Unit 3-A

Chemistry of d - Block Elements

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3.1 DEFINITION :

The elements lying between *s*-block and *p*-block elements of the periodic table are collectively known as transition elements. The elements from Sc_{21} to Zn_{30} (ten elements); Y_{39} to Cd_{48} (ten elements); La_{57}, Hf_{72} to Hg_{80} (ten elements); Ac_{89}, Ku_{104}, Ha_{105}, Unh_{106} etc. are called transition elements. These elements either in their atomic state or in any of their common oxidation state have partly filled $(n-1)$ *d* orbitals of $(n-1)^{th}$ main shell. In these elements the differentiating electron enters $(n-1)$ *d* orbitals of $(n-1)^{th}$ main shell are called *d*-block elements.

3.2 POSITION OF d-BLOCK ELEMENTS IN THE PERIODIC TABLE :

The position of *d*-block elements in the periodic table has been shown in figure 3.1. From the figure the following points may be noted :

(i) *d*-block elements lie in between *s*- and *p*-block elements. i.e. these elements are located in the middle of the periodic table.

(ii) *d*-block elements are present in 4^{th} (Sc_{21} to Zn_{30} = 10 elements), 5^{th} (Y_{39} to Cd_{48} = 10 elements), 6^{th} (La_{57}, Hf_{72} to Hg_{80} = 10 elements) and 7^{th} (incomplete) period which contains 8 elements viz. Ac_{89}, Ku_{104} to Uun_{110}.

(iii) *d*-block elements are present in III B (3), IV (B) (4), V B (5), VI B (6), VII B (7), VIII (8, 9, 10), I B (11) and II B (12) groups.

Groups → Period number ↓	1 (IA)	2 (IIA)	3 (IIIB)	4 (IVB)	5 (VB)	6 (VIB)	7 (VIIB)	8 ←	9 (VIII)	10 →	11 (IB)	12 (IIB)	13 (IIIA)	14 (IVA)	15 (VA)	16 (VIA)	17 (VIIA)	18 zero
1	H_1																	He_2
2	Li_3	Be_4											B_5					Ne_{10}
3	Na_{11}												Al_{13}					Ar_{18}
4	*s*-Block Elements		Sc_{21}									Zn_{30}			*p*-Block Elements			
5			Y_{39}									Cd_{48}						
6			La_{57}	Hf_{72}			*d*-Block Elements					Hg_{80}	Tl_{81}					Rn_{86}
7	Fr_{87}	Ra_{88}	Ac_{89}	Ku_{104}						Uun_{110}								

Fig. 3.1 Position of *d*-block elements in the periodic table

Table 3.1 Complete and valence-shell configurations of the atoms of *d*-block elements. Here $[Ar]_{18}$ = 2, 8, 8; $[Kr]_{36}$ = 2, 8, 18, 8; $[Xe]_{54}$ = 2, 8, 18, 18, 8 and $[Rn]_{86}$ = 2, 8, 18, 32, 18, 8. Valence-shell configurations are given in bracket.

