

CHAPTER - 03

CLASSIFICATION OF ELEMENTS AND PERIODICITY IN PROPERTIES

SYNOPSIS

1. Need to classify elements

A systematic study of the known elements and their compounds is possible only when these elements are arranged in such a fashion that the arrangement is closely related to their properties and makes the study simpler.

2. Genesis of Periodic Table

Johann. W. Dobereiner (1817-29) - Attempted to classify elements into Triads

J.P. Cooke (1854) - Classified the elements into homologous series.

A.E. deChancourtois (1862 - 63) - Made Telluric Helix

John Alexander Newlands (1865) - Proposed Law of Octaves. He was honoured by awarding Davy Medal by Royal Society of London in 1887

Lothar Meyer (1868-69) - Plotted Atomic Volume curve, but published only after 1895

Dmitri.I. Mendeleev (1869) - Published the periodic table for the first time (63 elements, 12 series, 9 groups)

H.G. Mosely (1913) - Worked on X-ray spectra. Proved atomic number is a more fundamental property than atomic mass

Modern Periodic Table - Compiled by Ranganath (1893) developed by Werner (1905) and modified by Bury (1921) and it is known as Bohr Table

3. Mendeleev's Periodic Law : "The physical and chemical properties of elements are periodic functions of their atomic Masses". He arranged elements in the increasing order of atomic weight in horizontal rows and vertical columns

4. Merits of Mendeleev's Periodic Table :

(i) The first comprehensive and exclusive classification

(ii) It helped correction of atomic masses of a few elements.

(iii) It helped prediction of properties of undiscovered elements

He could predict the discovery of 10 elements (Sc, Ga, Tc, Re, Po, Fr, Ra, Ac and Pa) but failed to predict the existence of noble gases.

iv) Stimulated research and discovery of new elements.

5. Demerits

- (i) No clear distinction b/w metals, metalloids and non-metals
- (ii) No undisputed position of hydrogen
- (iii) Dissimilar elements were grouped together
- (iv) No vacant space for noble gases
- (v) No room for isotopes
- (vi) Anomalous pairs of elements, violating the increasing order of atomic masses.
 - 1) Ar & K (39.95, 39.09) 2) Co & Ni (58.93 & 58.69)
 - 3) Te & I (127.6 & 126.9) 4) Th & Pa (232.03 & 231)

6. Moseley's Work on X-ray spectra

Moseley plotted square root of frequency of X-rays ($\sqrt{\nu}$) vs atomic masses of elements but failed to produce any periodic relationship b/w the two. When he plotted $\sqrt{\nu}$ of frequency of X-rays vs atomic number, he got a straight line. He deduced the relation $\sqrt{\nu} = a(Z - b)$

7. Modern Periodic Table

MENDELEEV'S ORIGINAL PERIODIC TABLE OF ELEMENTS

S. No.	Group I R_2O	Group II RO	Group III R_2O_3	Group IV RO_2/RH_4	Group V RH_3/R_2O_5	Group VI RH_2/RO_3	Group VII RH/R_2O_7	Group VIII RO_4
1.	H = 1							
2.	Li = 7	Be = 9.4	B = 11	C = 12	N = 14	O = 16	F = 19	
3.	Na = 23	Mg = 24	Al = 27.3	Si = 28	P = 31	S = 32	Cl = 35.5	
4.	K = 39	Ca = 40	... = 44	Ti = 48	V = 51	Cr = 52	Mn = 55	Fe = 56, Co = 59 Ni = 59, Cu = 63
5.	(Cu = 63)	Zn = 65	... = 68	... = 72	As = 75	Se = 78	Br = 80	
6.	Rb = 85	Sr = 87	*Yt = 88	Zr = 90	Nb = 94	Mo = 96	... = 100	Ru = 104, Rh = 104 Pd = 106, Ag = 108
7.	(Ag = 108)	Cd = 112	In = 113	Sn = 118	Sb = 122	Te = 128	I = 127	
8.	Cs = 133	Ba = 137	*Di = 138	*Ce = 140	—	—	—	—
9.	—	—	—	—	—	—	—	—
10.	—	—	*Er = 178	*La = 180	Ta = 182	W = 184	—	Os = 195, Ir = 197 Pt = 198
11.	(Au = 199)	Hg = 200	Tl = 204	Pb = 207	Bi = 208			
12.	—	—	—	Th = 231	—	U = 240	—	—

