

## Cosmic Chemistry: An Elemental Question

## A Historic Overview: Mendeleev and the Periodic Table

### STUDENT TEXT

#### It's All in the Family

Think about your family today. It may consist of you, one or two adults who are your parents or guardians, and one or more siblings. You may have an extended family including one or more grandparents, aunts, uncles, and cousins. All of you share a family relationship. You may share certain characteristics. Has anyone ever told you that you look, walk, or talk like your mother or father, grandmother or grandfather? You might even have a family member who has an interest in genealogy and who has mapped out your family history, including a chart known as a family tree. If you have seen such a tree, you know that each name represents a person, and that some individuals on the tree are more closely related than others.



Now, think of the periodic table of elements. It too is a chart that shows relationships. Like many families, certain individual elements in this chart share characteristics, some more closely than others. However, all are related.

#### The Triad Model

A German scientist, Johan Dobereiner (1780-1849), tried to classify elements into smaller and simpler subgroups. In 1829, he observed that elements with similar physical and chemical properties fall into groups of three. He called these related groups of three elements **triads**.

One of these triads included chlorine, bromine, and iodine; another consisted of calcium, strontium, and barium. In each of these triads, the atomic weight of the intermediate element is approximately the average of the atomic weights of the other two elements. The density of that element is approximately the average of the densities of the other two elements.

The problem with this arrangement was that Dobereiner's model became outdated as new elements were identified. A good model is able to incorporate newly understood information. Dobereiner's Triad Model was not useful, since several newly discovered elements did not "fit" into it.



#### The Law of Octaves

In 1864, an English chemist, John Newlands, arranged the known elements in increasing order of their atomic weights. He noted that chemically similar elements occurred every eight elements. Lighter sodium was like potassium, and so on through pairs of elements until fluorine and chlorine, the seventh pair. Since potassium followed fluorine (the noble gases had not yet been discovered), Newlands called the repeating pattern the Law of Octaves since the eighth element resembled the first. His Law of Octaves was based on this observation.

However, there were some deficiencies in Newland's proposed arrangement. Several known elements did not "fit" his pattern. Newlands did not allow for the possibility of the discovery of additional elements at a later date. Further, he did not question whether all the atomic masses known to that date were correct. Newlands' Law of Octaves was not a good model for explaining the relationship among the elements.

## Mendeleev

In the mid-1800s, most chemists worldwide were convinced that the elements existed in families that had similar physical and chemical properties. However, there was no widely accepted chart that explained relationships in chemical properties among chemical groups. The periodic table, an information organizing tool that we take for granted today, began as a simple question in the mind of a Russian scientist, Dmitrii I. Mendeleev (1843-1907). What is the relationship of the elements to one another and to the chemical families to which they belong?



Mendeleev's passion for understanding the families of elements took him into previously uncharted territory. He felt that the newly understood atomic mass measurements would have greater significance once scientists clearly understood the relationships among the elements. Mendeleev wrote his ideas into the chemistry textbooks from which he taught. In *Principles of Chemistry*, published in 1869, Mendeleev introduced a concept he called the Periodic Law that stated:

The properties of the elements are a periodic function of their atomic weights.

He subsequently published several versions of a periodic table of the elements, including all elements known at that time. How was Mendeleev able to chart the relationships among the 63 known elements? It all started in a game of cards.

## A Game of Cards

In order to understand the properties of the known elements and their relationships to one another, Mendeleev developed a card game. He wrote out the properties of each element on a different card and spent a great deal of time arranging and rearranging them. He was looking for patterns or trends in the data on the cards. His friends called this game "Patience."

Mendeleev first arranged all the cards from lowest to highest atomic mass. The lightest element known in Mendeleev's time was hydrogen. Its properties were not like any other known element. So Mendeleev decided to leave it out of his game.

Scientists who are initially struggling to understand a large mass of data commonly ignore, at least for a time, those data points that seem too different from the others. These unusual instances are termed **outliers**. Whether or not outliers can eventually be explained by a model often makes or breaks the scientific theory from which the model derives.

The second lightest element known to Mendeleev was lithium.

H

We now know that the second lightest element, between hydrogen and lithium, is helium. But helium was not discovered on earth until 1895.

So Mendeleev started his game with the element lithium.

Li  
Be  
B  
C  
N  
O  
F

In order of increasing atomic mass, Mendeleev thought about the elements beryllium, boron, carbon, nitrogen, oxygen, and fluorine. These elements were all different in their physical and chemical properties, thus seeming to belong to different families. Mendeleev put their cards in a vertical row, with lithium at the top and fluorine at the bottom.

Li	Na
Be	
B	
V	
N	
O	
F	

The known element next most massive after fluorine was sodium. It shared many physical and chemical properties with lithium. They seemed enough alike to be classified as belonging to the same family. Thus Mendeleev put sodium's card as the top of a second column, just to the right of lithium's card.

