1. Details of Module and its structure

Module Detail	
Subject Name	Chemistry
Course Name	Chemistry 01 (Class XI, Semester 01)
Module Name/Title	Classification of Elements and Periodicity in Properties: Part 1
Module Id	kech_10301
Pre-requisites	Periodic law, atomic number, electronic configuration & periodic classification
Objectives	After going through this module, the learner will be able to: 1. Learn about the development of periodic table to the long form of periodic table and the periodic law 2. Understand the significance of atomic number and electronic configuration as a basis for classification 3. Name the elements with Z>100 using IUPAC Nomenclature
Keywords	atomic mass, atomic number, Mendeleev's periodic table, electronic configuration, long form of periodic table, IUPAC nomenclature

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1. Introduction: Classification of elements based on their properties:

The Periodic Table is the most important concept in chemistry, both in principle and in practice. It has an everyday application for students to deepen their understanding, it suggests new avenues of research to professionals, and it provides a concise structure to the whole of chemistry. It is a remarkable fact, that the chemical elements are not a random cluster of entities but instead display trends and are grouped together in families. The periodic table helps one understand that the whole world is built up from the fundamental building blocks of chemistry, the chemical elements and that the elements are the basic units of all types of matter.

Imagine the confusion among chemists during the middle of the nineteenth century. By 1860, more than 60 elements had been discovered. Chemists had to learn the properties of these elements as well as those of the many compounds that they formed—a difficult task. And to make matters worse, there was no method for accurately determining an element's atomic mass or the number of atoms of an element in a particular chemical compound. Different chemists used different atomic masses for the same elements, resulting in different compositions being proposed for the same compounds. This made it nearly impossible for one chemist to understand the results of another.

In the year 1860, somewhere in September, a group of scientists in chemistry collected for the First ever International Congress of Chemists in Karlsruhe, Germany, to resolve the issue of atomic mass. They also discussed some other matters that were making communication difficult amongst the scientists working independently in different countries. At this meeting an Italian chemist named Stanislao Cannizzaro presented a definite method for measuring the relative masses of atoms accurately. This method facilitated chemists to agree on standard values for atomic mass and introduced a search for relationships between atomic mass and other properties of the elements.

In 1800, only 31 elements were known and by 1865, the elements identified had more than doubled to 63. And as on date, 118 elements are known. Of them, the recently discovered elements are man-made. Efforts to synthesize new elements are continuing. It was difficult to study individually the chemistry of all these elements and their innumerable compounds. Therefore, the necessity to classify the element arose. Hence, scientists searched for a systematic way to organize their knowledge by classifying the elements into what we today call as the Long form of periodic table. This not only rationalized the known chemical facts about elements, but could also predict new ones for undertaking a further study.

2. Genesis of the Periodic Classification: classification: Newland's Octaves, Dobereiner's Triads & Mendeleev's periodic table

Classification of elements into groups and development of Periodic Law and Periodic Table are the consequences of organizing the knowledge gained by a number of scientists through their observations and experiments. The German chemist, Johann Dobereiner in early 1800's was the first to consider the idea of trends among properties of elements. By 1829 he noted a similarity among the physical and chemical properties of several groups of three elements (Triads). It was noticed that the middle element of each of the Triads had an atomic weight about half way between the atomic weights of the other two and its properties too were in between those of the other two members. Dobereiner's Law of Triads (Table 1), worked only for a few elements; hence it was dismissed as a coincidence.

Table 1 Dobereiner's Triads

Element	Atomic weight	Element	Atomic weight	Element	Atomic weight
Li	7	Ca	40	Cl	35.5
Na	23	Sr	88	Br	80
K	39	Ba	137	I	127

The English chemist, John Alexander Newlands in 1865 founded the Law of Octaves in which the elements were arranged in increasing order of their atomic weights and that every eighth element had properties similar to the first element (Table 2). The relationship was just like every eighth note that resembles the first in octaves of music. Newlands's Law of Octaves seemed to be true only for elements up to calcium. He was awarded Davy Medal in 1887, for his contribution to the classification of elements by the Royal Society, London.

