decreases across a period, increases down a group (See KC? Discoverer)
Explain in terms of the three factors

Trends in Atomic Radius
Which member of each pair has the greater atomic radius? Why?
• F or Cl
• N or O
• O or F
• Na or Mg
• K or Na

Trends in Ionic Radius (pm)
See Section 8.3
Compare isoelectronic series of ions to see the effect of the factors
Which is larger?
• Be$^{2+}$ or B$^{3+}$
• Al$^{3+}$ or P$^{3-}$
• Ca\(^{2+}\) or Mg\(^{2+}\)
• K or Ca
• O\(^{2-}\) or F\(^{-}\)

7.3 Ionization Energy

- \(\text{El}(g) \rightarrow \text{El}^+(g) + e^-\) 1st IE
- \(\text{El}^+(g) \rightarrow \text{El}^{2+}(g) + e^-\) 2nd IE
- Which would require the most energy? Why?
- See values in Table 7.2
- Note that there is a sudden jump after some of the electrons are removed. At which electron will this occur for a specific element? Why?

*Trends in Ionization Energy*

- The 2nd ionization energy is greater than the 1st ionization energy by nearly a constant proportion. Certain elements show a much greater increase. Which elements are these?
- See KC Discoverer
- Which elements have an unusually high ratio of 3rd IE to 2nd IE? ... 3rd IE to 1st IE? Which element is this?
- Ionization energy plotted against the number of electrons removed.
- Explain trends in terms of three factors

*7.4 Electron Affinities*

- \(\text{El}(g) + e^- \rightarrow \text{El}^-(g)\)
- Also can have successive values for addition of more electrons
- Negative values indicate that energy is released
- The largest negative values occur for the halogens
- The most non-metallic elements have the most negative values

*7.5 Metals, Nonmetals, and Metalloids*

- Elements can be grouped into three broad categories: metals, nonmetals, and metalloids.
- These categories are primarily established by the electrical conductivity of the elements:
  - metals: electrical conductors
• nonmetals: electrical insulators
• metalloids: semiconductors
• Elements of a type are grouped together in the periodic table

Metals
• Metallic character refers to the properties of metals (shiny or lustrous, malleable and ductile, oxides form basic ionic solids, and tend to form cations in aqueous solution).
• Metallic character increases down a group and decreases across a period.
• Metals have low ionization energies.
• Most neutral metals are oxidized rather than reduced.
• When metals are oxidized they tend to form characteristics cations.
  • All group 1A metals form M\(^+\) ions.
  • All group 2A metals form M\(^{2+}\) ions.
• Most transition metals have variable charges.
• Most metal oxides are basic:
  • Metal oxide + water \(\rightarrow\) metal hydroxide
  • Na\(_2\)O(s) + H\(_2\)O(l) \(\rightarrow\) 2NaOH(aq)

Nonmetals
• Nonmetals are more diverse in their behavior than metals.
• When nonmetals react with metals, nonmetals tend to gain electrons:
  • metal + nonmetal \(\rightarrow\) salt
  • 2Al(s) + 3Br\(_2\)(l) \(\rightarrow\) 2AlBr\(_3\)(s)
• Most nonmetal oxides are acidic:
  • nonmetal oxide + water \(\rightarrow\) acid
  • P\(_4\)O\(_{10}\)(s) + H\(_2\)O(l) \(\rightarrow\) 4H\(_3\)PO\(_4\)(aq)

Metalloids
• Example: Si has a metallic luster but it is brittle.
• Metalloids are useful in the semiconductor industry.

7.6 Group Trends for the Active Metals
• Correlates with position in periodic table, electronic configuration, ionization energy, electron affinity
• Alkali Metals: Group 1A in the periodic table
• Alkali metals are all soft.
• Their chemistry is characterized by loss of one electron: \(M \rightarrow M^+ + e^-\)
• They combine directly with most nonmetals: \(2Na + Cl_2 \rightarrow 2NaCl\)
• They react with water to form MOH and H\(_2\): \(2Na + 2H_2O \rightarrow 2NaOH + H_2\)
• Reaction with oxygen gives oxides (Li), peroxides (Na, K, Rb, Cs) and superoxides (K, Rb, Cs)
• What trends would be predicted for the reaction of the alkali metals with air or water?
Chapter 7

Alkaline Earth Metals

- Harder and denser than the alkali metals
- Their chemistry is characterized by loss of two electrons: \( M \rightarrow M^{2+} + 2e^- \)
- Be does not react with water. Mg will only react with steam. Ca, Sr, Ba react with water:
  \[ \text{Ca(s) + 2H}_2\text{O(l) \rightarrow Ca(OH)\textsubscript{2}(aq) + H}_2\text{(g)} \]

7.7 Group Trends for Selected Nonmetals

- Hydrogen
  - Hydrogen is a unique element.
  - Most often occurs as a colorless diatomic gas, \( \text{H}_2 \).
  - It can either gain another electron to form the hydride ion, \( \text{H}^- \), or lose its electron to become \( \text{H}^+ \):
    \[ 2\text{Na(s) + H}_2\text{(g) \rightarrow 2NaH(s)} \]
    \[ 2\text{H}_2\text{(g) + O}_2\text{(g) \rightarrow 2H}_2\text{O(g)} \]

Group 6A: The Oxygen Group

- O, S, Se, Te, Po
  - Trend that affects other properties is the increase in metallic character down the group, indicated by the decreases in ionization energy and electronegativity
  - Nonmetallic character dominates in this group
  - Nonmetallic O exists as diatomic molecules (\( \text{O}_2 \)) and as ozone (\( \text{O}_3 \))
  - Nonmetallic S exists as various covalently bonded polyatomic forms
  - Metalloids Se and Te are more metallic than S, but bear some resemblance to S, which exists primarily as \( \text{S}_8 \)
  - Po is even more metallic, but its behavior is not well known since it is a rare, radioactive element

Group 7A: The Halogens

- The chemistry of the halogens is dominated by gaining an electron to form an anion: \( \text{X}_2 + 2e^- \rightarrow 2\text{X}^- \).
- Fluorine is one of the most reactive substances known:
  \[ 2\text{F}_2\text{(g) + 2H}_2\text{O(l) \rightarrow 4HF(aq) + O}_2\text{(g) \DeltaH = -758.7 kJ)} \]
- All halogens consists of diatomic molecules, \( \text{X}_2 \).
- Chlorine is the most industrially useful halogen. It is produced by the electrolysis of brine (\( \text{NaCl} \)):
  \[ 2\text{NaCl(aq) + 2H}_2\text{O(l) \rightarrow 2NaOH(aq) + H}_2\text{(g) + Cl}_2\text{(g)} \]
- The reaction between chlorine and water produces hypochlorous acid (\( \text{HOCl} \)) which disinfects pool water:
  \[ \text{Cl}_2\text{(g) + H}_2\text{O(l) \rightarrow HCl(aq) + HOCl(aq)} \]
- Hydrogen compounds of the halogens are all strong acids with the exception of HF.
Chapter 7

**Group 8A: The Noble Gases**

- These are all nonmetals and monatomic.
- They are notoriously unreactive because they have completely filled s and p subshells.
- In 1962 the first compound of the noble gases was prepared: XeF₂, XeF₄, and XeF₆.
- To date the only other noble gas compound known is KrF₂.