4

Periodic Classification of Elements

You must have visited a library. There are thousands of books in a large library. In spite of this if you ask for a particular book, the library staff can locate it easily. How is it possible? In library the books are classified into various categories and sub-categories. They are arranged on shelves accordingly. Therefore location of books becomes easy.

In the last two lessons you have studied about the structure of atoms and their electronic configurations. You have also studied that elements with similar electronic configurations show similar chemical properties. Electrons are filled in various shells and subshells in a fairly regular fashion. Therefore, properties of elements are repeated periodically. Such trends in their physical and chemical properties were noticed by chemists in the nineteenth century and attempts were made to classify elements on their basis long before structure of atom was known.

In this lesson we shall study about the earlier attempts for classification, the first successful classification which included all the known elements at that time namely Mendeleev's periodic table, and about the long form of modern periodic table which is an improvement over Mendeleev's work. Finally we shall learn about some properties of elements and their variations in the periodic table.

OBJECTIVES

After completing this lesson, you will be able to:

- state different historical classifications of elements in brief;
- state main features of Mendeleev's periodic table;
- explain the defects of Mendeleev's periodic table;
- state modern periodic law;
- describe the features of the long form of periodic table;
- define various periodic properties;
- discuss the trends in various periodic properties in the periodic table.

4.1 EARLIER ATTEMPTS OF CLASSIFICATION OF ELEMENTS

The first classification of elements was as metals and non-metals. This served only limited purpose mainly because of two reasons:

1. All the elements were grouped in to these two classes only. Moreover the group containing metals was very big.

2. Some elements showed properties of both-metals and non-metals and they could not be placed in any of the two classes.

After this, scientists made attempts to recognize some pattern or regularity in variation of properties of elements and to classify them accordingly. Now we shall learn about some of them.

4.1.1 Dobereiner's triads

In 1829, **Dobereiner**, a German scientist made some groups of three elements each and called them **triads**. All three elements of a triad were similar in their properties. He observed that the atomic mass* of the middle element of a triad was nearly equal to the arithmetic mean of atomic masses of other two elements. Also, same was the case with their other properties.

Element	Atomic mass
Lithium, Li	7
Sodium, Na	23
Potassium, K	39

Let us take the example of three elements lithium, sodium and potassium. They form a Dobereiner's triad.

Mean of the atomic masses of the first (Li) and the third (K) elements: $\frac{7+39}{2} = 23\,\text{u}$

The atomic mass of the middle element, sodium, Na is equal to 23 u. Two more examples of Dobereneir's triads are given below.

Element	Atomic mass
Calcium, Ca	40
Strontium, Sr	88
Barium, Ba	137

Element	Atomic mass
Chlorine, Cl	35.5
Bromine, Br	80
Iodine, I	127

Mean of the atomic masses of the first and third elements = $\frac{40+137}{2}$ = 88.5 u

Mean of the first atomic masses of the and third elements = $\frac{35.5+127}{2}$ = 81.5 u

Actual atomic mass of the second element = 88 u

Actual atomic mass of the second element = 80 u

Dobereneir's idea of classification of elements into triads did not receive wide acceptance as he could arrange only a few elements in this manner.

4.1.2 Newland's law of Octaves

In 1864 **John Alexander Newland**, an English chemist noticed that "when elements are arranged in the increasing order of their atomic masses* every eighth element had properties similar to the first element." Newland called it the **Law of Octaves.** It was due to its similarity with musical notes where, in every octave, after seven different notes the eighth note is repetition of the first one as shown below.

1	2	3	4	5	6	7	8
lk	j	xk	e	i	/k	uh	lk

*Then known as atomic weight

Look carefully at the Newland's arrangement of elements shown below:

Li	Be	B	C	N	O	F
(6.9)	(9.0)	(10.8)	(12.0)	(14.0)	(16.0)	(19.0)
Na	Mg	Al	Si	P	S	Cl
(23.0)	(24.3)	(27.0)	(28.1)	(31.0)	(32.1)	(35.5)
K	Ca					
(39.1)	(40.1)					

With the help of the arrangement given above, can you tell starting from lithium which is the eighth element? Sodium. And starting from sodium? It is potassium. Properties of all three are similar. Similarly, aluminnium is the eighth element from boron it shows properties similar to it.

However, **Newland** could arrange elements in this manner only up to calcium out of a total of over sixty elements known at his time. Because of this shortcoming his work was not received well by the scientific community. The next break through in classification of elements came in the form of Mendeleev's work.

4.1.3 MENDELEEV'S PERIODIC LAW AND PERIODIC TABLE

4.3.1a Mendeleev's periodic law

Dmitry Mendeleev** a Russian chemist while trying to classify elements discovered that on arranging in the increasing order of atomic mass*, elements with similar chemical properties occurred periodically. In1869, he stated this observation in the following form which is known as **Mendeleev's Periodic Law**.