Mendeleev's periodic table (1871)

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 ₂ O ₃	Ga ₂ O ₃	EO ₂	GeO ₂
Formula of chloride	ECl ₃	GaCl ₃	ECl ₄	GeCl ₄

Modern Periodic Law:

The properties of elements are periodic functions of their atomic numbers.

Modern Periodic Table consists of 18 vertical columns called groups and 7 horizontal rows called periods. The elements are classified into s-block, p-block, d-block and f-block based on the electronic configuration $ns^{1-2}, np^{1-6}, (n-1)d^{1-10}, (n-2)f^{1-14}$ where n is the number of the respective period. They are further classified into (i) Noble gases (ii) Normal or representative elements (iii) Transition elements (iv) Inner transition elements (v) Trans uranic elements (vi) trans fermiums etc.

Repetition of properties after 2, 8, 8, 18, 18 and 32 elements. These numbers are called magic numbers.

8. Nomenclature of elements with atomic number above 100. (newly given by IUPAC on 31st October 2017)

112 - Copernicium (Cn); 113 - Nihonium (Nh); 114 - Flerovium (Fl); 116 - Livermorium (Lv); 115 - Moscovium (Mc); 117 - Tennessine (Ts); 118 - Oganesson (Og).

9. Periodic properties:

1. Atomic Radius : The hypothetical distance b/w the nucleus and the outermost shell of electrons of an atom may be called atomic radius.

Atomic radius can be represented as : (i) Vander waal's radius (ii) covalent radius and (iii) metallic radius.

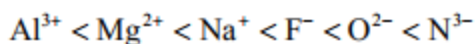
Periodic trends - Decreases from L to R across a period. Increases from top to bottom down the group. There are exceptions to this order of variation due to difference in the effective nuclear charge

The following table illustrates the metallic radii of a few elements

The following table illustrates the metallic radii (Crystal radii) in angstroms:

Li	Be													
1.52	1.12													
Na	Mg											Al	Si	P
1.86	1.60											1.43	1.32	1.28
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As
2.31	1.97	1.64	1.47	1.35	1.29	1.37	1.26	1.25	1.25	1.28	1.37	1.23	1.37	1.39
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb
2.48	2.15	1.82	1.60	1.47	1.40	1.35	1.34	1.34	1.37	1.44	1.52	1.67	1.62	1.59
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi
2.65	2.22	1.87	1.59	1.47	1.41	1.37	1.35	1.36	1.39	1.44	1.57	1.70	1.75	1.70

Ionic Radius : For isoelectronic species the ionic radius is in the order



2. Ionization Enthalpy ($\Delta_i H$) : The energy required to remove the most loosely bound electron from an isolated gaseous neutral atom in its ground state is called first I.E. or IE_1 ($\Delta_i H_1$). Ionisation Enthalpies are always +ve.

Factors affecting I.E.

- (i) Size of the atom (inversely)
- (ii) Nuclear charge (directly)
- (iii) Penetration effect of orbitals (directly)
- (iv) Screening effect of inner electrons and (inversely)
- (v) Stability of electronic configuration (directly)

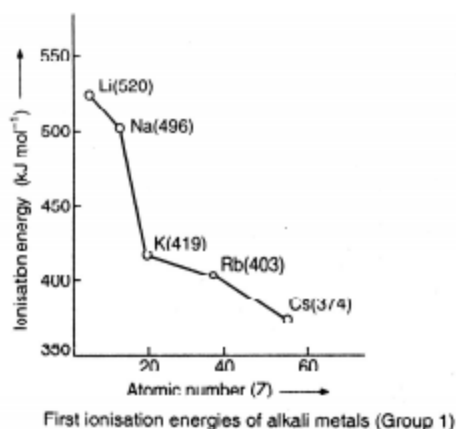
Periodic Trend : In case of normal elements I.E. increases along a period and decreases along a group. The first I.E. of representative elements and noble gases are given in the following table. The values are in kJ/mol.

