

## Lecture 8

### Coordination Compounds

#### The d-block elements (Transition Metals)

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	1A (1)		2A (2)		d-block transition metals												8A (18)	
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1																		
2																		
3			3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	(9)	(10)	1B (11)	2B (12)						
4			21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn						
5			39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd						
6			57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg						
7			89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112						

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				
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				

## Properties of the Transition Metals

Malleable, ductile, conducting

### First row transition metals

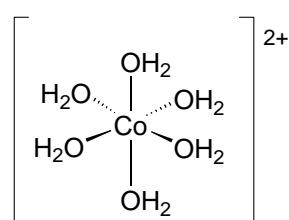
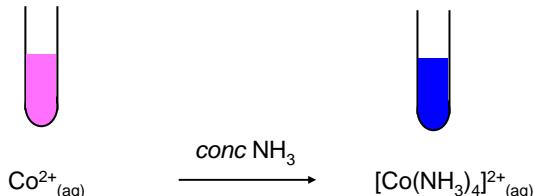


Higher melting and boiling points than main group metals:

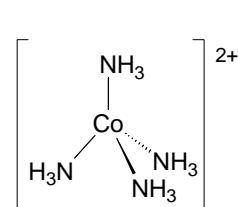
m.p.  $\sim 1\ 500^\circ\text{C}$ , b.p.  $\sim 2\ 500^\circ\text{C}$

## Complexes you will meet...

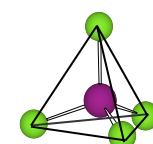
### Ligand exchange reaction



Octahedral complex  
Six ligands  
Coordination number = 6



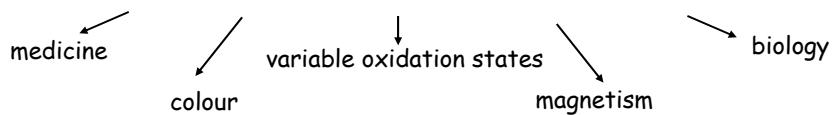
Tetrahedral complex  
Four ligands  
Coordination number = 4



Ions are formed when a transition metal loses electrons  
 positive ions = cations



Transition metal ions form coordination complexes  
 with useful and interesting properties



Which orbitals?

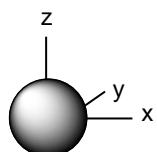
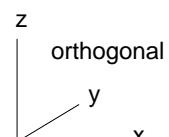
The valence electrons in s- and p-block elements occupy s and p-orbitals

s-orbitals:  $l = 0$ ,  $m = 0$

1 s-orbital per shell

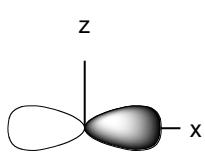
p-orbitals:  $l = 1$ ,  $m = +1, 0, -1$

3 p-orbitals per shell

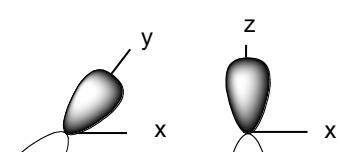


s

Non-directional



$p_x$



$p_y$

$p_z$

lie along coordinate axes

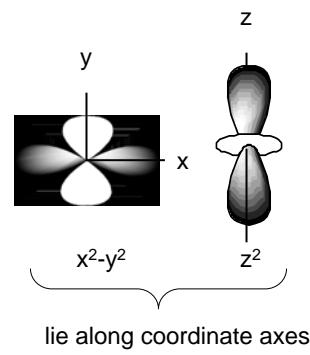
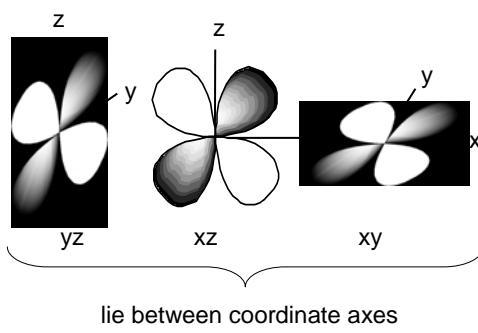
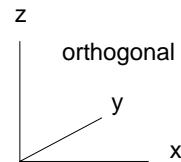
Two electrons fill 1 s-orbital = 2 elements in each row of the s-block  
 Six electrons fill 3 p-orbitals = 6 elements in each row of the p-block

### Which orbitals?

The valence electrons occupy d-orbitals in transition metals

d-orbitals:  $l = 2$ ,  $m = +2, +1, 0, -1, -2$

therefore there are 5 d-orbitals



Ten electrons fill 5 d-orbitals so there are ten elements in each row of the d-block