A periodic function is the one which repeats itself after a certain interval. Thus, according to the periodic law the chemical and physical properties of elements repeat themselves after certain intervals when they are arranged in the increasing order of their atomic mass. Now we shall learn about the arrangement of elements on the basis of the periodic law.

> The chemical and physical properties of elements are a periodic function of their atomic masses*.

A tabular arrangement of the elements based on the periodic law is called **periodic table**. Mendeleev believed that atomic mass of elements was the most fundamental property and arranged them in its increasing order in horizontal rows till he encountered an element which had properties similar to the first element. He placed this element below the first element and thus started the second row of elements. Proceeding in this manner he could arrange all the known elements according to their properties and thus created the *first periodic table.*

* Then known as atomic weight
** Also spelled as Mendeleef or Mendeleyev

PERIODIC TABLE (*Modified form of Mendleeff's Table*)

PERIODS	Group : I	II	III	IV	V	VI	VII	VII	Zero
Oxide:	R_2O	RO	R_2O_3	R_2O_5	R_2O_5	RO_3	R_2O_7	Ro_4	Noble gases
Hydride:	RH	RH_2	RH_3	RH_4	RH_3	RH_2	RH	Transition Traids	
	A B	A B	A B	A B	A B	A B	A B		
1	H 1 (At. No.) 1.008(At.Wt.)								He 2 4.0026
2	Li 3 6.939	Be 4 9.012	B 5 10.811	C 6 12.011	N7 14.007	O 8 15.999	F 9 18.998		Ne 10 20.183
3	Na 11 22.99	Mg 12 24.312	Al 13 26.981	Si 14 28.086	P 15 30.974	S 16 32.06	Cl 17 35.453		Ar 18 39.948
4 First series	K 19 39.102	Ca 20 40.08	Sc 21 44.96	Ti 22 47.90	V 23 50.94	Cr 24 51.99	Mn 25 54.939	Fe 26 Co 27 Ni 28 55.85 58.93 58.71	
4 second series	Cu 29 63.54	Zn 30 65.37	Ga 31 69.72	Ge 32 72.59	As 33 74.92	Se 34 78.96	Br 35 79.909		Kr 36 83.80
5 First series	Rb 37 85.47	Sr 38 87.62	Y 39 88.905	Zr 40 91.22	Nb 41 92.906	Mo 42 95. 94	Tc 43 (99)	Ru 44 Rh 45 Pd 46 101.07 102.91 106.4	
5 second series	Ag 47 107.87	Cd 48 112.40	In 49 114.82	Sn 50 118.69	Sb 51 121.75	Te 52 127.60	I 53 124.9014		Xe 54 131.30
6 First series	Cs 55 132.90	Ba 56 137.34	*Rare Earths 57-71	Hf 72 178.49	Ta 73 180.948	W 74 183.85	Re 75 186.2	O s 76 Ir 77 Pt 78 190.2 192.2 195.09	
6 second series	Au 79 196.97	Hg 80 200.59	Tl 81 204.37	Pb 82 207.19	Bi 83 208.98	Po 84 (210)	At 85 (210)		Rn 86 (222)
7	Fr 87 (223)	Ra 88 (226)	† Actinide Elements 89-103	Ku 104	Ha 105				

*** Lanthaandie Elements** *(Rare Earth Series)* (La 57 Ce 58 Pr 59 Nd 60 Pm 61 Sm 62 Eu 63 Gd 64 Tb 65 Dy 66 Ho 67 Er 68 Tm 69 Yb 70 Lu 71
(138.91 140.12 140.91 144.24 (147) 150.35 151.96 157.25 158.92 162.50 164.93 167.26 168.93 173.04 174.97

† Actinide Series (Ac 89 Th 90 Pa 91 U 92 Np 93 Pu 94 Am 95 Cm 96 Bk 97 Cf 98 Es 99 Fm 100 Md 101 No 102 Lr 103
((227) 232.04 (231) 238.3 (237) (244) (243) (245) (247) (249) (254) (253) (256) (253) (257)

Fig. 4.1 Mendeleev's periodic table

4.1.3b Main features of Mendeleev's periodic table

Look at the Mendeleev's periodic table shown in fig.4.2 carefully. What do you observe? Here, elements are arranged in tabular form in rows and columns. Now let us learn more about these rows and columns and the elements present in them.

1. The horizontal rows present in the periodic table are called **periods**. You can see that there are seven periods in the periodic table. These are numbered from 1 to 7 (Arabic numerals).
2. Properties of elements in a particular period show regular gradation (i.e. increase or decrease) from left to right.
3. The vertical columns present in it are called **groups**. You must have noticed that these are nine in number and are numbered from I to VIII and Zero (Roman numerals).
4. Groups I to VII are subdivided into A and B subgroups. Groups Zero and VIII don't have any subgroups.
5. All the elements in a particular group are chemically similar in nature. They show regular gradation in their physical properties and chemical reactivities.