Variation of ionisation enthalpy in the Periodic Table:

In a normal group, the ionisation enthalpy decreases from top to bottom.

The first ionisation enthalpies of the representative elements and noble gases are given in the following table. The values are in kJ mol^{-1} .

H							He
1312							2372
Li	Be	B	C	N	O	F	Ne
520	899	801	1086	1402	1314	1681	2081
Na	Mg	Al	Si	P	S	Cl	Ar
496	737.6	577	786	1011	999	1255	1520
K	Ca	Ga	Ge	As	Se	Br	Kr
419	590	579	760	946	941	1142	1350
Rb	Sr	In	Sn	Sb	Te	I	Xe
403	549	558	708	834	869	1009	1170
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
374	502	589	715	703	813	917	1037



3. Electron Gain Enthalpy : EGE ($\Delta_{eg}H$)

EGE is the enthalpy change involved in the addition of an electron to the outermost shell of isolated gaseous atom to convert it into a -ve ion.

Electron Affinity (Ae) : The energy released at zero kelvin when an extra electron of zero K.E. is added to an isolated gaseous neutral atom is called electron affinity (Ae).

At room temperature the "electron affinity" becomes EGE and it is given by the expression,

$$\Delta_{eg}H = -(Ae + \frac{5}{2}RT)$$

Negative value of EGE depends on the following factors

- (i) Size of the atom (inversely)
- (ii) Nuclear charge (directly)
- (iii) Penetration effect of orbital (directly)
- (iv) Stability of electronic configuration (inversely)
- (v) Electron density of the outershell (inversely)
- (vi) Exchange energy of resulting electronic configuration (directly)

Periodic Trend : - EGE becomes more and more -ve along a period. Becomes less -ve down a group.

Group → Period ↓	1	2	13	14	15	16	17	18
1	H -73							He +48
2	Li -60	Be +66	B -83	C -122	N +31	O -141	F -328	Ne +116
3	Na -53	Mg +67	Al -50	Si -119	P -74	S -200	Cl -349	Ar +96
4	K -48	Ca -	Ga -36	Ge -116	As -77	Se -195	Br -325	Kr +96
5	Rb -47	Sr -	In -29	Sn -120	Sb -101	Te -190	I -295	Xe +77
6	Cs -46	Ba -	Tl -30	Pb -101	Bi -110	Po -174	At -270	Rn +68

4. Electronegativity (EN) : The ability of an atom to attract a pair of shared electrons of a covalent bond is called electronegativity

It depends on the following factors

1. Effective nuclear charge (directly)
2. Atomic radius (inversely)
3. Oxidation state (directly)
4. Bond length (inversely)
5. Hybridisation state ($sp > sp^2 > sp^3$)

The electronegativity values of representative elements on the following scale are given in the following table:

	1	2	13	14	15	16	17
Group →	IA	IIA	IIIA	IVA	VA	VIA	VIIA
I period	H						
	2.1						
II period	Li	Be	B	C	N	O	F
	1.0	1.5	2.0	2.5	3.0	3.5	4.0
III period	Na	Mg	Al	Si	P	S	Cl
	0.9	1.2	1.5	1.8	2.1	2.5	3.0
IV period	K	Ca	Ga	Ge	As	Se	Br
	0.8	1.0	1.6	1.8	2.0	2.4	2.8
V period	Rb	Sr	In	Sn	Sb	Te	I
	0.8	1.0	1.7	1.8	1.9	2.01	2.5
VI period	Cs	Ba	Tl	Pb	Bi	Po	At
	0.7	0.9	1.8	1.9	1.9	1.76	2.2
	→ Increases						

Pauling scale : The EN difference between two atoms A and B is given by

$$\chi_A - \chi_B = 0.1017 \sqrt{\Delta}; \text{ where } \Delta \text{ is in kJ mol}^{-1}$$

Where $\Delta = [E_{A-B} - \sqrt{E_{A-A} \cdot E_{B-B}}]$ and is called resonance energy.