Table 2 Newlands' Octaves

Element	Li	Be	B	C	N	O	F
At. wt.	7	9	11	12	14	16	19
Element	Na	Mg	Al	Si	P	S	Cl
At. wt.	23	24	27	29	31	32	35.5
Element	K	Ca					
At. wt.	39	40					

Dmitri Mendeleev, a Russian chemist was writing a book during the time the chemists met at Karlsruhe. When he heard about the new atomic masses discussed there, he decided to include the new values in the chemistry textbook that he was writing. Mendeleev had thought to organize the elements according to their properties. And he hit upon this thought while writing for a research paper, so he organised the information on classification based on the properties of the elements known then. He made cards for each known element and wrote the atomic mass of the element and also listed its physical and chemical properties on it. He subsequently arranged these cards according to various properties and tried drawing inferences based on observations of certain trends or patterns. He found certain similarities in the chemical properties of elements which seemed to repeat at regular intervals when the elements were arranged in increasing order of their atomic masses. A pattern referred to as periodic is one that repeats over regular intervals. For example, the hands of a clock pass over any given mark at periodic 60- second intervals. Another example is the circular waves created by a drop of water hitting a water surface, are also periodic. Mendeleev generated a table in which the elements with similar chemical and physical properties were assembled together in the form of a periodic table of the elements. The image of Mendeleev's first periodic table is shown below. It was published in 1869.

но въ ней, мнѣ кажется, уже ясно выражается примѣнимость выставляемаго мною начала ко всей совокупности элементовъ, пай которыхъ извѣстенъ съ достовѣрностію. На этотъ разъ я и желалъ преимущественно найдти общую систему элементовъ. Вотъ этотъ опытъ:

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,4
			Fe=56	Ru=104,4	Ir=198.
			Ni—Co=59	Pl=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be=9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,4	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

а потому приходится въ разныхъ рядахъ имѣть различное измѣненіе разностей, чего нѣтъ въ главныхъ числахъ предлагаемой таблицы. Или же придется предполагать при составленіи системы очень много недостающихъ членовъ. То и другое мало выгодно. Мнѣ кажется притомъ, наиболѣе естественнымъ составить

https://web.lemoyne.edu/giunta/EA/MENDELEEVann.HTML

The Periodic Law was developed by Dmitri Mendeleev (1834-1907) and the German chemist, Lothar Meyer (1830-1895) simultaneously. In 1869, both the chemists observed similarities at regular intervals for physical and chemical properties when the elements are arranged in the increasing order of their atomic weights. Lothar Meyer studied the physical properties such as atomic volume, melting point and boiling point against atomic weight and obtained a periodically repeated pattern. Unlike Newlands, Lothar Meyer observed a change in length of that repeating pattern and by 1868, Lothar Meyer had developed a table of the elements that closely resembles the Modern Periodic Table. Although Dobereiner initiated the study of periodic relationship, it was Mendeleev who published the Periodic Law for the first time and got the credit for developing the Modern Periodic Table. The periodic law states that, “The properties of the elements are a periodic function of their atomic weights”. Mendeleev arranged elements in horizontal rows and vertical columns of a table in order of their increasing atomic weights in such a way that the elements with similar properties occupied the same vertical column or group. Mendeleev’s system of classifying elements was more elaborate than that of Lothar Meyer’s. The classification recognized the significance of periodicity and was based on broader range of physical and chemical properties of elements. Mendeleev relied on the similarities in the empirical formulas and properties of the compounds formed by the elements. For elements that did not fit in with the atomic weight scheme of classification, he ignored the order of atomic weights completely, thinking that the atomic measurements might be incorrect, and placed the elements with similar properties together. For example, iodine with lower atomic weight than that of tellurium (Group VI) was placed in Group

VII along with fluorine, chlorine, bromine because of similarities in properties (Fig.1). At the same time, keeping his primary aim of arranging the elements of similar properties in the same group, he proposed that some of the elements were still undiscovered and, therefore, left several gaps in the table. For example, both gallium and germanium were unknown at the time Mendeleev published his Periodic Table. He left the gap under aluminium and a gap under silicon, and called these elements Eka-Aluminium and Eka-Silicon. Mendeleev predicted not only the existence of gallium and germanium, but also described some of their general physical properties. These elements were discovered later. Some of the properties predicted by Mendeleev for these elements and those found experimentally are listed in Table 3. The boldness of Mendeleev's quantitative predictions and their eventual success made him and his Periodic Table famous. Mendeleev's Periodic Table published in 1905 is shown herewith:

