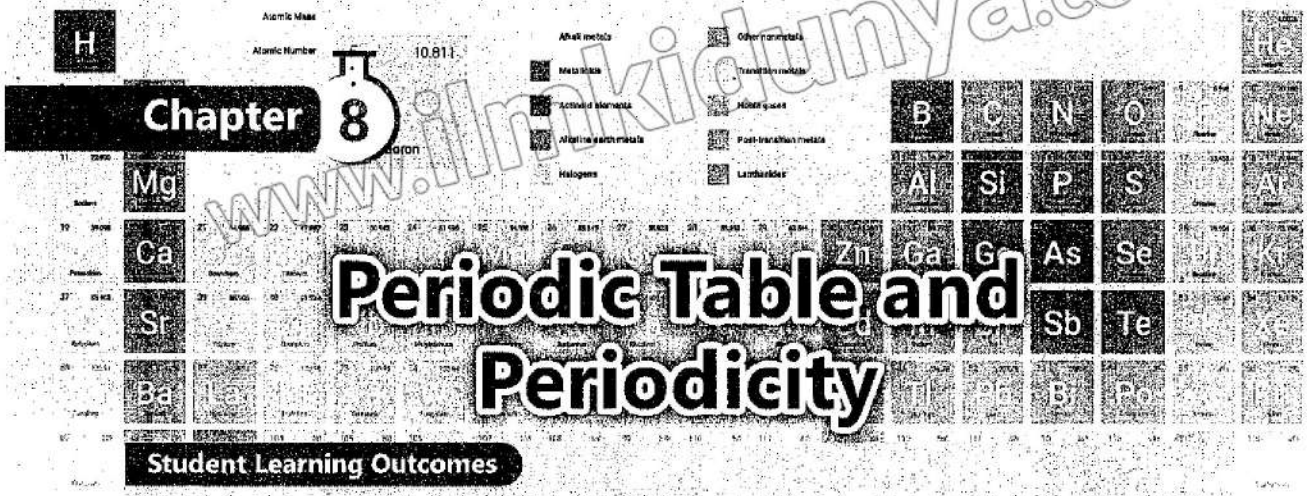


Chapter 8

Periodic Table and Periodicity

Student Learning Outcomes

After studying this chapter, students will be able to:

- Define the periodic table as an arrangement of elements in periods and groups, in order of increasing proton number/atomic number
- Identify the group or period or block of an element using its electronic configuration (only the idea of subshells related to the blocks can be introduced)
- Explain the relationship between group number and the charge of ions formed from elements in the group in terms of their outermost shells
- Explain similarities in the chemical properties of elements in the same group in terms of their electronic configuration
- Identify trends in group and periods, given information about the elements, including trends for atomic radius, electron affinity, electronegativity, ionization energy, metallic character, reactivity and density
- Use terms alkali metals, alkaline earth metals, halogens, noble gases, transition metals, lanthanides and actinides in reference to the periodic table
- Predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity
- Deduce the nature, possible position in the Periodic Table and the identity of unknown elements from given information about their physical and chemical properties

8.1 Modern Periodic Table

The modern periodic table is based upon the arrangement of elements according to increasing atomic number. When the elements are arranged according to ascending order of their atomic numbers from left to right in a horizontal row, properties of elements are found repeating after regular intervals. This results in the form of a table in which elements of similar properties are placed in the same vertical columns.

The horizontal rows of elements in the periodic table are called periods while the vertical columns are called groups.

In the modern periodic table, the electronic configuration of the elements continues changing when we move from left to right in a period. Due to this, the elements in a period show a gradual change in the properties. Against this, elements present in a group possess similar electronic configurations in their outermost shells. Therefore, the elements in a group show similar chemical properties. As a whole the periodic table shows the repetition of the properties of elements after regular intervals. The study of properties in a sequence is called periodicity in the properties of elements.

8.2 Salient Features of Modern Periodic Table

Periods

The horizontal rows in the modern periodic table are called periods. There are seven periods in total. Each period except the first starts with an alkali metal and ends at a noble gas. Each period also represents the completion of a shell. Since the number of electrons to be accommodated in a particular shell is fixed, the number of elements in a period is also fixed. The detail about the periods is given in Table (8.1).

