Chapter 6

The Periodic Table

by Christopher Hamaker
Chemists had been looking for a method to classify the elements.

In 1829, the German chemist J. W. Döbereiner observed that several elements could be classified into groups of three, or triads.

All three elements in a triad showed very similar chemical properties and an orderly trend in physical properties.
In 1865, J.A.R. Newlands suggested that the 62 known elements be arranged into groups of seven according to increasing atomic mass.

– His theory was called the law of octaves.

He proposed that every eighth element would repeat the properties of the first in the group.

His theory was not widely accepted for about 20 years even though it was mostly correct.
Mendeleev’s Periodic Table

- Mendeleev proposed that the properties of the chemical elements repeat at regular intervals when arranged in order of increasing atomic mass.

- Mendeleev is the architect of the modern periodic table.

- He arranged his periodic table in columns by the formula of the element’s oxide.
Prediction of New Elements

- Mendeleev noticed that there appeared to be some elements missing from the periodic table.
- He was able to accurately predict the properties of the unknown element ekasilicon in 1869. It was discovered in 1886 as germanium.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>EKASILICON PREDICTED (1869)</th>
<th>GERMANIUM DISCOVERED (1886)</th>
</tr>
</thead>
<tbody>
<tr>
<td>color</td>
<td>gray</td>
<td>gray</td>
</tr>
<tr>
<td>atomic mass</td>
<td>72 amu</td>
<td>72.6 amu</td>
</tr>
<tr>
<td>density</td>
<td>5.5 g/mL</td>
<td>5.32 g/mL</td>
</tr>
<tr>
<td>melting point</td>
<td>very high</td>
<td>937 °C</td>
</tr>
<tr>
<td>formula of oxide</td>
<td>EkO₂</td>
<td>GeO₂</td>
</tr>
<tr>
<td>density of oxide</td>
<td>4.7 g/mL</td>
<td>4.70 g/mL</td>
</tr>
<tr>
<td>formula of chloride</td>
<td>EkCl₄</td>
<td>GeCl₄</td>
</tr>
<tr>
<td>boiling point of chloride</td>
<td>100 °C</td>
<td>86 °C</td>
</tr>
</tbody>
</table>
Dmitri Mendeleev

• Dmitri Mendeleev was born in Siberia in 1834 as the youngest of 14 to 17 children.
• He was a student and professor at the University of St. Petersburg.
• Based on periodic trends, Mendeleev predicted the existence of three elements (gallium, scandium, and germanium) before they were discovered.
• He narrowly missed being awarded the Nobel Prize in 1906.
The Noble Gases

- The periodic table was expanded by one group at the far right of the periodic table with the discovery of argon in 1894.
- Helium, neon, krypton, xenon, and radon were subsequently discovered in the next 5 years.
- They were originally called the *inert gases*.
- Recently, several compounds of xenon and krypton have been made and the term *noble gases* is currently used.
H. G. J. Moseley discovered that the nuclear charge increased by one for each element on the periodic table. He concluded that if the elements are arranged by increasing nuclear charge rather than atomic mass, the trends on the periodic table are better explained. Recall that atomic charge is due to the number of neutrons in the nucleus, the atomic number.
The Periodic Law

• The periodic law states that the properties of elements recur in a repeating pattern when arranged according to increasing atomic number.

• With the introduction of the concept of electron energy levels by Niels Bohr, the periodic table took its current arrangement.
Groups and Periods of Elements

• A vertical column on the periodic table is a *group* or *family* of elements.

• A horizontal row on the periodic table is a *period* or *series* of elements.

• There are 18 groups and seven periods on the periodic table.
Periods on the Periodic Table

- The seven periods are labeled 1 through 7.
- The first period has only two elements, H and He.
- The second and third periods have eight elements each:
  - Li through Ne and
  - Na through Ar
- The fourth and fifth periods each have 18 elements:
  - K through Kr and
  - Rb through Xe
Hydrogen on the Periodic Table

- Hydrogen occupies a special position on the periodic table.
- It is a gas with properties similar to nonmetals.
- It also reacts by losing one electron, similar to metals.
- We will place hydrogen in the middle of the periodic table to recognize its unique behavior.
Groups on the Periodic Table

- There are 18 groups on the periodic table.
- American chemists designated the groups with a Roman numeral and the letter A or B.