Table 3. Mendeleev's Predictions for the Elements Eka-aluminium (Gallium) and Eka-silicon (Germanium)

Property	Eka-aluminium (predicted)	Gallium (found)	Eka-silicon (predicted)	Germanium (found)
Atomic weight	68	70	72	72.6
Density / (g/cm^3)	5.9	5.94	5.5	5.36
Melting point /K	Low	302.93	High	1231
Formula of oxide	E_2O_3	Ga_2O_3	EO_2	GeO_2
Formula of chloride	ECl_3	$GaCl_3$	ECl_4	$GeCl_4$

Though the success of Mendeleev's predictions persuaded most chemists to accept his periodic table and earned him credit as the discoverer of the periodic law. However, two questions remained,

1. Why could most of the elements be arranged in the order of increasing atomic mass, but a few could not?
2. What was the reason for chemical periodicity?

Moseley arranged elements by their atomic numbers.

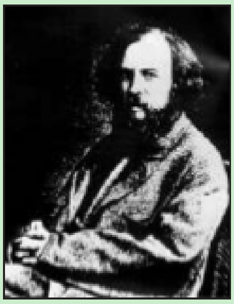
The questions remained unanswered for more than 40 years, much after Mendeleev's first periodic table was published. But in 1911, the discovery of certain unrecognized pattern in the spectral data of 38 metals by an English scientist Henry Moseley along with Ernest Rutherford led to the inference that the elements in the periodic table fit better into these patterns when arranged in increasing order according to nuclear charge or the number of protons in the nucleus. This important discovery led to the modern definition of atomic number and also that the atomic number and not atomic mass, is the basis for the assemblage of the periodic table. This discovery was consistent with Mendeleev's periodic table based on the properties rather than by atomic mass. For example, as per Moseley, tellurium’s (atomic number of 52) correct position is before iodine (atomic number 53). Today, Mendeleev’s principle of chemical periodicity is correctly stated in what is known as the periodic law: **The physical and chemical properties of the elements are periodic functions of their atomic numbers**. In other words, when the elements are arranged in order of increasing atomic number, elements with similar properties appear at regular intervals.

PERIODIC SYSTEM OF THE ELEMENTS IN GROUPS AND SERIES

SERIES	GROUPS OF ELEMENTS								
	0	I	II	III	IV	V	VI	VII	VIII
1	-	Hydrogen H 1.008	-	-					
2	Helium He 4.0	Lithium Li 7.03	Beryllium Be 9.1	Boron B 11.0	Carbon C 12.0	Nitrogen N 14.04	Oxygen O 16.00	Fluorine F 19.0	
3	Neon Ne 19.9	Sodium Na 23.5	Magnesium Mg 24.3	Aluminium Al 27.0	Silicon Si 28.4	Phosphorus P 31.0	Sulphur S 32.06	Chlorine Cl 35.45	
4	Argon Ar 38	Potassium K 39.1	Calcium Ca 40.1	Scandium Sc 44.1	Titanium Ti 48.1	Vanadium V 51.4	Chromium Cr 52.1	Manganese Mn 55.0	Iron Cobalt Nickel Fe Co Ni (Cu) 55.9 59 59
5		Copper Cu 63.6	Zinc Zn 65.4	Gallium Ga 70.0	Germanium Ge 72.3	Arsenic As 75	Selenium Se 79	Bromine Br 79.95	
6	Krypton Kr 81.8	Rubidium Rb 85.4	Strontium Sr 87.6	Yttrium Y 89.0	Zirconium Zr 90.6	Niobium Nb 94.0	Molybdenum Mo 96.0	-	Ruthenium Rhodium Palladium Ru Rh Pd (Ag) 101.7 103.0 106.5
7		Silver Ag 107.9	Cadmium Cd 112.4	Indium In 114.0	Tin Sn 119.0	Antimony Sb 120.0	Tellurium Te 127.6	Iodine I 126.9	
8	Xenon Xe 128	Caesium Cs 132.9	Barium Ba 137.4	Lanthanum La 139	Cerium Ce 140	-	-	-	
9		-	-	-	-	-	-	-	
10	-	-	-	Ytterbium Yb 173	-	Tantalum Ta 183	Tungsten W 184	-	Osmium Iridium Platinum Os Ir Pt (Au) 191 193 194.9
11		Gold Au 197.2	Mercury Hg 200.0	Thallium Tl 204.1	Lead Pb 206.9	Bismuth Bi 208	-	-	
12	-	-	Radium Ra 224	-	Thorium Th 232	-	Uranium U 239		
					HIGHER SALINE OXIDES				
	R	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4
					HIGHER GASEOUS HYDROGEN COMPOUNDS				
					RH_4	RH_3	RH_2	RH	