From there things worked amazingly well. Mendeleev was thinking about the similar properties of the next elements. Magnesium, following sodium, had physical and chemical properties similar to beryllium, which followed lithium. In the same manner, Mendeleev placed aluminum next to boron; silicon next to carbon; phosphorus next to nitrogen; sulfur next to oxygen; and chlorine next to fluorine.

Mendeleev must have felt great pleasure in how this card game was turning out. Repeating patterns are called periodic. Mendeleev eventually called this arrangement the periodic table of the elements.

Li	Na
Be	Mg
B	Al
V	Si
N	P
O	S
F	Cl

Li	Na	K
Be	Mg	Ca
B	Al	
C	Si	
N	P	
O	S	
F	Cl	

## Problems and Predictions

Mendeleev encountered the first problem with his model in the next set of elements. Potassium headed the third column, since its properties were similar to those of sodium and lithium. Calcium was next, and it fit well with magnesium and beryllium.

The next known element was titanium. According to Mendeleev's model, it should have belonged to the same chemical family as boron and aluminum. But titanium's properties were similar to those of silicon.

Li	Na	K
Be	Mg	Ca
B	Al	
C	Si	Ti
N	P	
O	S	
F	Cl	

Mendeleev did not give up. He decided to put titanium in the row with carbon and silicon. He left a gap next to boron and aluminum. He predicted that an unknown element would some day be found with an atomic mass between 40 (for calcium) and 48 (for titanium), whose properties would be similar to those of boron and aluminum.

In fact, in 1878 the element scandium was discovered. Its atomic mass was almost 45, and it had properties as predicted by Mendeleev.

Li	Na	K
Be	Mg	Ca
B	Al	??Ti?
C	Si	
N	P	
O	S	
F	Cl	

Mendeleev continued laying down his cards and felt comfortable identifying two more gaps or “missing” elements in the fourth column, in the third and fourth rows. His genius is shown in his ability to recognize the potential for missing data and to use existing data to predict the properties of these unknown elements. Mendeleev left spaces on his periodic tables because he did not “force” the known elements to fit any preconceived pattern. The absence of elements with certain physical and chemical properties also indicated that not all existing elements had yet been discovered. Mendeleev **interpolated** from what he knew to make predictions about what was missing. These predictions guided the search for other elements.

Mendeleev not only suggested that elements similar to aluminum and silicon should exist. He predicted several properties of “ekasilicon”. “Eka” means “first,” “beyond,” or “after” in Greek.

Mendeleev thought ekasilicon would have a specific gravity of 5.5, and its oxide would have a specific gravity of 4.7. He was right on both counts. These values are close to those eventually found for germanium. Gallium (similar to aluminum) and germanium (similar to silicon) were discovered in 1871 and 1886, respectively.

Prediction of Properties of an Unknown Element		
	Ekasilicon	Germanium
Atomic weight	72	72.32
Specific gravity	5.5	5.47
Color	dark grey	greyish-white
Formula of oxide	EsO <sub>2</sub>	GeO <sub>2</sub>
Specific gravity of oxide	4.7	4.70
Formula of chloride	EsCl <sub>4</sub>	GeCl <sub>4</sub>
Specific gravity of chloride	1.9	1.887
Boiling point of chloride	below 100°C	83°C

Mendeleev focused on the chemical properties of the elements. He concluded that certain commonly accepted values for atomic masses were incorrect. He calculated that the atomic mass of chromium would be greater than the value being used at that time. Although there was a place in the table for chromium between calcium and titanium based on the incorrect value for its atomic weight, the properties of chromium did not fit with this placement.

By 1871, Mendeleev had modified and improved his first periodic table of the elements. He used its organization of information to predict the existence of ten elements (now known as Sc, Ga, Ge, Tc, Re, Po, Fr, Ac, and Pa). He fully described in great detail four of these (Sc, Ga, Ge, and Po). He did this by interpolating information from what was known.

Mendeleev became world famous because of his development of the periodic table of the elements. He traveled throughout Europe, visiting with other famous scientists. However, Mendeleev was a political liberal. Czar Alexander II, who ruled Russia in the late 1800s, did not approve of Mendeleev. Therefore, Mendeleev was never recognized by being elected to the Russian Academy of Sciences. However, Mendeleev was honored posthumously in 1955 when Mendelevium, manmade element number 101 in the modern periodic table, was named for him.

101	258
<b>Md</b>	
Mendelevium	

### Conclusion

The periodic table that hangs in many classrooms and laboratories today has a 130 year history. It is the family tree of the elements. Although Dimitri Mendeleev's periodic table is certainly not the only chart that organizes elements based on their properties, his table was the first to illustrate the periodic relationship between chemical groups. This table is a tool that furthers understanding of the chemistry of the elements. From Mendeleev's Periodic Law and his determination to find some order to the characteristics of the elements, scientists have been able to proceed with their scientific inquiries in a logical and systematic manner.