After learning about the main features we shall now learn about the main merits of Mendeleev's periodic table.

4.1.3c Merits of Mendeleev's periodic classification

1. **Classification of all elements**

   Mendeleev's was the first classification which successfully included all the elements.

2. **Prediction of new elements**

Mendeleev's periodic table had some blank spaces in it. These vacant spaces were for elements that were yet to be discovered. For example, he proposed the existence of an unknown element that he called *eka-aluminium*. The element *gallium* was discovered four years later and its properties matched very closely with the predicted properties of *eka-aluminium*.

In this section we have learnt about the success of Mendeleev's periodic classification and also about its merits. Does it mean that this periodic table was perfect? No. Although it was a very successful attempt but it also had some defects in it. Now we shall discuss the defects in this classification.

4.3.1d Defects in Mendeleev's periodic classification

In spite of being a historic achievement Mendeleev's periodic table had some defects in it. The following were the main defects in it:

1. **Position of hydrogen**
   Hydrogen resembles alkali metals (forms H^+ ion just like Na^+ ions) as well as halogens (forms H^- ion similar to Cl^- ion).Therefore, it could neither be placed with alkali metals (group I) nor with halogens (group VII).
2. **Position of isotopes**
   Different isotopes of same elements have different atomic masses, therefore, each one of them should be given a different position in the periodic table. On the other hand, because they are chemically similar, they had to be given same position.
3. **Anomalous pairs of elements**
   At certain places, an element of higher atomic mass has been placed before an element of lower atomic mass. For example, Argon (39.91) is placed before potassium (39.1)

CHECK YOUR PROGRESS 4.1

1. Elements A, B and C constitute a Dobereiner's triad. What is the relationship in their atomic masses?
2. How many elements were included in the arrangement given by Newland?
3. Which property of atoms was used by Mendeleev to classify the elements?
4. How many groups were originally proposed by Mendeleev in his periodic table?
5. Where in the periodic table are chemically similar elements placed, in a group or in a period?
6. Mendeleev's periodic table had some blank spaces in it. What do they signify?
7. What name was given to the element whose properties were similar to the element *eka-aluminium* predicted by Mendeleev?

4.2 MODERN CLASSIFICATION

Henry Moseley, an English physicist discovered in the year 1913 that *atomic number*, is the most fundamental property of an element and not its atomic mass. **Atomic number, (*Z*), of an element is the number of protons in the nucleus of its atom.** The number of electrons in the neutral atom is also equal to its atomic number. This discovery changed the whole perspective about elements and their properties to such an extent that a need was felt to change the periodic law also. Now we shall learn about the changes made in the periodic law.

4.2.1 Modern periodic law

After discovery of atomic number the periodic law was modified and the new law was based upon atomic numbers in place of atomic masses of elements.

The Modern Periodic Law states "The chemical and physical properties of elements are a periodic function of their atomic numbers"

After the change in the periodic law many changes were suggested in the periodic table. Now we shall learn about the modern periodic table which finally emerged.

4.2.2 Modern periodic table

The periodic table based on the modern periodic law is called the **Modern Periodic Table**. Many versions of this periodic table are in use but the one which is most commonly used is the **Long Form of Modern Periodic Table.** It is shown in figure 4.3.

1 H																															2 He
3 Li	4 Be																									5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg																									13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc															22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y															40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	72 Hf	73 Ta	74 Ru	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	104 Unq	105 Unp	106 Unh												

Fig. 4.3 Modern periodic table

If you look at the modern periodic table shown in the fig.4.3 you will observe that it is not much different from Mendeleev's periodic table. Now let us learn the main features of this periodic table.

4.2.2a Groups

There are 18 vertical columns in the periodic table. Each column is called a **group**. The groups have been numbered from 1 to 18 (in Arabic numerals) from left to right. Group 1 on extreme left position contains alkali metals (Li, Na, K, Rb, Cs and Fr) and group 18 on extreme right side position contains noble gases (He, Ne, Ar, Kr, Xe and Rn).

All elements present in a group have similar electronic configurations and have same number of valence electrons. You can see in case of group 1 (alkali metals) and group 17 elements (halogens) that as one moves down a group, more and more shells are added.

Group 1		**Group 17**	
Element	**Electronic configuration**	**Element**	**Electronic configuration**
Li	2,1	F	2,7
Na	2,8,1	Cl	2,8,7
K	2,8,8,1	Br	2,8,8,7
Rb	2,8,8,8,1	I	2,8,18,8,7

All elements of group 1 have only one valence electron. Li has electrons in two shells, Na in three, K in four while Rb has electrons in five shells. Similarly all the elements of group 17 have seven valence electrons however the number of shells is increasing from two in F to five in I.