Interesting Reading:

Dmitri Mendeleev was born in Tobalsk, Siberia in Russia. After his father's death, the family moved to St. Petersburg. He received his Master's degree in Chemistry in 1856 and the doctoral degree in 1865. He taught at the University of St.Petersburg where he was appointed Professor of General Chemistry in 1867. Preliminary work for his great textbook "Principles of Chemistry" led Mendeleev to propose the ***Periodic Law*** *and to construct his* ***Periodic Table*** *of elements. At that time, the structure of atom was unknown and Mendeleev's idea to consider that the properties of the elements were in someway related to their atomic masses was a very imaginative one. To place certain elements into the correct group from the point of view of their chemical properties, Mendeleev reversed the order of some pairs of elements and asserted that their atomic masses were incorrect. Mendeleev also had the foresight to leave gaps in the Periodic Table for elements unknown at that time and predict their properties from the trends that he observed among the properties of related elements. Mendeleev's predictions were proved to be astonishingly correct when these elements were discovered later.*



Dmitri Ivanovich Mendeleev
(1834-1907)

Mendeleev's Periodic Law spurred several areas of research during the subsequent decades. The discovery of the first two noble gases helium and argon in 1890 suggested the possibility that there must be other similar elements to fill an entire family. This idea led Ramsay to his successful search for krypton and xenon. Work on the radioactive decay series for uranium and thorium in the early years of twentieth century was also guided by the Periodic Table.

Mendeleev was a versatile genius. He worked on many problems connected with Russia's natural resources. He invented an accurate barometer. In 1890, he resigned from the Professorship. He was appointed as the Director of the Bureau of Weights and Measures. He continued to carry out important research work in many areas until his death in 1907.

You will notice from the modern Period Table (Fig. 3.2) that Mendeleev's name has been immortalized by naming the element with atomic number 101, as Mendelevium. This name was proposed by American scientist Glenn T. Seaborg, the discoverer of this element, "in recognition of the pioneering role of the great Russian Chemist who was the first to use the periodic system of elements to predict the chemical properties of undiscovered elements, a principle which has been the key to the discovery of nearly all the transuranium elements".

3. Modern Periodic Law and the Long Form of the Periodic Table: Then Mendeleev developed his Periodic Table, chemists knew nothing about the internal structure of atom. However, in the beginning of the 20th century there were many developments in theories about sub-atomic particles. In 1913, the English physicist, Henry Moseley observed particular trends in the characteristic X-ray spectra of the elements. A plot of ν (frequency of X-rays emitted) against atomic number (Z) of elements gave a straight line and not the plot of ν Vs atomic mass. Henry thereby proved that the atomic number (Z) is a more fundamental property of an element than its atomic mass. Mendeleev's Periodic Law was, accordingly modified as: The physical and chemical properties of the elements are periodic functions of their atomic numbers. This was henceforth known as Modern Periodic Law. It revealed important analogies among the 94 naturally occurring elements (neptunium and plutonium like actinium and protactinium are also found in pitch blende – an ore of uranium). It stimulated renewed interest in Inorganic Chemistry and has carried into the present the creation of artificially produced short-lived elements.

The significance of quantum numbers and electronic configuration in periodicity of elements is easy to visualize from the fact that the atomic number is equal to the nuclear charge, number of protons or the number of electrons in a neutral atom. The periodic law is basically the consequence of the periodic variation in electronic configurations, which actually determine the physical and chemical properties of elements and their compounds.