Table 3.1

The elements shown in box have anomalous configurations

Group ↓	1st or 3*d* series (4th period)	2nd or 4*d* series (5th period)	3rd or 5*d* series (6th period)	4th or 6*d* series (7th period)
IIIB (3)	Sc_{21} $[Ar]_{18}\ 3d^1\ 4s^2$ = 2, 8, 9, 2 $(3d^1\ 4s^2)$	Y_{39} $[Kr]_{36}\ 4d^1\ 5s^2$ = 2, 8, 18, 9, 2 $(4d^1\ 5s^2)$	La_{57} $[Xe]_{54}\ 4f^0\ 5d^1\ 6s^2$ = 2, 8, 18, 9, 2 $(4f^0\ 5d^1\ 6s^2)$	Ac_{89} $[Rn]_{89}\ 5f^0\ 6d^1\ 7s^2$ = 2, 8, 18, 32, 18, 9, 2 $(5f^0\ 6d^1\ 7s^2)$
IVB (4)	Ti_{22} $[Ar]_{18}\ 3d^2\ 4s^2$ = 2, 8, 10, 2 $(3d^2\ 4s^2)$	Zr_{40} $[Kr]_{36}\ 4d^2\ 5s^2$ = 2, 8, 18, 10, 2 $(4d^2\ 5s^2)$	Hf_{72} $[Xe]_{54}\ 4f^{14}\ 5d^2\ 6s^2$ = 2, 8, 18, 32, 10, 2 $(4f^{14}\ 5d^2\ 6s^2)$	Rf Ku_{104} $[Rn]_{86}\ 5f^{14}\ 6d^2\ 7s^2$ = 2, 8, 18, 32, 32, 10, 2 $(5f^{14}\ 6d^2\ 7s^2)$
VB (5)	V_{23} $[Ar]_{18}\ 3d^3\ 4s^2$ = 2, 8, 11, 2 $(3d^3\ 4s^2)$	Nb_{41} $[Kr]_{36}\ 4d^4\ 5s^1$ = 2, 8, 18, 12, 1 $(4d^4\ 5s^1)$	Ta_{73} $[Xe]_{54}\ 4f^{14}\ 5d^3\ 6s^2$ = 2, 8, 18, 32, 11, 2 $(4f^{14}\ 5d^3\ 6s^2)$	Db Ha_{105} $[Rn]_{86}\ 5f^{14}\ 6d^3\ 7s^2$ = 2, 8, 18, 32, 32, 11, 2 $(5f^{14}\ 6d^3\ 7s^2)$
VIB (6)	Cr_{24} $[Ar]_{18}\ 3d^5\ 4s^1$ = 2, 8, 13, 1 $(3d^5\ 4s^1)$	Mo_{42} $[Kr]_{36}\ 4d^5\ 5s^1$ = 2, 8, 18, 13, 1 $(4d^5\ 5s^1)$	W_{74} $[Xe]_{54}\ 4f^{14}\ 5d^4\ 6s^2$ = 2, 8, 18, 32, 12, 2 $(4f^{14}\ 5d^4\ 6s^2)$	Unh_{106} $[Rn]_{86}\ 5f^{14}\ 6d^4\ 7s^2$ = 2, 8, 18, 32, 32, 12, 2 $(5f^{14}\ 6d^4\ 7s^2)$
VIIB (7)	Mn_{25} $[Ar]_{18}\ 3d^5\ 4s^2$ = 2, 8, 13, 2 $(3d^5\ 4s^2)$	Tc_{43} $[Kr]_{36}\ 4d^5\ 5s^2$ = 2, 8, 18, 13, 2 $(4d^5\ 5s^2)$	Re_{75} $[Xe]_{54}\ 4f^{14}\ 5d^5\ 6s^2$ = 2, 8, 18, 32, 13, 2 $(4f^{14}\ 5d^6\ 6s^2)$	

Group ↓	1st or 3*d* series (4th period)	2nd or 4*d* series (5th period)	3rd or 5*d* series (6th period)	4th or 6*d* series (7th period)
VIII (8)	Fe_{26} $[Ar]_{18}\ 3d^6\ 4s^2$ = 2, 8, 14, 2 $(3d^6\ 4s^2)$	Ru_{44} $[Kr]_{36}\ 4d^7\ 5s^1$ = 2, 8, 18, 15, 1 $(4d^7\ 5s^1)$	Os_{76} $[Xe]_{54}\ 4f^{14}\ 5d^6\ 6s^2$ = 2, 8, 18, 32, 14, 2 $(4f^{14}\ 5d^6\ 6s^2)$	
VIII (9)	Co_{27} $[Ar]_{18}\ 3d^7\ 4s^2$ = 2, 8, 15, 2 $(3d^7\ 4s^2)$	Rh_{45} $[Kr]_{36}\ 4d^8\ 5s^1$ = 2, 8, 18, 16, 1 $(4d^8\ 5s^1)$	Ir_{77} $[Xe]_{54}\ 4f^{14}\ 5d^7\ 6s^2$ = 2, 8, 18, 32, 15, 2 $(4f^{14}\ 5d^7\ 6s^2)$	
VIII (10)	Ni_{28} $[Ar]_{18}\ 3d^8\ 4s^2$ = 2, 8, 16, 2 $(3d^8\ 4s^2)$	Pd_{46} $[Kr]_{36}\ 4d^{10}\ 5s^0$ = 2, 8, 18, 18, 0 $(4d^{10}\ 5s^0)$	Pt_{78} $[Xe]_{54}\ 4f^{14}\ 5d^9\ 6s^1$ = 2, 8, 18, 32, 17, 1 $(4f^{14}\ 5d^9\ 6s^1)$	
IB (11)	Cu_{29} $[Ar]_{18}\ 3d^{10}\ 4s^1$ = 2, 8, 18, 1 $(3d^{10}\ 4s^1)$	Ag_{47} $[Kr]_{36}\ 4d^{10}\ 5s^1$ = 2, 8, 18, 18, 1 $(4d^{10}\ 5s^2)$	Au_{79} $[Xe]_{54}\ 4f^{14}\ 5d^{10}\ 6s^1$ = 2, 8, 18, 32, 18, 1 $(4f^{14}\ 5d^{10}\ 6s^1)$	
IIB (12)	Zn_{30} $[Ar]_{18}\ 3d^{10}\ 4s^2$ = 2, 8, 18, 2 $(3d^{10}\ 4s^2)$	Cd_{48} $[Kr]_{36}\ 4d^{10}\ 5s^2$ = 2, 8, 18, 18, 2 $(4d^{10}\ 5s^2)$	Hg_{80} $[Xe]_{54}\ 4f^{14}\ 5d^{10}\ 6s^2$ = 2, 8, 18, 32, 18, 2 $(4f^{14}\ 5d^{10}\ 6s^2)$	