- IA is Li to Fr
- IIA is Be to Ra
- IIB is Zn, Cd, Hg
- VA is N to Bi
In 1920, the International Union of Pure and Applied Chemistry (IUPAC) proposed a new numbering scheme. In it, the groups are assigned numbers 1 through 18.

- Group 1 is Li to Fr
- Group 2 is Be to Ra
- Group 12 is Zn, Cd, and Hg
- Group 15 is N to Bi
Groupings of Elements

- There are several groupings of elements.
- The *representative elements* or *main-group elements*, are in the A groups (Groups 1, 2, and 12–18).
- The *transition elements* are in the B groups (Groups 3–12).
- The *inner transition elements* are found below the periodic table. They are also referred to as the *rare earth elements*.
Groupings of Elements, Continued

- The inner transition elements are divided into the **lanthanide series** and the **actinide series**.
Several families have common trivial names.

- **Group 1** are the alkali metals.
- **Group 2** are the alkaline earth metals.
- **Group 17** are the halogens.
- **Group 18** are the noble gases.
Periodic Trends

- The arrangement of the periodic table means that the physical properties of the elements follow a regular pattern.

- We can look at the size of atoms, or their atomic radius.

- There are two trends for atomic radii:
  1. Atomic radius decreases as you go up a group.
  2. Atomic radius decreases as you go left to right across a period.
Atomic Radius

• Figure 6.4 shows the atomic radii of the main group elements.

• The general trend in atomic radius applies to the main group elements, not the transition elements.
Atomic Radius Trend

- Atoms get smaller as you go bottom to top on the periodic table because as you travel up a group, there are fewer energy levels on the atom.

- Atomic radius decreases as you travel left to right across the periodic table because the number of protons in the nucleus increases.

- As the number of protons increases, the nucleus pulls the electrons closer and reduces the size of the atom.
Metallic Character

- **Metallic character** is the degree of metal character of an element.
- Metallic character decreases left to right across a period and from bottom to top in a group.
- It is similar to the trend for atomic radius.
Atomic Radius and Metallic Character
Physical Properties of Elements

• Since the properties of the elements follow regular patterns, we can predict unknown properties of elements based on those around it.

• For example, Table 6.2 lists several properties of the alkali metals except francium, Fr.

• We can predict the properties of francium based on the other alkali metals.
We can predict that the atomic radius of Fr is greater than 0.266 nm, that its density is greater than 1.87 g/mL, and that its melting point is less than 28.4 °C.
Members of a family also have similar chemical properties.

All of the alkali metals have oxides of the general formula $M_2O$:
- $\text{Li}_2\text{O}$, $\text{Na}_2\text{O}$, $\text{K}_2\text{O}$, $\text{Rb}_2\text{O}$, $\text{Cs}_2\text{O}$, and $\text{Fr}_2\text{O}$.

The formula for the chloride of calcium is $\text{CaCl}_2$. What is the formula for the chloride of barium?
- The general formula is $M\text{Cl}_2$, so the formula must be $\text{BaCl}_2$. 
Blocks of Elements

• Recall the order for the filling of sublevels with electrons:
  – \(1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < 5s \ldots\)

• We can break the periodic table into blocks of elements where certain sublevels are being filled:
  – Groups IA/1 and IIA/2 are filling \(s\) sublevels, so they are called the \(s\) block of elements.
  – Groups IIIB/3 through IIB/12 are filling \(d\) sublevels, so they are called the \(d\) block of elements.
Blocks and Sublevels

- We can use the periodic table to predict which sublevel is being filled by a particular element.
Noble Gas Core Electron Configuration

• Recall, the electron configuration for Na is as follows:

\[
\text{Na: } 1s^2 \ 2s^2 \ 2p^6 \ 3s^1
\]

• We can abbreviate the electron configuration by indicating the innermost electrons with the symbol of the preceding noble gas.