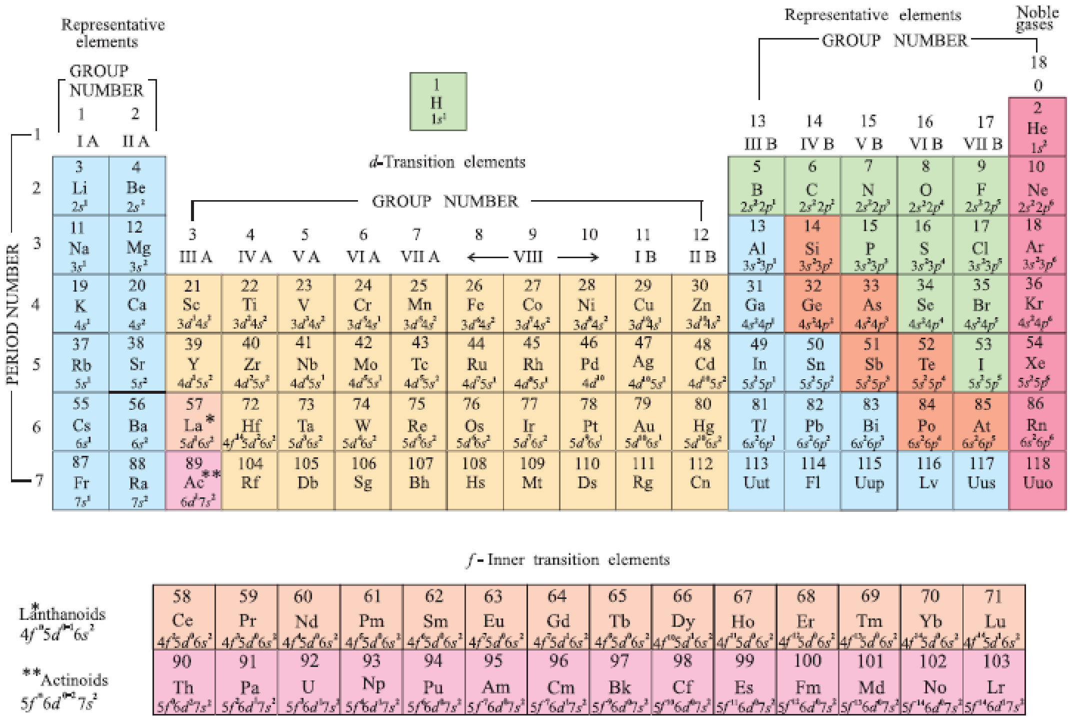


Fig. 2 Long form of the Periodic Table of the Elements with their atomic numbers and ground state outer electronic configurations. The groups are numbered 1-18 in accordance with the 1984 IUPAC recommendations. This notation replaces the old numbering scheme of IA–VIIA, VIII, IB–VIIB and 0 for the elements.

Many forms of Periodic Table were devised from time to time. Some forms are based on chemical reactions and valence, whereas others on the electronic configuration of elements. A modern version called “long form” of the Periodic Table of the elements (Fig.2) is the most convenient and widely used. The horizontal rows (which Mendeleev called series) are called periods and the vertical columns, groups. Elements having similar outer electronic configurations in their atoms are arranged in vertical columns, referred to as groups or families. According to the recommendation of International Union of Pure and Applied Chemistry (IUPAC), the groups are numbered from 1 to 18 replacing the older notation of groups IA … VIIA, VIII, IB … VIIB and 0. There are altogether seven periods. The period number corresponds to the highest principal quantum number (n) of the elements in the period. The first period contains 2 elements. The subsequent periods consists of 8, 8, 18, 18 and 32 elements, respectively. The seventh period is incomplete and like the sixth period would have a theoretical maximum (on the basis of quantum numbers) of 32 elements. In this form of the Periodic Table, 14 elements of both sixth and seventh periods (lanthanides and actinides, respectively) are placed in separate panels at the bottom*.