Table (8.1) Periods in the Periodic Table

Period No.	Name of the Period	Number of Elements	Number of Shell being filled
1st	Short	2	1st
2nd	Normal	8	2nd
3rd	Normal	8	3rd
4th	Long	18	4th
5th	Long	18	5th
6th	Very long	32	6th
7th	Incomplete	23	7th

In 6th and 7th periods, two series of fourteen elements each have been accommodated. Because of the space problem, these two series were placed at the bottom of the periodic table to keep it in a manageable and presentable form. The first series starts after lanthanum (La = 57) and it is called lanthanides. The second series starts after actinium (Ac = 89) and it is called actinides. Together the elements present in these two series are also called rare earths or f-block elements.

Groups

The vertical columns present in the periodic table are called groups. There are in total eighteen groups. Elements present in a group resemble one another in their chemical properties since they contain the same number of electrons in their outermost shells. Elements present in a group are also called a family and each group has also been given a family name. The distribution of electrons in the outer most shells (electronic configuration) and other information about the groups are given in the following Table (8.2).

Table (8.2) Electronic Configurations of Elements In The Outermost Shell

Group No.	Family Name	Electronic Configuration In the Outermost Shell
1	Alkali metals	ns^1
2	Alkaline earth metals	ns^2
3 to 12	Transition metals	$nd^x\ ns^2$
13	Boron family	$ns^2\ np^1$
14	Carbon family	$ns^2\ np^2$
15	Nitrogen family	$ns^2\ np^3$
16	Oxygen family	$ns^2\ np^4$
17	Halogen family	$ns^2\ np^5$
18	Noble gases	$ns^2\ np^6$

The groups 1 to 2 and 13 to 17 contain the normal elements. In the normal elements, all the inner shells are completely filled while the outermost shell is incomplete. The groups 3 to 12 are called transition elements and in these elements the inner sub-shells are in the process of completion.

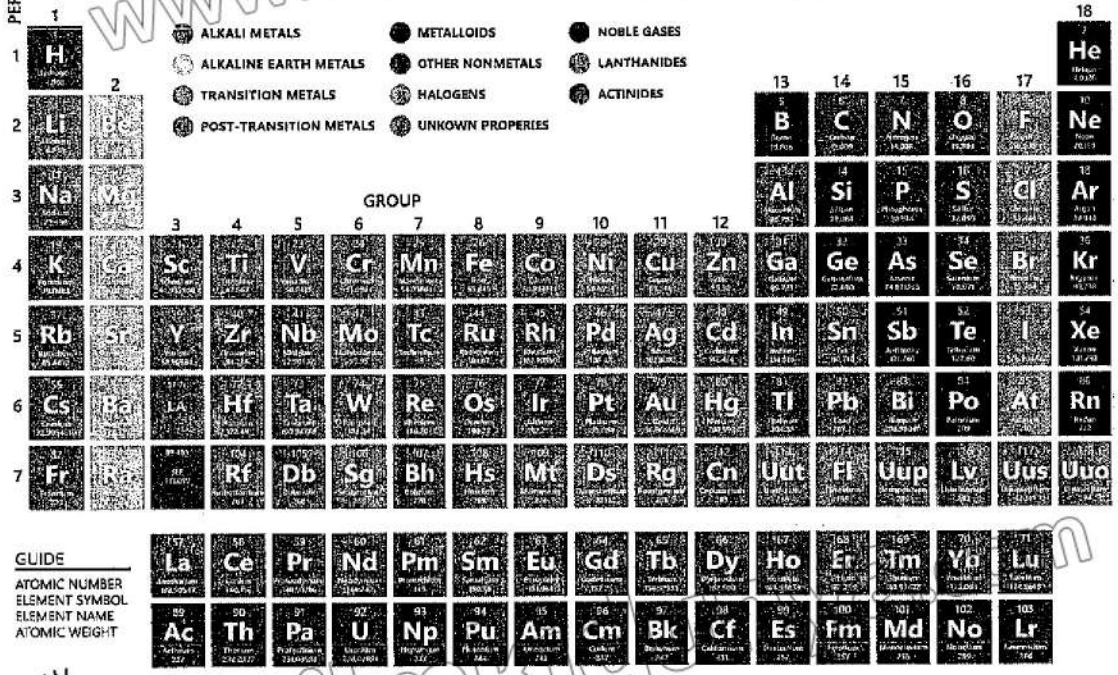
Elements present in the periodic table are also classified into blocks. It depends upon the type of the subshell which is being filled; s, p, d and f. Elements of group 1 and 2 are called s-block elements because in them s-subshell of outermost shell is being filled. Similarly, elements present in groups 13 to 18 are called p-block elements because p-subshell is filled in these elements. The d-block elements lie between the s and p blocks, while f-block elements lie separate at the bottom of the periodic table.

