Unit 2.3 Atomic Theory & Periodic Table

Dalton’s Atomic Theory (1804)

From his experiments and observations, as well as the work from peers of his time, Dalton proposed a new theory of the atom. This later became known as Dalton’s atomic theory. The general tenets of this theory were as follows:

- All matter is composed of extremely small particles called atoms.
- Atoms of a given element are identical in size, mass, and other properties. Atoms of different elements differ in size, mass, and other properties.
- Atoms cannot be subdivided, created, or destroyed.
- Atoms of different elements can combine in simple whole number ratios to form chemical compounds.
- In chemical reactions, atoms are combined, separated, or rearranged.

Dalton’s atomic theory has been largely accepted by the scientific community, with the exception of three changes. We know now that (1) an atom can be further subdivided, (2) all atoms of an element are not identical in mass, and (3) using nuclear fission and fusion techniques, we can create or destroy atoms by changing them into other atoms.

Early History of the Periodic Table

When you go to the library to find a book, how do you locate it? If it is a fiction book, you look by author since the fiction materials are filed by the author’s last name. If you are looking for a non-fiction publication, you look in a catalog (most likely on a computer these days). The book you are looking for will have a number by the title. This number refers to the Dewey Decimal system, developed by Melvil Dewey in 1876 and used in over 200,000 libraries throughout the world. Another system in wide use is the Library of Congress approach, developed in the late 1800s-early 1900s to organize the materials in the federal Library of Congress. This method is one of the most widely used ways to organize libraries in the world. Both approaches organize information so that people can easily find what they are looking for. Chemistry information also needs to be organized so we can see patterns of properties in elements.
Early Attempts to Organize Elements

By the year 1700, only a handful of elements had been identified and isolated. Several of these, such as copper and lead, had been known since ancient times. As scientific methods improved, the rate of discovery dramatically increased. With the ever-increasing number of elements, chemists recognized that there may be some kind of systematic way to organize the elements. The question was: how?

A logical way to begin grouping elements together was by their chemical properties. In other words, putting elements in separate groups based on how they reacted with other elements. In 1829, a German chemist, Johann Dobereiner (1780-1849), placed various groups of three elements into groups called triads. One such triad was lithium, sodium, and potassium. Triads were based on both physical as well as chemical properties. Dobereiner found that the atomic masses of these three elements, as well as other triads, formed a pattern. When the atomic masses of lithium and potassium were averaged together \( \frac{(6.94+39.10)}{2} = 23.02 \), it was approximately equal to the atomic mass of sodium (22.99). These three elements also displayed similar chemical reactions, such as vigorously reacting with the members of another triad: chlorine, bromine, and iodine. While Dobereiner’s system would pave the way for future ideas, a limitation of the triad system was that not all of the known elements could be classified in this way.

<table>
<thead>
<tr>
<th>Dobereiner’s Triads.</th>
<th>Group</th>
<th>Elements and their Atomic Mass</th>
<th>Arithmetic mean of Atomic mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Lithium(Li)</td>
<td>Sodium(Na)</td>
<td>Potassium(K)</td>
</tr>
<tr>
<td>B</td>
<td>Calcium(Ca)</td>
<td>Strontium(Sr)</td>
<td>Barium(Ba)</td>
</tr>
<tr>
<td>C</td>
<td>Chlorine(Cl)</td>
<td>Bromine(Br)</td>
<td>Iodine(I)</td>
</tr>
</tbody>
</table>

English chemist John Newlands (1838-1898) ordered the elements in increasing order of atomic mass and noticed that every eighth element exhibited similar properties. He called this relationship the “Law of Octaves.” Unfortunately, there were some elements that were missing and the law did not seem to hold for elements that were heavier than calcium. Newlands’s work was largely ignored and even ridiculed by the scientific community in his day. It was not until years later that another more extensive periodic table effort would gain much greater acceptance and the pioneering work of John Newlands would be appreciated.

Mendeleev’s Periodic Table

When you study for a test, how do you approach the task? One useful way is to use flash cards. You write down the vocabulary words, the foreign language terms, the math formulas, the chemistry reactions - anything you want to learn. Then you sort these cards into categories, topics that go together. This organization of information helps you see patterns in the material so you can tie different ideas together and make better sense of them. The periodic table was first built using a set of cards. With this strategy, Mendeleev could organize and rearrange material until patterns emerged.
Mendeleev’s Periodic Table

In 1869, Russian chemist and teacher Dmitri Mendeleev (1836-1907) published a periodic table of the elements. The following year, German chemist Lothar Meyer independently published a very similar table. Mendeleev is generally given more credit than Meyer because his table was published first and because of several key insights that he made regarding the table.

Mendeleev was writing a chemistry textbook for his students and wanted to organize all of the known elements at that time according to their chemical properties. He famously organized the information for each element on to separate note cards that were then easy to rearrange as needed. He discovered that when he placed them in order of increasing atomic mass, certain similarities in chemical behavior repeated at regular intervals. This type of a repeating pattern is called “periodic.” A pendulum that swings back and forth in a given time interval is periodic, as is the movement of the moon around the Earth.