Mulliken - Jaffe scale : $EN = \frac{IE_1 + \Delta_{eg} H_1}{2}$

Allred-Rochow : They found that the Pauling scale of EN values are related to the effective nuclear

charge (Z_{eff}) and covalent radius (r_0) as $\chi_{(Pauling)} = \frac{0.359 Z_{(eff)}}{r_0^2} + 0.744$

Where $Z_{(eff)}$ is in esu / atom and r_0 is in Å°

5. Periodic Trends in Chemical Properties:

For normal elements, valency w.r.t oxygen increases from 1 to 7 and valency w.r.t hydrogen increases from 1 to 4 and then decreases to 1. The normal oxide formed by the element on extreme left is the most basic (ex : Na_2O) whereas that formed by the element on extreme right is the most acidic (ex : Cl_2O_7). Oxides of elements in the centre are amphoteric (ex : Al_2O_3)

ART-I (JEE MAIN)

SECTION-I- Straight objective type questions

1. The electronic configuration of the element which is placed just above the element with atomic number 43 in modern periodic table is

1) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$

2) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

3) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^1$

4) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$

2. B has a smaller first ionization enthalpy than Be. Consider the following statements:
- (I) It is easier to remove 2p electron than 2s electron
 (II) 2p electron of B is more shielded from the nucleus by the inner core of electrons than the 2s electrons of Be.
 (III) 2s electron has more penetration power than 2p electron.
 (IV) atomic radius of B is more than Be
- The correct statements are:
- 1) I, II and III 2) II, III and IV 3) I, III and IV 4) I, II and IV
3. Which of the following processes involves absorption of energy?
- 1) $S(g) + e^- \rightarrow S^-(g)$ 2) $S^-(g) + e^- \rightarrow S^{2-}(g)$ 3) $Cl(g) + e^- \rightarrow Cl^-(g)$ 4) $H(g) + e^- \rightarrow H^-(g)$
4. **Assertion:** F atom has a less negative electron gain enthalpy than Cl atom
Reason: Additional electron is repelled more effectively by 3p electrons in Cl atom than by 2p electrons in F atom
- Choose the correct option
- 1) Both assertion and reason are true and the reason is the correct explanation of the assertion.
 2) Both assertion and reason are true but reason is not the correct explanation of the assertion.
 3) Assertion is true but reason is false.
 4) Assertion is false but reason is true.
5. In which of the following arrangements the order is NOT according to the property indicated against it?
- 1) $Al^{3+} < Mg^{2+} < Na^+ < F^-$ - increasing ionic size
 2) $B < Al < K < Mg$ - increasing metallic character
 3) $In < Al < Ga < Tl < B$ - increasing first ionisation enthalpy
 4) $I < Br < Cl < F$ - increasing reactivity
6. Increasing order of electronegativity is
- 1) $Si < P < At < S < Cl$ 2) $At < P < Si < S < Cl$
 3) $S < Si < P < At < Cl$ 4) $At < Cl < S < Si < P$
7. Among Al_2O_3 , SiO_2 , P_2O_3 and SO_2 the correct order of acid strength is
- 1) $Al_2O_3 < SiO_2 < SO_2 < P_2O_3$ 2) $SiO_2 < SO_2 < Al_2O_3 < P_2O_3$
 3) $SO_2 < P_2O_3 < SiO_2 < Al_2O_3$ 4) $Al_2O_3 < SiO_2 < P_2O_3 < SO_2$

SECTION-II - Numerical Type Questions

8. A p - block element has successive ionization enthalpies as 940, 2080, 3090, 4140, 7030, 7870, 16000 and 19500 kJ mol⁻¹. To which group of the periodic table does this element belong?