Interesting Information!

Mendeleev arranged only 63 elements in his periodic table because only these elements were discovered at that time. He left many spaces vacant for those elements which were yet to be discovered.

Table (8.3)

PERIODIC TABLE OF THE ELEMENTS



Interesting Information!

E.G. Mazurs collected 700 different published versions of the periodic table. Many forms retain the regular rectangular structure. Some forms had spirals, circles and triangular shapes.

Exercise

(1) The electronic configuration of the outermost shell of an element is s^2p^3. Find out period number and the group number of the element. In which block will you place this element?

(2) What is the group of the element having eight electrons in its outermost shell? In which physical state does this element exist?

(3) An element belongs to sixth group and it is a gas. To which period does it belong?

8.3 Similarities in the Chemical Properties of Elements in the Same Group

The chemical properties of elements depend largely upon the number of electrons present in their outermost shells. Since in a group of the periodic table all the elements have the same number of electrons in the outermost shell, they are expected to show similar chemical properties.

All elements of group I have one electron in their outermost shells, so they show a strong tendency to lose their electron forming cations. They are thus

known as electropositive metals. These metals react vigorously with water producing hydrogen and giving alkali in the solution.

$$Na_{(s)} + H_2O_{(l)} \longrightarrow \underset{\text{Alkali}}{NaOH_{(aq)}} + H_{2\,(g)}$$

Oxides of these metals are also strongly basic in nature. They are readily soluble in water giving alkalies.

$$K_2O_{(s)} + H_2O_{(l)} \longrightarrow 2KOH_{(aq)}$$

Alkali metals also react with halogens giving halides.

$$Na_{(s)} + Cl_{2\,(g)} \longrightarrow 2NaCl_{(s)}$$

The reactivity of alkali metals gradually increases down the group.

The second group elements also show a tendency to lose both of their outermost electrons forming dipositive ions.

$$Mg_{(s)} \longrightarrow Mg^{2+}_{(s)} + 2e$$

The tendency to lose electrons down the group increases due to gradual increase in their atomic sizes. The oxides of these metals are also basic in nature and form alkalies in water.

$$CaO_{(s)} + H_2O_{(l)} \longrightarrow Ca(OH)_{2\,(aq)}$$

All elements in group 17 have s^2, p^5 configuration in their outer shells. They show a strong tendency to gain one electron to become an anion. They are called electronegative elements. These elements are very reactive non-metals and form salts with metals. Hence they are called halogens (salt forming). Unlike alkali metals, the reactivity of halogens decreases down the group.

$$Cl_{2\,(g)} + 2e \longrightarrow 2Cl^{1-}_{(g)}$$

$$Ca_{(s)} + Cl_{2\,(g)} \longrightarrow CaCl_{2\,(s)}$$

Elements present in group 16 have s^2,p^4 configuration in their outermost shells, so they have a tendency to accept two electrons to form a dinegative ion. Oxygen behaves as a strong electronegative element.

$$O_{2\,(g)} + 2e \longrightarrow 2O^{2-}_{(g)}$$

Relationship between Group Number and Charge of Ions

When we move from left to right in the periodic table, the main-group elements tend to form cations having a charge equal to the group number. For example, group 1 elements form 1+ ions, group 2 elements forms 2+ ions and

group 3 elements forms 3+ ions. The number of charges on the cations also correspond to the number of electrons present in their outermost shells.