- Elements present in groups 1 and 2 on left side and groups 13 to 17 on the right side of the periodic table are called **normal elements** or **representative elements**. Their outermost shells are incomplete. They are also called typical or main group elements

- Elements present in groups 3 to 12 in the middle of the periodic table are called **transition elements**. (Although groups 11 and 12 elements are, strictly speaking, not transition elements). Their two outermost shells are incomplete.

  However, it should be noted here that more and more electrons are added to valence shell only in case of normal elements. In transitions elements, the electrons are added to incomplete inner shells.

  Elements 113, 115 and 117 are not known but included at their expected positions.
- Group 18 on extreme right side of the periodic table contains **noble gases**. Their outermost shells contain 8 electrons.
- **Inner transition elements:**14 elements with atomic numbers 58 to 71 (Ce to Lu) are called **lanthanides**# and they are placed along with the element lanthanum (La), atomic number 57 in the same position (group 3 in period 6) because of very close resemblance between them. However, for convenience sake they are shown separately below the main periodic table
- 14 elements with atomic numbers 90 to103 (Th to Lr) are called **actinides*** and they are placed along with the element actinium (Ac), atomic number 89 in the same position (group 3 in period 7) because of very close resemblance between them. They are shown also separately below the main periodic table along with lanthanides.

4.2.2b Periods

There are seven rows in the periodic table. Each row is called a **period**. The periods have been numbered from 1 to 7 (Arabic numerals).

In each period a new shell starts filling up. The period number is also the number of shell which starts filling up in it. For example, in elements of 3rd period, the third shell (*M* shell) starts filling up as we move from left to right@ . The first element of this period sodium Na (2,8,1) has only one electron in its valence shell (third shell) while the last element of this period, argon Ar (2,8,8) has eight electrons in its valence shell. The gradual filing of the third shell can be seen below.

Element	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
Electronic configuration	2,8,1	2,8,2	2,8,3	2,8,4	2,8,5	2,8,6	2,8,7	2,8,8

- The first period is the **shortest period** of all and contains only 2 elements, H and He.
- The second and third periods are called **short periods** and contain 8 elements each.
- Fourth and fifth periods are **long periods** and contain 18 elements each.
- Sixth and seventh periods are **very long periods** containing 32 elements* * each.

@ However, it should be noted here that more and more electrons are added to valence shell only in case of normal elements. In transitions elements, the electrons are added to incomplete inner shells.

These elements have been named after the 1st elements lanthanum present in their position in the periodic table.

* These elements have been named after the 1st elements actinium present in their position in the periodic table.

** Including elements up to atomic number 118. Elements 114, 116 and 118 have been reported only recently.

4.2.2c Merits of modern periodic table over Mendeleev's periodic table

The modern periodic table is based on atomic number which is more fundamental property of an atom than atomic mass. The long form of modern periodic table is therefore free of main defects of Mendeleev's periodic table.

1. Position of isotopes

All isotopes of the same elements have different atomic masses but same atomic number. Therefore, they occupy the same position in the modern periodic table which they should have because all of them are chemically similar.

2. Anomalous pairs of elements

When elements are arranged in the periodic table according to their atomic numbers the anomaly regarding certain pairs of elements in Mendeleev's periodic table disappears. For example, atomic numbers of argon and potassium are 18 and 19 respectively. Therefore, argon with smaller atomic number comes before potassium although its atomic mass is greater and properties of both the elements match with other elements of their respective groups.

CHECK YOUR PROGRESS 4.2

1. According to the modern periodic law the properties of elements are periodic function of which property of theirs?
2. List any two defects of Mendeleev's periodic table which have been corrected in the modern periodic table?
3. How many group and periods are present in the long form of periodic table?
4. What is the name of the family of elements present in group 2 of the modern periodic table?
5. The elements that are present in the right hand portion of the periodic table are metals or non-metals?
6. How many elements are present in 6^{th} period of the periodic table?

4.3 PERIODIC PROPERTIES

In the previous section we have learnt about the main features of the Modern Periodic Table. We have also learnt that in a period the number of valence electrons and the nuclear charge increases from left to right. It increases the force of attraction between them. In a group the number of filled shells increases and valence electrons are present in higher shells. This decreases the force of attraction between them and the nucleus of the atom. These changes affect various properties of elements and they show gradual variation in a group and in a period and they repeat themselves after a certain interval of atomic number. Such properties are called **periodic properties**. In this section we shall learn about some periodic properties and their variation in the periodic table.

4.3.1 VALENCY

(a) Valency in a period : You have already learnt in the previous section that the number of valence electrons increases in a period. In *normal elements* it increases from 1 to 8 in a period from left to right. It reaches 8 in group 18 elements (noble gases) which show practically no chemical activity under ordinary conditions and their valency is taken as zero. Carefully look at the table given below. What do you observe? *Valency of normal elements with respect oxygen increases from 1 to 7* as shown below for elements of third period. This valency is equal to the *number of valence electrons* or *group number* for groups 1 and 2, or (*group number-10*) for groups 13 to 17.