In the figure above, atomic mass increases from top to bottom of vertical columns, with successive columns going left to right. As a result, elements that are in the same horizontal row are groups of elements that were known to exhibit similar chemical properties. One of Mendeleev’s insights is illustrated by the elements tellurium (Te) and iodine (I). Notice that tellurium is listed before iodine even though its atomic mass is higher. Mendeleev reversed the order because he knew that the properties of iodine were much more similar to those of fluorine (F), chlorine (Cl), and bromine (Br) than they were to oxygen (O), sulfur (S), and selenium (Se). He simply assumed that there was an error in the determination of one or both of the atomic masses. As we will see shortly, this turned out not to be the case, but Mendeleev was indeed correct to group these two elements as he did.
How has the English dictionary evolved over time? Language changes with time. New words enter the language and old words often disappear from lack of use. Dictionaries are published so that people can keep up with changes in language and know how to use words properly. These publications may be in print or they may be electronic. Dictionaries can be found on the internet and apps are now available for smartphones. Dictionaries are invaluable for good, reliable communication.

The Modern Periodic Table

The periodic table has undergone extensive changes in the time since it was originally developed by Mendeleev. Many new elements have been discovered, while others have been artificially synthesized (manmade). Each fits properly into a group of elements with similar properties. In the early 1900's, Henry Moseley organized the elements in order of their atomic numbers so that elements with similar properties appear in the same vertical column or group.

The figure below shows the most commonly used form of the periodic table. Each square shows the chemical symbol of the element along with its name. Notice that several of the symbols seem to be unrelated to the name of the element: Fe for iron, Pb for lead, etc. Most of these are the elements that have been known since ancient times and have symbols based on their Latin names. The atomic number of each element is written above the symbol.
A **period** is a horizontal row of the periodic table. There are seven periods in the periodic table, with each one beginning at the far left. A new period begins when a new principal energy level begins filling with electrons. Period 1 has only two elements (hydrogen and helium), while periods 2 and 3 have 8 elements. Periods 4 and 5 have 18 elements. Periods 6 and 7 have 32 elements because the two bottom rows that are separated from the rest of the table belong to those periods. They are pulled out in order to make the table itself fit more easily onto a single page.

The properties of elements found in a period, for example the second period, slowly change as elements are examined from the left side (Li) of the periodic table to the right side (Ne). Upon examination of the third period, starting on the left side (Na) to the right side (Ar), very similar change in the properties appears. The periodic table is said to exhibit **periodicity**, a regular repeating of properties.

A **group** is a vertical column of the periodic table, based on the organization of the outer shell electrons. There are a total of 18 groups. There are two different numbering systems that are commonly used to designate groups and you should be familiar with both. The traditional system used in the United States involves the use of the letters A and B. The first two groups are 1A and 2A, while the last six groups are 3A through 8A. The middle groups use B in their titles. Unfortunately, there was a slightly different system in place in Europe. To eliminate confusion, the International Union of Pure and Applied Chemistry (IUPAC) decided that the official system for numbering groups would be a simple 1 through 18 from left to right. Many periodic tables show both systems simultaneously.
Summary

- Dalton proposed his atomic theory in 1804.
- The general tenets of this theory were as follows:
  - All matter is composed of extremely small particles called atoms.
  - Atoms of a given element are identical in size, mass, and other properties. Atoms of different elements differ in size, mass, and other properties.
  - Atoms cannot be subdivided, created, or destroyed.
  - Atoms of different elements can combine in simple whole number ratios to form chemical compounds.
  - In chemical reactions, atoms are combined, separated, or rearranged.
- Johann Dobereiner organized elements in groups called triads.
- John Newland proposed the “Law of Octaves” for organizing the elements.
- Mendeleev published his periodic table in 1869.
- His organization of elements was based on atomic mass.
- Mendeleev's periodic table made it possible to predict properties of elements that had not yet been discovered.
- The periodic table is arranged in order of atomic number.
- A period is a horizontal row of the periodic table.
- A group is a vertical column of the periodic table.

Review

1. Did Dalton believe that atoms could be created or destroyed?
2. List the basic components of Dalton's atomic theory.
3. What parts of the theory are not considered valid anymore?
4. Why did Dobereiner believe that lithium, sodium, and potassium belonged in a triad?
5. When did Mendeleev publish his periodic table?
6. Why was Mendeleev's table considered to be superior?
7. What element was named after Mendeleev?
8. How is today's periodic table different from the one that Mendeleev published?
9. Are all the elements in today's periodic table naturally occurring? Explain your answer.
10. What is a “period”? What does it represent?
11. What is a “group”? What does it represent?
**Answers**

1. Dalton believed that atoms could not be created, destroyed, or subdivided.
2. Dalton's atomic theory stated:
   a. All matter is composed of extremely small particles called atoms.
   b. Atoms of a given element are identical in size, mass, and other properties. Atoms of different elements differ in size, mass, and other properties.
   c. Atoms cannot be subdivided, created, or destroyed.
   d. Atoms of different elements can combine in simple whole number ratios to form chemical compounds.
   e. In chemical reactions, atoms are combined, separated, or rearranged.
3. We know now that (1) an atom can be further subdivided, (2) all atoms of an element are not identical in mass, and (3) using nuclear fission and fusion techniques, we can create or destroy atoms by changing them into other atoms.
4. When the atomic masses of lithium and potassium were averaged together \( \frac{6.94 + 39.10}{2} = 23.02 \), it was approximately equal to the atomic mass of sodium (22.99).
5. Mendeleev published his periodic table in 1869.
6. He predicted elements that would be found in the future. He is also given credit for discovering the periodic law.
7. The element mendeleevium was named after Mendeleev?
8. Mendeleev’s table was based on atomic mass, the modern periodic table is based on atomic number?
9. Not all elements are naturally occurring. Element over # 92 are all manmade.
10. A period is a row across the periodic table. Each period is the beginning of the next energy level that electrons are placed into.
11. Groups or families are columns of elements on the periodic table. It represents elements that exhibit similar properties.