9. The total number of following species with positive electron gain enthalpy is —
 Li, Be, N, Mg, Ne, He, Ar, Kr, Xe, Al, Rn, K, Cs, O^- , Cl^-
10. How many of the following oxides is/are amphoteric in nature?
 SnO_2 , SiO_2 , CO_2 , CaO , As_2O_3 , Al_2O_3 , Cl_2O_7 , Na_2O , PbO_2

PART-II (JEE ADVANCED)

Section-III - Only one option correct type

11. An element with one of the following electronic configurations is expected to have a maximum difference between Δ_1H_2 and Δ_1H_3 . Identify the correct option
 A) $1s^2 2s^2 2p^1$ B) $1s^2 2s^2 2p^6 3s^1$ C) $1s^2 2s^2 2p^6 3s^2$ D) $1s^2 2s^2 2p^6 3s^2 3p^6$
12. The amount of energy released for the process, $X(g) + e^- \rightarrow X^-(g)$ is maximum and minimum respectively for
 i) F ii) Cl iii) N iv) B
 A) iii and iv B) ii and iv C) i and iii D) ii and iii
13. In general, the configuration of lanthanides is $(n-2)f^{1-14}(n-1)s^2 p^6 d^{0-1} ns^2$. It has been observed that, with increase in atomic number of lanthanides, there is a gradual decrease in ionic radii from $La(1.22 \text{ \AA})$ to $Lu(0.99 \text{ \AA})$. The reason for regular decrease in ionic radii is
 A) More effective shielding of one electron by another in the $(n-2) f$ subshell
 B) Increase in number of valence electrons and inter electronic repulsion
 C) More effective shielding of one electron by another in $(n-1) d$ orbitals
 D) Less effective shielding of one electron by another in the $(n-2) f$ subshell
14. Although nitrogen and phosphorous belong to the same group in the periodic table, yet the later forms more number of oxyacids (H_3PO_3 , H_3PO_4 , $(HPO_3)_n$, $H_4P_2O_7$) than the former (HNO_3 , HNO_2 , HNO). This is because
 A) N is more electronegative than P
 B) N is smaller in size compared to P
 C) N does not have d-orbitals in its valence shell but P has
 D) N has a lower affinity for H than P
15. From top to bottom in a group in the periodic table, which of the following trends in atomic properties would be generally true?
 1) Number of valence electrons remains the same
 2) Atomic volume increases
 3) Electronegativity decreases
 4) Metallic character decreases and basic nature of their oxides increases
 Select the correct option
 A) 3 and 4 B) 1, 3 and 4 C) 1, 2 and 3 D) 1, 2, 3 and 4

16. Identify whether the following statements are true (T) or false (F)

S-1:- Formation of Mg^{2+} , Al^{3+} and O^{2-} in the gas phase require absorption of energy.

S-2:- Cations have greater effective nuclear charge than the parent atom.

S-3: The size of isoelectronic species is affected by electron-electron interaction in the outer orbitals.

S-4:- Chemical properties of elements depend upon the valence shell electronic configuration as well as the nuclear mass.

Choose the correct option

- A) TTFF B) TFTF C) TTFT D) TTTT

17. How many of the following statements is/are true?

S-1:- Long form of periodic table completely helps in predicting stability of oxidation states of elements.

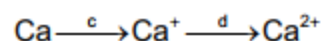
S-2:- van der Waals and covalent radii of chlorine are 180pm and 99pm, respectively.

S-3: - The $(n-2)f$ subshell is half filled in the ground state of elements with atomic number 64 and 96

- A) two B) zero C) three D) one

Section IV - One or more option correct type

18. $\text{K} \xrightarrow{a} \text{K}^+ \xrightarrow{b} \text{K}^{2+}$



If a, b, c and d are ionisation energies, then which of the following arrangements is/are not correct?

- A) $a > c$ B) $b > a$ C) $b > d$ D) $b > c$

19. Which among the following is/are incorrect regarding electronegativity?

A) It is a measurable quantity

B) The most widely used numerical scale of electronegativity is the Pauling scale

C) Electronegativity does not provide a means of predicting the nature of force that holds a pair of elements together

D) The electronegativity of any given element is not a constant, it varies depending upon the element to which it is bound.