3.3 ELECTRONIC CONFIGURATION :

The electronic configurations of the d-block elements are given in Table 3.1. In this table $[Ar]_{18}$, $[Kr]_{36}$, $[Xe]_{54}$ and $[Rn]_{86}$ indicate the electronic configurations of Ar, Kr, Xe and Rn respectively, which are given below :

$[Ar]_{18}$ = 2, 8, 8 (Three shells)
$[Kr]_{36}$ = 2, 8, 18, 8 (Four shells)
$[Xe]_{54}$ = 2, 8, 18, 18, 8 (Five shells)
$[Rn]_{86}$ = 2, 8, 18, 32, 18, 8 (Six shells)

The electronic configuration in Table 3.1 show that :

(a) *d*-block elements can be defined as those elements in which the last electron (differentiating electron) enters $(n-1)d$ orbitals (i.e. d-orbitals of the penultimate shell) or in which $(n-1)d$ orbitals are progressively filled up with electrons.

(b) d-block elements are also defined as those elements whose two outer-most shells are incomplete (i.e. partially – filled).

(c) The valence electronic configurations of the atoms of d-block elements can be represented by a general electronic configuration $(n-1)d^{1-10}\ ns^{0-2}$

3.4 CLASSIFICATIONS OF *d*-BLOCK ELEMENTS IN 3*d*, 4*d*, 5*d* AND 6*d* SERIES (FOUR SERIES) :

(1) 3*d* – series (1st series : 4th period) :

This series contains ten elements viz. Sc_{21} to Zn_{30}. These elements are present in 4th period. In the atoms of these elements the last electron goes to 3d-orbitals, i.e. in this series 3d orbitals are progressively filled up with electrons as we move from Sc_{21} to Zn_{30}. It may be noted that the configurations of Cr_{24} and Cu_{29} (two elements) are anomalous, since Cr_{24} has 5 electrons (instead of 4) in 3*d* orbitals and Cu_{29} has 10 electrons (instead of 9) in these orbitals. Thus the correct electronic configurations of Cr_{24} and Cu_{29} are $[Ar]_{18}\ 3d^5\ 4s^1$ [instead of $[Ar]_{18}\ 3d^4\ 4s^2$] and $[Ar]_{18}\ 3d^{10}\ 4s^1$ [instead of $[Ar]_{18}\ 3d^9\ 4s^2$] respectively. Complete and valence-shell electronic configurations of the atoms of 3d-series elements can be written as follows. Here $[Ar]_{18}$ = 2, 8, 8 (three shells)

Complete configuration $= [Ar]_{18}\ 3d^{1-10}\ 4s^{1-2}$

$= 2, 8, (8 + 1 \text{ to } 10), 1 \text{ or } 2$ (four shells)

$= 2, 8, (9 \text{ to } 18), 1 \text{ or } 2$

$= 2, 8, 3s^2\ p^6\ d^{1-10}\ 4s^2$

Valence-shell configuration $= 3d^{1-10}\ 4s^{1-2}$

(2) 4d – series (2nd series : 5th period) :

This series also has ten elements namely Y_{39} to Cd_{48}. These elements are present in 5th period. The elements of this series involve in the progressive filling of 4d orbitals as we proceed from Y_{39} to Cd_{48}. In this series there are more elements which have anomalous configurations. The elements having anomalous configurations are Nb_{41}, Mo_{42}, Ru_{44}, Rh_{45}, Pd_{46} and Ag_{47} (six elements). These anomalous configurations are explained on the basis of nuclear-electron and electron-electron forces existing in these atoms. Complete and valence-shell electronic configurations of the atoms of 4d – series elements can be written as follows. Here $[Kr]_{36}$ = 2, 8, 18, 8 (four shells).

Complete configuration = $[Kr]_{36}\ 4d^{1-10}\ 5s^{0-2}$

= 2, 8, 18 (8 + 1 to 10), 0 to 2 (five shells)

= 2, 8, 18 (9 to 18), 0 to 2

= 2, 8, 18, $4s^2p^6d^{1-10}\ 5s^{0-2}$

Valence-shell configuration = $4d^{1-10}\ 5s^{0-2}$

(3) 5*d* – series (3rd series : 6th period) :