Group	1	2	13	14	15	16	17
Element	Na	Mg	Al	Si	P	S	Cl
No. of valence electrons	1	2	3	4	5	6	7
Valency with respect to oxygen	1	2	3	4	5	6	7
Formula of oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3	Cl_2O_7

In the following table for elements of second period you will observe that *valency of elements of with respect to hydrogen and chlorine increases from 1 to 4 and then decreases to 1 again.*

Group	1	2	13	14	15	16	17
Element	Li	Be	B	C	N	O	F
No. of valence electrons	1	2	3	4	5	6	7
Valency with respect to hydrogen and chlorine	1	2	3	4	3	2	1
Formula of hydride	LiH	BeH_2	BH_3	CH_4	NH_3	H_2O	HF
Formula of chloride	$LiCl$	$BeCl_2$	BCl_3	CCl_4	NCl_3	Cl_2O	ClF

(b) Valency in a group : *All the elements of a group have the same number of valence electrons. Therefore, they all have the same valency*. Thus valency of all group 1 elements, *alkali metals*, is 1. Similarly valency of all group 17 elements, *halogens*, is 1 with respect to hydrogen and 7 with respect to oxygen.

4.3.2 Atomic radii

A number of physical properties like density and melting and boiling points are related to the sizes of atoms. Atomic size is difficult to define. **Atomic radius** determines the size of an atom. For an isolated atom it may be taken as the distance between the centre of atom and the outermost shell. Practically, measurement of size of an isolated atom is difficult; therefore, it is measured when an atom is in company of another atom of same element. It is defined *as one-half the distance between the nuclei of two atoms when they are linked to each other by a single covalent bond.*

4.3.2a Variation of atomic radii in a period

Atomic radii (in picometer) of 2nd and 3rd period elements are given in the table given below. What do you observe? *In a period, atomic radius generally decreases from left to right.*

2nd Period	Li	Be	B	C	N	O	F
	155	112	98	91	92	73	72
3rd Period	Na	Mg	Al	Si	P	S	Cl
	190	160	143	132	128	127	99

Can you explain this trend? You have learnt in the beginning of this section that in a period there is a gradual increase in the nuclear charge. Since valence electrons are added in the same shell, they are more and more strongly attracted towards nucleus. This gradually decreases atomic radii.

4.3.2b Variation of atomic radii in a group

What happens to atomic radii in a group? *Atomic radii increase in a group from top to bottom*. This can be seen from the data of atomic radii in picometers given for groups 1 and 17 elements below.

Element	Atomic radius	Element	Atomic radius
Li	155	F	72
Na	190	Cl	99
K	235	Br	114
Rb	248	I	133

As we go down a group the number of shells increases and valence electrons are present in higher shell and the distance of valence electrons from nucleus increases. For example, in lithium the valence electron is present in 2nd shell while in sodium it is present in 3rd shell. Also, the number of filled shells between valence electrons and nucleus increases. Thus in group 1 Li (2,1) has one filled shell between its nucleus and valence electron while Na (2,8,1) has two filled shells between them. Both the factors decrease the force of attraction between nucleus and valence electron. Therefore, atomic size increases on moving down a group.

4.3.3 Ionic radii

Ionic radius *is the radius of an ion.* On converting into an ion the size of a neutral atom changes. Anion is bigger than the neutral atom. This is because addition of one or more electrons increases repulsions among electrons and they move away from each other. On the other hand a cation is smaller than the neutral atom. When one or more electrons are removed, the repulsive force between the remaining electrons decreases and they come a little closer.

4.3.3a Variation of ionic radii in periods and groups

Ionic radii show variations similar to those of atomic radii. Thus, *ionic radii increase in a group*. You can see such increases in groups 1 and 16 elements from the data given below.

Group 1		Group 16	
Element	**Electron radius**	**Element**	**Ionic radius**
Li^+	60	O^{2-}	140
Na^+	95	S^{2-}	184
K^+	133	Se^{2-}	198
Rb^+	148	Te^{2-}	221

Ionic radii decrease in a period . It can be seen from the data of ionic radii in picometer for 2nd period elements given below.

Element	Li^+	Be^{2+}	B	C	N^{3-}	O^{2-}	F^-
Ionic radii	60	31	-	-	171	140	136

In the data given above, the positions of boron and carbon have been left vacant as they do not form ions. Also, the trend in radii of cations is seen in Li^{+} and $Be^{2+}$and in radii of anions is seen in N^{3-}, O^{2-} and F^{-}.