4. Nomenclature of Elements with Atomic Numbers > 100 The naming of the new elements had traditionally been the privilege of the discoverer (or Discoverer's) and the suggested name was ratified by the IUPAC. The new elements with very high atomic numbers are highly unstable that only minute quantities, sometimes only a few atoms of these are obtained. Their synthesis and characterization, therefore, require costly & highly sophisticated equipment and laboratory. Such work is carried out with competitive spirit only in some laboratories in the world. Scientists, before collecting the reliable data on the new element, at times get tempted to claim for its discovery. For example, both American and Soviet scientists claimed credit for discovering element 104. The Americans named it Rutherfordium whereas the Soviets named it Kurchatovium. To avoid such problems, the IUPAC has made recommendation that until a new element's discovery is proved, and its name is officially recognized, a systematic nomenclature be derived directly from the atomic number of the element using the numerical roots for 0 and numbers 1-9. These are shown in Table 4. The roots are put together in order of digits which make up the atomic number and "ium" is added at the end. The IUPAC names for elements with Z above 100 are shown in Table 5.

Table 5 Nomenclature of Elements with Atomic Number Above 100

Atomic Number	Name according to IUPAC nomenclature	Symbol	IUPAC Official Name	IUPAC Symbol
101	Unnilunium	Unu	Mendelevium	Md
102	Unnilbium	Unb	Nobelium	No
103	Unniltrium	Unt	Lawrencium	Lr
104	Unnilquadium	Unq	Rutherfordium	Rf
105	Unnilpentium	Unp	Dubnium	Db
106	Unnilhexium	Unh	Seaborgium	Sg
107	Unnilseptium	Uns	Bohrium	Bh
108	Unniloctium	Uno	Hassium	Hs
109	Unnilennium	Une	Meitnerium	Mt
110	Ununnillium	Uun	Darmstadtium	Ds
111	Unununnium	Uuu	Rontgenium	Rg
112	Ununbium	Uub	Copernicium	Cn
113	Ununtrium	Uut	Nihonium *	Nh
114	Ununquadium	Uuq	Flerovium	Fl
115	Ununpentium	Uup	Muscovium *	Mc
116	Ununhexium	Uuh	Livermorium	Lv
117	Ununseptium	Uus	Tenessine *	Ts
118	Ununoctium	Uuo	Oganesson *	Og

* Official IUPAC name announced

Table 4 Notation for IUPAC Nomenclature of Elements

Digit	Name	Abbreviation
0	nil	n
1	un	u
2	bi	b
3	tri	t
4	quad	q
5	pent	p
6	hex	h
7	sept	s
8	oct	o
9	enn	e

Thus, the new element first gets a temporary name, with symbol consisting of three letters. Later permanent name and symbol are given by a vote of IUPAC representatives from each country. The permanent name might reflect the country (or state of the country) in which the element was discovered, or pay tribute to a notable scientist. As of now, elements with atomic numbers up to 118 have been discovered. Official names of elements with atomic numbers 113, 115, 117 and 118 have been announced by IUPAC and are added in table 5.

Example 1: What would be the IUPAC name and symbol for the element with atomic number 120?

Solution: From Table 4, the roots for 1, 2 and 0 are un, bi and nil, respectively. Hence, the symbol and the name respectively are Ubn and unbinilium.

Example 2: Deduce the IUPAC name and symbol for the element with atomic number 131.

Solution: The roots for 1, 3 and 1 are un, tri and un respectively. Therefore, the name of the element would be Untriunium and the symbol would be Utu.

Example 3: Why are the new elements with very high atomic numbers not found abundantly?

Solution: The new elements with very high atomic numbers are not found abundantly as these are highly unstable and found only in minute quantities, sometimes only a few atoms of these are obtained.

6. Summary: In this Module, we have discussed the development of the **Periodic Law** and the **Periodic Table.** Mendeleev's **Periodic Table** was based on atomic masses. Modern **Periodic Table** arranges the elements in the order of their atomic numbers in seven horizontal rows **(periods)** and eighteen vertical columns **(groups** or **families).** Atomic numbers in a period are consecutive, whereas in a group they increase in a pattern. Elements of the same group have similar **valence shell** electronic configuration and, therefore, exhibit similar chemical properties. However, the elements of the same period have incrementally increasing number of electrons from left to right, and therefore, have different valencies.