This series also contains ten elements which are La_{57} and Hf_{72} to Hg_{80}. The elements of this series involve the gradual filling of 5d orbitals. In between La_{57} and Hf_{72}, there are 14 elements, viz. Ce_{58} to Lu_{71} which are called Lanthanides or Lanthanones. These 14 elements involve the progressive filling of 4f orbitals and hence donot belong to 5d series. Thus at Lu_{71}, 4*f* –orbitals are completely filled. Consequently at La_{57}, 4*f*-orbitals are vacant ($4f^0$ configuration) while in the remaining nine elements (Hf_{72} to Hg_{80}) 4*f* – orbitals are compeltely filled ($4f^{14}$ configuration). The elements namely Pt_{78} and Au_{79} (two elements) have anomalous configurations. Complete and valence-shell electronic configurations of the atoms of 5d-series elements can be written as follows. Here $[Xe]_{54}$ = 2, 8, 18, 18, 8 (five shells)

Complete configuration = $[Xe]_{54}\ 4f^{0,14}\ 5d^{1-10}\ 6s^2$ ← 1-2

= 2, 8, 18, $4s^2\ 4p^6\ d^{10}\ f^{0,14}\ 5s^2p^6d^{1-10}\ 6s^2$ (six shells)

Valence-shell configuration = $4f^{0,14}\ 5d^{1-10}\ 6s^2$

(4) 6*d*-series (4th series : 7th period-incomplete period) :

The elements of this series are present in 7th period which is an incomplete period. At present this series consists of Ac_{89}, Ku_{104}, Ha_{105} and Unh_{106} (four elements)

These elements involve the gradual filling of 6d-orbitals. In between Ac_{89} and Ku_{104} there are 14 elements. viz. Th_{90} to Lw_{103} which are called Actinides or actinones. These 14 elements involve the prograssive filling of 5f-orbitals and donot belong to 6d-series. Thus at Lw_{103}, 5f-orbitals are completely filled. Consequently at Ac_{89}, 5f-orbitals are vacant ($5f^0$ configuration) while in the remaining elements viz. Ku_{104}, Ha_{105} and Unh_{106} (three elements), 5*f* – orbitals are completely-filled ($5f^{14}$ configuration). Complete and valence-shell configurations of the atoms of 6d-series elements can be written as follows. Here $[Rn]_{86}$ = 2, 8, 18, 32, 18, 8 (six shells).]

Complete configuration = $[Rn]_{86}\ 5f^{0,14}\ 6d^{1-14}\ 7s^2$

= 2, 8, 18, 32, $5s^2\ p^6\ d^{10}\ f^{0,14}\ 6s^2p^6d^{1-4}\ 7s^2$ (7 shells)

Valence-shell configuration = $5f^{0,14},\ 6d^{1-4}\ 7s^2$

QUESTIONS

Q.1 Multiple Choice Questions :

1. d-block elements are also defined as those elements whose _____ outer-most shells are partially filled.

   (a) one (b) two (c) three (d) four

2. The electronic configuration of the atoms of d-block elements can be represented by a general electronic configuration is _____ .

   (a) $(n-1)\ d^{1-10}\ ns^{0-2}$ (b) $(n-1)\ d^{1-8}\ ns^{1}$

   (c) $(n-1)\ d^{1-10}$ (d) $(n-1)\ d^{1-9}\ ns^{0,1}$

3. The outer-shell configuration of Cr is _____ .

   (a) $3d^4\ 4s^2$ (b) $3d^5\ 4s^1$ (c) $3d^3\ 4s^2$ (d) $3d^6\ 4s^0$

   (**Note :** Similar question for other d-block elements can be asked)

4. The number of unpaired electrons in Cr-atom is _____ .

   (a) 3 (b) 4 (c) 5 (d) 6

   (**Note :** Similar question for other d-block elements can be asked)

5. d-block elements comprise the sub-groups _____ .

   (a) 3 to 12 (b) IIIA to VIIA

   (c) between IIA and IIIA (d) IB to VIIIB

6. Fe, Co, Ni belong to sub-group _____ .

   (a) VIII (b) 8, 9, 10 (c) 11, 12, 13 (d) 14, 15, 16

   (**Ntoe :** Similar question for other d-block elements can be asked)

7. The general electronic configuration of Mn (Z = 25) is _____ .

   (a) 2, 8, 13, 2 (b) 2, 8, 12, 3 (c) 2, 8, 14, 1 (d) 2, 8, 11, 4

   (**Note :** Similar question for other d-block elements can be asked)

ANSWERS

1. (b) **2.** (a) **3.** (b) **4.** (d) **5.** (a) **6.** (b) **7.** (a)

Q.2 Short questions :

1. What are transition elements ?
2. Give the general electronic configuration of d-block elements.
3. Give the position of d-block elements in periodic table.
4. Give the general electronic configuration of Fe-atom.

(**Note :** Similar question can be asked for other d-block elements)

Q.3 Long questions :

1. Give the complete and valence-shell electron configurations of the atoms of
   (i) 3d – series, (ii) 4d – series (iii) 5d – series.
2. Discuss the classification of d-block elements in 3d, 4d, 5d and 6d series.

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