When we move from right to left in the periodic table, elements often form anions with a negative charge equal to the number of group towards the left side of the noble gases. For example, group 17 elements (which are located one group towards left to the noble gases) form 2- ions. The negative charges presents on these ions correspond to number of electrons which these groups need to complete their octets.

8.4 Variation of Periodic Properties in Periods and Groups

Periodic properties of the elements occur due to recurrence of similar electronic configuration in the outermost shells. They include:

i) Atomic radius
ii) Ionization Energy
iii) Electron affinity
iv) Electronegativity

Atomic Radius

The electron cloud of an atom has no definite limit. Because of this, the size of an atom cannot be defined easily. However, it is possible to measure the radius of an atom when it is bonded to an identical atom.

Atomic radius is defined as half the distance between the nuclei of the two identical bonded atoms. It is expressed in pm(1pm = 10^{-12}m). For example, the distance between the nuclei of two bonded carbon atoms is 154 pm. Half of this distance i.e. 77pm is therefore the radius of carbon atom. This is also called covalent radius of carbon atom.

Variation of Atomic Radius in Periods

When we move from left to right in a period, the size of atoms decreases generally. It is because as we go from lithium (Li) to neon (Ne) in the second period, we are adding electrons to the outermost shell. The charge on the nucleus also increases from +3 to +10. This tends to pull the electrons closer to the nucleus and hence the sizes of atoms decrease from lithium to neon Table (8.4).

Table(8.4) Atomic Radii of Second Period Elements

2nd period elements	Li	Be	B	C	N	O	F	Ne
Atomic Radii (pm)	152	113	88	77	75	73	71	69

The atomic radii of atoms increase from top to bottom in a group. It is because a new shell is being added in the successive period down the group which increases the shielding effect Table (8.5).

Table (8.5) Atomic Radii of First Group Elements

First Group Elements	No. of electrons in the Inner Shells	Atomic Radius (pm)
Li	2	152
Na	10	186
K	18	227
Rb	36	248
Cs	54	265

Interesting Information!

Although you might expect atoms to become larger with the increase in their atomic numbers, this does not always occur because the size of an atom is determined by the diameter of its electron shells.

Ionization Energy

Ionization energy is the amount of energy required to remove the most loosely bound electron from the valence shell of an isolated gaseous atom. When there is only one electron present in the valence shell, the energy required to remove it will be called first ionizations energy. It is expressed in kJ mol^{-1}. For example, the first ionization energy of sodium atom is +496 kJ mol^{-1}.

$$Na \longrightarrow Na^{+} + e^{-} \qquad \Delta H = +496 \text{ kJ mol}^{-1}$$

When there are more than one electrons in the valence shell, they can be removed one by one providing more and more energy. For example, Mg has two electrons in its outermost shell. It is easier to remove the first electron from magnesium than the second one.

$$Mg_{(g)} \longrightarrow Mg^{+}_{(g)} + e^{-} \qquad \Delta H = +737 \text{ kJ mol}^{-1}$$

$$Mg^{+}_{(g)} \longrightarrow Mg^{2+}_{(g)} + e^{-} \qquad \Delta H = +1450 \text{ kJ mol}^{-1}$$

Ionization energy value is related to the atomic size. The smaller the radius of an atom, the stronger the attraction between the nucleus and the outer electrons and higher the value for ionization energy. The ionization energy values thus increase from left to right in a period and decrease from top to bottom in a group. Table (8.6) and Table (8.7)

Table (8.6) Ionization Energies of Elements of Second Period

2nd period elements	Li	Be	B	C	N	O	F	Ne
Ionization energy (kJ mol^{-1})	520	899	801	1086	1402	1314	1681	2081

Table (8.7) Ionization Energies of Elements of First Group

First Group Elements	Ionization Energy ($kJ\ mol^{-1}$)
Li	520
Na	496
K	419
Rb	403
Cs	377

Electron Affinity

Electron affinity is the amount of energy released when an electron is added up in the outermost shell of an isolated gaseous atom. For example, 328 $kJmol^{-1}$ energy is released when an electron enters in the fluorine atom.

$$F^{+}_{(g)} + e^{-} \longrightarrow F^{1-}_{(g)} \qquad \Delta H = -328\ kJmol^{-1}$$

Electron affinity values are also related to the sizes of the atoms. The smaller the size of an atom, the higher the force of attraction with which the nucleus will attract the entering electron and hence higher is the value of electron affinity. Table (8.8)

Table (8.8) Electron Affinities of Second Period Elements

2nd period elements	Li	Be	B	C	N	O	F
Electron Affinity ($kJ\ mol^{-1}$)	–60	0	–29	–122	7	–141	–328

In a group, the electron affinity values decrease from top to bottom because the sizes of atoms increase down the group. In a bigger atom, the nucleus will attract the incoming electron with a weaker force and hence the electron affinity will also be low.