4.3.4 Ionization energy

Negatively charged electrons in an atom are attracted by the positively charged nucleus. For removing an electron this attractive force must be overcome by spending some energy. *The minimum amount of energy required to remove an electron from a gaseous atom in its ground state to form a gaseous ion is called* **ionization energy**. It is measured in unit of kJ mol^{-1}. It is a measure of the force of attraction between the nucleus and the outermost electron. Stronger the force of attraction, greater is the value of ionization energy. It corresponds to the following process:

If only one electron is removed, the ionization energy is known as the **first ionization energy**. If second electron is removed the ionization energy is called the **second ionization energy**. Now we shall study the variation of ionization energy in the periodic table.

4.3.3a Variation of ionization energy in a group

We have already seen earlier, that the force of attraction between valence electrons and nucleus decreases in a group from top to bottom. What should happen to their ionization energy values? *Ionization energy decreases in a group from top to bottom*. This can be seen from ionization energy values (in kJ mol^{-1}) of groups 1 and 17 elements given below.

Group 1		**Group 17**	
Element	**Ionization Energy**	**Element**	**Ionization Energy**
Li	520	F	1680
Na	496	Cl	1251
K	419	Br	1143
Rb	403	I^{-}	1009

4.3.4b Variation of ionization energy in a period

We know that the force of attraction between valence electron and nucleus increases in a period from left to right. As a consequence of this, *the ionization energy increases in a period from left to right.* This trend is can be seen in ionization energies (in kJ mol^{-1}) of elements belonging to 2nd and 3rd periods.

2nd Period Elements

Element	Li	Be	B	C	N	O	F	Ne
Ionization Energy	520	899	801	1086	1400	1314	1680	2080

3rd Period Elements

Element	Na	Mg	Al	Si	P	S	Cl	Ar
Ionization Energy	496	738	578	786	1021	1000	1251	1521

4.3.5 Electron affinity

Another important property that determines the chemical properties of an element is the tendency to gain an additional electron. This ability is measured by **electron affinity**. *It is* *the energy change when an electron is accepted by an atom in the gaseous state.* It corresponds to the process

$$X(g) + e^{-} \rightarrow X^{-}(g) + E$$

Here, X is an atom of an element. The energy change is measured in the unit kJ mol^{-1}. *By convention*, electron affinity is assigned a positive value when energy is released during the process. Greater the value of electron affinity, more energy is released during the process and greater is the tendency of the atom to gain electron. Let us now learn about its variation in the periodic table.

4.3.5a Variation of electron affinity in a group

In a group, the electron affinity decreases on moving from top to bottom, that is, less and less amount of energy is released. Such trends in its values (in kJ mol^{-1}) for group 1 and group 17 elements are given below.

Group 1		Group 17	
Element	**Electron affinity**	**Element**	**Electron affinity**
Li	58	F	333
Na	53	Cl	348
K	48	Br	324
Rb	45	I^{-}	295

4.3.5b Variation of electron affinity in a period

In a period, the electron affinity increases from left to right, that is, more and more amount of energy is released. You can see this increase in electron affinity values (in kJ mol^{-1}) below for elements of 2nd and 3rd periods.

2nd Period elements							
Element	Li	Be	B	C	N	O	F
Electron affinity	58	-	23	123	0	142	333

3rd Period elements							
Element	Na	Mg	Al	Si	P	S	Cl
Electron affinity	53	-	44	120	74	200	348

4.3.6 Electronegativity

You have learnt in the previous section that electron affinity of an element is a measure of an *isolated atom* to attract electrons towards it self. We normally do not deal with isolated atoms. Mostly we come across atoms which are bonded to other atoms. There is another property which deals with the power of *bonded atoms* to attract electrons. This property is known as *electronegativity*. **Electronegativity** *is relative tendency of a bonded atom to attract the bond-electrons towards itself*. Electronegativity is a dimensionless quantity and does not have any units. It just compares the tendency of various elements to attract the bond-electrons towards themselves. The most widely used scale of electronegativity was devised by Linus Pauling. Electronegativity is a useful property. You will learn in the next chapter how it helps to understand the nature of chemical bond formed between two atoms. Now let us learn about its variation in groups 1 and 17.

Group 1		Group 17	
Element	**Electronegativity**	**Element**	**Electronegativity**
Li	1.0	F	4.0
Na	0.9	Cl	3.0
K	0.8	Br	2.8
Rb	0.8	I^-	2.5

What do you observe? Electronegativity decreases in a group from top to bottom.

Now let us see its variation in 2nd and 3rd period elements.

2nd Period Elements

Element	Li	Be	B	C	N	O	F
Electronegativity	1.0	1.5	2.0	2.5	3.0	3.5	4.0

3rd Period Elements

Element	Na	Mg	Al	Si	P	S	Cl
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0

Now what do you observe? Electronegativity increases in a period from left to right.