• The preceding noble gas with an atomic number less than sodium is neon, Ne. We rewrite the electron configuration as follows:

\[
\text{Na: } [\text{Ne}] \ 3s^1
\]
Valence Electrons

- When an atom undergoes a chemical reaction, only the outermost electrons are involved.

- These electrons are of the highest energy and are furthest away from the nucleus. These are the *valence electrons*.

- The valence electrons are the $s$ and $p$ electrons beyond the noble gas core.
Predicting Valence Electrons

• The Roman numeral in the American convention indicates the number of valence electrons.
  – Group IA elements have one valence electron.
  – Group VA elements have five valence electrons.

• When using the IUPAC designations for group numbers, the last digit indicates the number of valence electrons.
  – Group 14 elements have four valence electrons.
  – Group 2 elements have two valence electrons.
• An **electron dot formula** of an element shows the symbol of the element surrounded by its valence electrons.

• We use one dot for each valence electron.

• Consider phosphorous, $P$, which has five valence electrons. Below is the method for writing the electron dot formula.

\[ \text{Core (nucleus + inner electrons)} \]

\[ \text{Valence electrons} \]

\[ P > P \cdot > P \cdot > \cdot P > \cdot P > \cdot P \]

\[ \text{core} + 1 \text{e}^- + 2 \text{e}^- + 3 \text{e}^- + 4 \text{e}^- + 5 \text{e}^- \]
Ionization Energy

• The *ionization energy* of an atom is the amount of energy required to remove an electron in the gaseous state.

• In general, the ionization energy *increases* as you go from the bottom to the top in a group.

• In general, the ionization energy *increases* as you go from left to right across a period of elements.

• The closer the electron is to the nucleus, the more energy is required to remove the electron.
Figure 6.8 shows the trend for the first ionization energy of the elements.
Ionic Charge

• Recall that metals tend to *lose electrons* and nonmetals tend to *gain electrons*.

• The charge on an ion is related to the number of valence electrons on the atom.

• Group IA/1 metals lose their one valence electron to form 1+ ions.

\[ \text{Na} \rightarrow \text{Na}^+ + e^- \]

• Metals lose their valence electrons to form ions.
Predicting Ionic Charge

- Group 1 metals form 1+ ions, Group 2 metals form 2+ ions, Group 13 metals form 3+ ions, and Group 14 metals form 4+ ions.

- By losing their valence electrons, they achieve a noble gas configuration.

- Similarly, nonmetals can gain electrons to achieve a noble gas configuration.

- Group 15 nonmetals form –3 ions, Group 16 nonmetals form –2 ions, and Group 17 elements form –1 ions.
Electron Configurations of Ions

• When we write the electron configuration of a positive ion, we remove one electron for each positive charge.

\[ \text{Na} \rightarrow \text{Na}^+ \]
\[ 1s^2 \ 2s^2 \ 2p^6 \ 3s^1 \rightarrow 1s^2 \ 2s^2 \ 2p^6 \]

• When we write the electron configuration of a negative ion, we add one electron for each negative charge.

\[ \text{O} \rightarrow \text{O}^{2-} \]
\[ 1s^2 \ 2s^2 \ 2p^4 \rightarrow 1s^2 \ 2s^2 \ 2p^6 \]
Evolution of Chemical Elements

• The universe is estimated to be 14 billion years old and began with the “big bang.”
• There is evidence for the formation of hydrogen and helium during the big bang, but not other elements.
• The fusion, or combining, of lighter elements into larger nuclei produced the heavier elements.
Chapter Summary

• The elements in the periodic table are arranged by increasing atomic number.

• The elements have regular repeating chemical and physical properties.

• The periodic table can be broken down into:
  – Groups or families, which are columns.
  – Periods or series, which are rows.
• Atomic radius and metallic character increase as you go from bottom to top and from left to right across the periodic table.

• The periodic table can be broken down into blocks where a certain sublevel is being filled.
• *Valence electrons* are the outermost electrons and are involved in chemical reactions.

• We can write *electron dot formulas* for elements, which indicate the number of valence electrons.

• *Ionization energy* is the amount of energy that is required to remove an electron from an atom in the gaseous state.
Chapter Summary, Continued

- We can predict the charge on the ion of an element from its position on the periodic table.