Things to Know

While first electron affinities can be negative, positive or zero, second electron affinities are always positive.

Electronegativity

Electronegativity of an atom is its electron-attracting ability. It is defined as the force with which an atom attracts the shared pair of electrons towards itself in a bond. Electronegative atoms are those whose outer electrons feel a large nuclear charge. It increases from left to right in a period and decreases from top to bottom in a group. Thus the most electronegative atoms are found at the

top right-hand corner of the periodic table. The most electronegative atoms are F,O,N and Cl. Table (8.9) and Table (8.10). The most electropositive elements lie at the bottom left of the periodic table.

Table (8.9) Electronegativities of Elements of Second Period

2nd period elements	Li	Be	B	C	N	O	F
Electronegativity	1.0	1.6	2.0	2.6	3.0	3.4	4.0

Interesting Information!

Electronegativity is one of the most well-known property for explaining why chemical reactions take place.

Table (8.10) Electronegativities of Elements of First Group

17th Group Elements	Electronegativity
F	4.0
Cl	3.2
Br	3.0
I	2.7

8.5 Metallic Character and Reactivity

The metallic character is the tendency of an element to lose electrons and form positive ions or cations.

Since the ionization energy decreases down the group, the elements have increased ability to lose electrons. For this reason both the metallic character and reactivity increase down the group.

As we move from left to right in a period, the nuclear charge increases due to a gradual increase in the number of protons in the nucleus. Owing to this the valence electrons are pulled strongly by the nucleus making it difficult for the atoms to lose electrons. Hence the metallic character decreases in a period from left to right.

The chemical reactivity gradually decreases as we move from left to right in a period. Aluminium and silicon are less reactive than sodium and magnesium. This is because the number of valence electrons increases, making it difficult to lose electrons. Moving further right in a period towards non-metals, the chemical reactivity gradually increases.

Things to Know

Metallic character of a metal generally determines its level of reactivity.

Density

It is mass of a substance in a unit volume. Density of elements generally increases from top to bottom in a group but varies less significantly from left to right in a period. It is expressed in g/cm^3.

Table (8.11) Densities of First Group Elements

First group	Li	Na	K	Rb	Cs
Elements density	0.53	0.97	0.89	1.63	1.879

Exercise

(1) Baruim (Ba) is present in 2nd group and 6th period. Answer the following questions about this element.
   (i) Is it a metal or a non-metal?
   (ii) Will it be electropositive or electronegative?
   (iii) What is the nature of its oxide?
   (iv) In which physical state you expect this element to exist?

(2) In which group and period you expect to find an element with the largest atomic radius?

(3) Can you predict the group number of the most electropositive and the most electronegative elements?

(4) Choose among the following the element having the lowest ionization energy and the element with highest electron affinity. Also assign its group number and period number Li, K, O, F, Cl.

(5) Which two elements of the periodic table react to give
   (i) A basic oxide and
   (ii) An acidic oxide?

Key Points

1. In the modern periodic table, elements have been arranged in the ascending order of their atomic numbers. There are eighteen groups and seven periods in this table.
2. In the modern periodic table, elements have been divided into s, p, d and f blocks.
3. Each period starts with an alkali metal and ends at a noble gas. A period also represents the completion of a shell.
4. The elements present in s and p blocks are called normal elements whereas those present in d and f blocks are called transition elements.
5. All elements in a group are expected to show similar chemical properties because of the same number of electrons present in their outermost shells.
6. Physical properties of the elements vary gradually as we move from left to right in a period and from top to bottom in a group.
7. Atomic sizes of elements decrease from left to right in a period and increase from top to bottom in a group.
8. Ionization energy values increase from left to right in a period and decrease from top to bottom in a group.
9. Electron affinity and electronegativity values increase from left to right in a period and decrease from top to bottom in a group.
10. Metallic character increases from top to bottom in a group and decreases from left to right in a period.