4.3.7 Metallic and non-metallic character

You know what are characteristic properties of a metal? They are its electropositive character (the tendency to lose electrons), metallic luster, ductility, malleability and electrical conductance. Metallic character of an element largely depends upon its ionization energy. Smaller the value of ionization energy, more electropositive and hence more metallic the element would be.

4.3.7a Variation of metallic character in a group

You know the variation of ionization energy in a group. Can you predict the variation of metallic character on its basis? *Metallic character of elements increases from top to bottom*. This can best be seen in elements of group 14. Its first element, carbon is a typical non-metal, next two elements Si and Ge are metalloids and the remaining elements Sn and Pb, are typical metals as shown below.

Group 14

Element	**Nature**
C	Non-metal
Si	Metalloid
Ge	Metalloid
Sn	Metal
Pb	Metal

4.3.7b Variation of metallic character in a period

How does metallic character change in a period? *Metallic character of elements decreases in a period from left to right* as shown below for 3rd period elements

Element	Na	Mg	Al	Si	P	S	Cl
Character	Metal	Metal	Metal	Metalloid	Non-metal	Non-metal	Non-metal

CHECK YOUR PROGRESS 4.3

Fill in the blanks with appropriate words.

1. The force of attraction between nucleus and valence electrons _______________ in a period.
2. Atomic radii of elements _______________ in a period from left to right.
3. Radius of cation is _______________ than that of the neutral atom of the same element
4. Electronegativity _______________ in a period from left to right and _______________ in a group from top to bottom.
5. Metallic character of elements _______________ from top to bottom in a group.
6. Ionization energy of the 1^{st} element in a period is _______________ in the entire period.

LET US REVISE

- The first classification of elements was s metals and non-metals. It served only limited purpose.
- After atomic masses (old term, atomic weight) of elements had been determined, it was thought to be their most fundamental property and attempts were made to correlate it to their other properties.
- Dobereiner grouped elements into triads. The atomic mass and properties of the middle element were mean of the other two. He could group only a few elements into triads. For example (i) Li, Na and K (ii) Ca, Sr and Ba (iii) Cl, Br and I.
- Newland tried to see the periodicity of properties and stated his law of octaves that, "When elements are arranged in the increasing order of their atomic weights every eighth element has properties similar to the first". He could arrange elements up to calcium only out of more than sixty elements known then.
- Mendeleev observed correlation between atomic masses and other properties and stated his periodic law as, "The chemical and physical properties of elements are a periodic function of their atomic weights".
- Mendeleev gave the first periodic table which is named after him which included all the known elements. It consists of seven horizontal rows called **periods** and numbered from 1 to 7. It has nine vertical columns called **groups** and numbered from zero to VIII.
- Main achievements of Mendeleev's periodic table were (i) inclusion of all the known elements and (ii) prediction of new elements.
- Main defects of Mendeleev's periodic table were (i) position of isotopes, (ii) anomalous pairs of elements like Ar and K and (iii) grouping of dissimilar elements and separation of similar elements.
- Moseley discovered that atomic number and not atomic mass is the most fundamental property of elements. In the light of this the periodic law was modified to " The chemical and physical properties of elements are a periodic function of their atomic numbers". This is the modern periodic table.
- Modern periodic table is based upon atomic number. Its long form has been accepted by IUPAC. It has seven periods (1 to 7) and 18 groups (1 to 18). It is free of main

defects of Mendeleev's periodic table. Elements belonging to same group have same number of valence electrons and thus show same valency and similar chemical properties.

- Arrangement of elements in the periodic table shows periodicity. Atomic and ionic radii and metallic character increase while ionization energy , electron affinity and electronegativity decrease in a group from top to bottom.
- Number of valence electrons, ionization energy, electron affinity and electronegativity increase while metallic character and atomic and ionic radii decrease in a period from left to right.

TERMINAL EXERCISES

A. Multiple choice type questions.

1 The first attempt to classify elements was made by
   (a) Mendeleev
   (b) Moseley
   (c) Newland
   (d) Dobereiner

2. Which group has maximum number of elements in the periodic table?
   (a) 1
   (b) 2
   (c) 3
   (d) 4

3. The law of octaves applies to
   (a) B,C,N
   (b) As, K, Ca
   (c) Be, Mg, Ca
   (d) Se, Te, As

4. Representative elements belong to groups
   (a) 1, 2, 3,4, 5, 6, 7 and 8
   (b) 1 and 2
   (c) 1, 2, 13, 14, 15, 16, 17 and 18
   (d) 1, 2, 13, 14, 15, 16 and 17

5. Which of the following ions is the largest in size?
   (a) Al^{3+}
   (b) Ba^{2+}
   (c) Mg^{2+}
   (d) Na^{+}

B. Mark the following statements as *true* or *false*.

1. Ionization energy of an element increases with an increase in atomic number.
2. Electron Affinity of fluorine is greater than that of chlorine.
3. Out of P^{3+}, S^{2-} and Cl^{-} ions Cl^{-} ion is the smallest one.