20. Be and Al exhibit diagonal relationship. Which of the following statements about them is/are true?

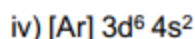
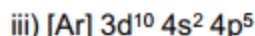
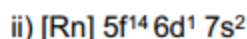
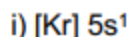
A) Both are not readily attacked by acids because of the presence of a protective oxide film on their surface

B) Both have nearly the same charge/radius ratio

C) Their chlorides are insoluble in organic solvents

D) They have strong tendency to form complexes, $[\text{BeF}_6]^{4-}$ and $[\text{AlF}_6]^{3-}$

21. The electronic configuration of four elements are given below



Which of the following statements is/are false?

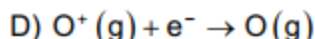
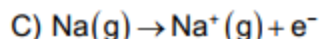
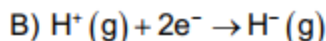
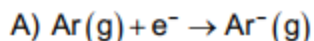
A) (i) shows variable oxidation state

B) (ii) is a d-block element

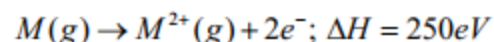
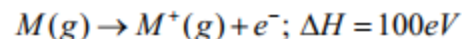
C) The compound formed between (i) and (iii) is covalent

D) (iv) forms coloured compounds

22. Among the following, exothermic process(es) is/are



23. Consider the following ionization steps :



Select the correct statement(s)

A) First ionisation enthalpy of M(g) is 100eV

B) First ionisation enthalpy of M⁺(g) is 150eV

C) Second ionisation enthalpy of M(g) is 250eV

D) Second ionisation enthalpy of M(g) is 150eV

Section V - Numerical type questions

24. Total number of elements that could be accommodated in the 8th period (when discovered) of the periodic table is

25. The 1st, 2nd and 3rd ionisation enthalpies I₁, I₂ and I₃ of four atoms with atomic numbers n, n + 1, n + 2 and n + 3, where n < 10 are tabulated below. What is the value of n ?

Atomic Number	Ionisation enthalpy (kJ/mol)		
	I ₁	I ₂	I ₃
n	1681	3374	6050
n + 1	2081	3952	6122
n + 2	496	4562	6900
n + 3	738	1451	7733

26. One mole of magnesium in vapour state absorbs 1200 kJ energy. If the first and second ionisation enthalpies of Mg are 750 and 1450 kJ mol⁻¹, respectively, the percentage of Mg⁺ in the mixture is
27. The first ionisation enthalpy of Cs is 376 kJ/mole. The number of Cs atoms that can be converted to Cs⁺ ions by 1J energy is — × 10¹⁸
28. The amount of energy released when 10⁶ atoms of iodine in vapour state are converted to iodide ions is 4.8 × 10⁻¹³ J. If electron gain enthalpy of iodine is -x eV/atom, the value of x is —

(Given: 1 J = 6.24 × 10¹⁸ eV)

Section VI - Matrix Match type

29. **Column-I (Atomic/ Ionic species)**

I) F > Cl > Br > I

II) Fe³⁺ > Fe²⁺ > Fe

III) I⁻ > I > I⁺

IV) O > C > B > N

A) I - PR, II - PQS, III - QS, IV - QR

C) I - RS, II - PQR, III - Q, IV - QR

30. **Column-I (Oxide)**

I) P₄O₁₀

II) SiO₂

III) Al₂O₃

IV) MgO

A) I - Q, II - Q, III - PS, IV - PR

C) I - QS, II - PR, III - PS, IV - PR

Column-II (Properties)

P) Ionisation energy

Q) Size

R) Magnitude of $\Delta_{eg}H$

S) Effective nuclear charge

B) I - PS, II - PRS, III - Q, IV - R

D) I - QS, II - QRS, III - QS, IV - QR

Column-II (Nature)

P) Ionic

Q) Covalent

R) Basic

S) Amphoteric

B) I - PR, II - PR, III - QS, IV - PR

C) I - PR, II - PR, III - QS, IV - PR