Exercise

1. Tick (✓) the correct answer.

(i) In which period and group will you place the element which is an important part of the solar cell?

(a) Third period and fourth group
(b) Second period and fourth group
(c) Third period and fifth group
(d) Third period and sixth group

(ii) Identify the electronic configuration of the outermost shell of a transition metal.

(a) ns^2np^4 (b) $ndxns^2$
(c) ns^2np^6 (d) ns^2np^5

(iii) Which is the softest metal?

(a) Na (b) Ca (c) Al (d) Zn

(iv) A yellow solid element exists in allotropic forms which is also present in fossil fuel. Indicate the name.

(a) Carbon (b) Iodine

(c) Aluminium (d) Sulphur

(v) How many electrons can nitrogen accept in its outermost shell?

(a) 2 (b) 3 (c) 4 (d) 5

(vi) Which element is the most reactive element?

(a) Oxygen (b) Chlorine (c) Fluorine (d) Nitrogen

(vii) Which element has the highest melting point?

(a) Na (B) K (c) R6 (d) Cs

(viii) In what order does the metallic character change in the second group?

(a) Mg > Ca > Ba > Sr (b) Sr > Ba > Ca > Mg

(c) Mg > Sr> Ca > Ba (d) Ba > Sr > Mg > Ca

(ix) Which of the following best describe the correct order of oxygen, fluorine, and nitrogen's atomic radii?

(a) O < F < N (b) N < F < O (c) F < O < N (d) O < N < F

(x) Which of the following elements has delete two shells, both of which are filled completely?

(a) Ne (b) Ca (c) B (d) He

2. Questions for Short Answers

i. Why was atomic number chosen to arrange the elements in the periodic table?

ii. What is the significance of the word periodic?

iii. Why does the size of a period increase as we move down the periodic table?

iv. In a group, the elements have the same number of electrons in the outermost shell. Why is it so?

v. Do you expect calcium to be more reactive than sodium? Give the reason of your answer.

vi. Which element has the maximum atomic radius and which element has the minimum atomic radius in third period?

vii. Why are the most electronegative elements present in sixth and seventh groups?

viii. The first ionization energy value of magnesium is less than the second one. Give reason.

ix. Is it possible for two metals or two non-metals to form an ionic bond?

x. Which element has the least value of ionization energy and which element has the highest value of electronegativity?

3. Constructed Response Questions

i. Suppose a new element is discovered. Where would you like to accommodate this element in the periodic table?
ii. What is the first element of the periodic table? Will it lose an electron or gain it?
iii. Atomic radii of boron and aluminum are 88 pm and 125 pm respectively. Which element is expected to lose electron or electrons easily?
iv. How would you find the atomic radius of an atom?
v. Why is it not possible for oxygen atom to accept three electrons to form O^{3-} ion like nitrogen which can accept electrons to form N^{3-}?

4. Descriptive Questions

i. Which information is needed to locate the elements in the periodic table if you do not know its atomic number? Is atomic mass helpful for this purpose?
ii. How many blocks of elements are present in the periodic table? Are these blocks helpful in studying the properties of elements?
iii. Explain the variation in the following properties in the periods giving reasons.
(a) Atomic radius (b) Ionization energy
iv. Which physical properties of elements may lead us to know what type of bond it will form?
v. Write down the names of four non-metals which exist in solid state at normal temperature.
vi. Why do second and third periods have equal number of elements while all other periods contain different number of elements?

5. Investigative Questions

i. Arrangement of the elements in the form of a periodic table is a remarkable achievement of chemists. Comment on this statement citing the benefits of this table.
ii. Both lithium and beryllium show behaviour different from rest of the alkali and alkaline earth metals respectively. Can you think of the possible reasons for this difference?
iii. Modern periodic table is the amended form of the earlier table developed by Mandeleev. Elaborate how these two tables are different from each other.