4. The first member of lanthanide series of elements is lanthanum.

C. Descriptive type questions.

1. Name the group and period of element having the atomic number 21.
2. Give an example of Dobereiner triad.
3. State Newland's law of Octaves.
4. State the Modern Periodic Law.
5. How many groups were present in Mendeleev's Periodic Table and give their numbers.
6. What are *periods* and *groups* in periodic table.
7. List two main achievements of Mendeleev's periodic table.
8. What are main defects of Mendeleev's periodic table?
9. How is modern periodic law different from the Mendeleev's periodic law?
10. Why argon (atomic mass 40) was placed before potassium (atomic mass 39)?
11. In each of the following pairs of ions, which one is bigger in size and why?
    (i) Li and Ne
    (ii) O and S
    (iii) K and K^+
    (iv) Br and Br^-
12. Define atomic radius. How does it vary in a period and in a group?
13. What is ionization energy? How does it vary in a group? Give two reasons for it.
14. Which element of the following has the highest ionization energy?
    Na, Ba and Cl
15. Explain why does ionization energy increase from left to right in a period but decrease from top to bottom in a group?
16. What do you understand by 'periodicity' of properties? Explain taking metallic character of elements as an example.
17. Potassium is more reactive than sodium. Explain with the help of ionization energy.
18. An element has atomic mass 32 and its nucleus has 16 neutrons. To which group of periodic table does it belong? Explain.
19. The following is a portion of periodic table. Look at it and answer the following questions.

1	2	3-15	16	17	18
H					He
			C	D	
A					
				E	
B					

(i) Out of A and B which one has lower ionization energy ?
(ii) Which is bigger atom C or D?
(iii) Which is the most electropositive element of all?
(iv) Which is more metallic in nature D or E?

(v) Which is more non-metallic in nature C or D?

(vi) Which is the least electronegative element of all?

ANSWERS TO CHECK YOUR PROGRESS

4.1

1. Atomic mass of the middle element B must be nearly equal to the average of the other two elements A and C.

   Or

   $$\text{Atomic mass of B} = \frac{\text{Atomic mass of A} + \text{Atomic mass of B}}{2}$$
2. 16
3. Atomic weight
4. 8
5. Group
6. These were the positions of elements which were yet to be discovered.
7. Gallium

4.2

1. Atomic number
2. Any *two* of the following:
   i. Position of isotopes
   ii. Anomalous pairs of elements
   iii. Grouping of dissimilar elements
   iv. Separation of similar element.
3. Seven periods and eighteen groups
4. Alkaline earths
5. Non-metals
6. 32

4.3

1. increases
2. decreases
3. smaller
4. increases, decreases
5. increases
6. minimum

GLOSSARY

Actinides: A group of 14 elements with atomic numbers 90-103 (Th–Lr) which are placed along with the element actinium (Ac), atomic number 89 in the some position in group 3 in the periodic table.

Atomic number: It is the number of protons in the nucleus of the atom of an element**.**

Atomic radius: It is defined as one-half the distance between the nuclei of two atoms when they are linked to each other by a single covalent bond.

Dobereiner's triad: A group of three chemically similar elements in which the atomic mass and properties of the middle element are mean of the other two.

Electron affinity: It is the energy change when an electron is accepted by an atom in an isolated gaseous state. By convention, it is assigned a positive value when energy is released during the process.

Electronegativity: It is a measure of the tendency of a bonded atom to attract the bond-electrons towards itself**.**

Groups: The vertical columns present in periodic table.

Ionic radius: It is the radius of an ion i.e. the distance between the centre of ion and its outermost shell.

Ionization energy: It is the minimum amount of energy required to remove an electron from an isolated gaseous atom in its ground state to form a gaseous ion.

Lanthanides: A group of 14 elements with atomic numbers 58 to 71 (Ce to Lu) which are placed along with the element lanthanum (La), atomic number 57 in the some position in group 3 in the periodic table

Mendeleev's periodic law: The chemical and physical properties of elements are a periodic function of their atomic masses.

Modern periodic law : The chemical and physical properties of elements are a periodic function of their atomic numbers.

Newland's law of octaves: When elements are arranged in the increasing order of their atomic weights every eighth element has properties similar to the first.

Noble gases: The elements present in group 18 on extreme right side of the periodic table. Their outermost shells contain 8 electrons.

Normal elements: These are the elements present in groups 1 and 2 on left side and groups 13 to 17 on the right side of the periodic table whose only outermost shells are incomplete.

Periodic properties: These are the properties which repeat themselves after a certain interval of atomic number.

Periodic table: A tabular arrangement of the elements based on the periodic law.

Periods: The horizontal rows present in the periodic table.

Transition elements: These are the elements present in groups 3 to 12 in the middle of the periodic table whose two outermost shells are incomplete.