### Electron configurations of transition metal atoms

K	1	4s	3d	4p	[Ar] 4s <sup>1</sup>
Ca	1l				[Ar] 4s <sup>1</sup>
Sc	1l	1			[Ar] 4s <sup>2</sup> 3d <sup>1</sup>
Ti	1l	1 1			[Ar] 4s <sup>2</sup> 3d <sup>2</sup>
V	1l	1 1 1			[Ar] 4s <sup>2</sup> 3d <sup>3</sup>
Mn	1l	1 1 1 1 1			[Ar] 4s <sup>2</sup> 3d <sup>5</sup>
Fe	1l	1l 1 1 1 1			[Ar] 4s <sup>2</sup> 3d <sup>6</sup>
Co	1l	1l 1l 1 1 1			[Ar] 4s <sup>2</sup> 3d <sup>7</sup>
Ni	1l	1l 1l 1l 1 1			[Ar] 4s <sup>2</sup> 3d <sup>8</sup>
Zn	1l	1l 1l 1l 1l			[Ar] 4s <sup>2</sup> 3d <sup>10</sup>

The element gains stabilisation from having a half-filled d-shell [Ar] 4s<sup>1</sup> 3d<sup>5</sup>

The element gains stabilisation from having a filled d-shell [Ar] 4s<sup>2</sup> 3d<sup>10</sup>

### Working out numbers of d-electrons from oxidation states:

#### 1st: how many electrons are there in the shell?

- count along the periodic table

e.g. Mn = 7 electrons      Cu = 11 electrons

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1A		2A		3A		4A		5A		6A		7A		He		(17)	
H		Be		B		C		N		O		F		Ne			
He	Mg	Al	Si	P	S	Cl	Ar	Ne	Ar	Br	Kr	Xe	Rn				
Li	Be	B	C	N	O	F	Ne										
Na	Mg	Al	Si	P	S	Cl	Ar										
Li	Be	B	C	N	O	F	Ne										
Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Mg	Al	Si	P	S	Cl	Ar											
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Y	Zr	Nb	Mo	Ta	Ru	Rh	Pd	Ag	Cd	In	Sn	Bh	Tc	I	Xe		
La	Hf	Ta	W	Ru	Ox	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
Lu	Rf	Dy	Rg	Bh	He	M	110	111	112	113	114	115	116	117	118		

#### 2nd: how many electrons are lost?

- oxidation state

e.g. Mn(VII) = 7 electrons lost      Cu(II) = 2 electrons lost

#### 3rd: how many electrons left over?

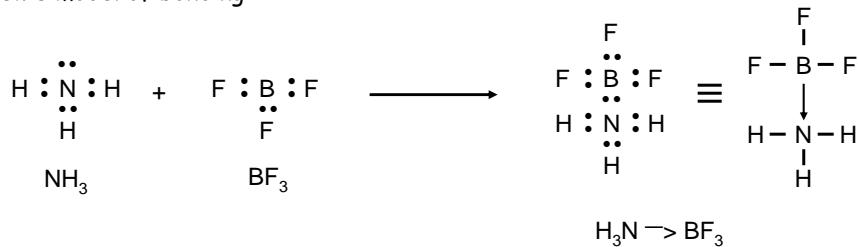
- subtract

e.g. Mn(VII) = no d-electrons, d<sup>0</sup>      Cu(II) = 9 d-electrons = d<sup>9</sup>

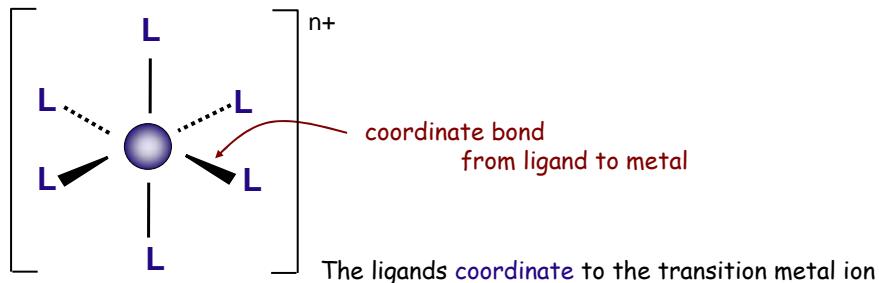
Rule: The electrons in the s-orbital are the first to be lost

Hence the only valence electrons available in a transition metal ion are d-electrons

### Lewis model of bonding



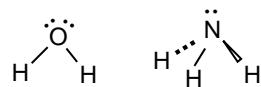
Each ligand donates both electrons in the bond to the metal centre



## Ligands

A **ligand** is Lewis base which donates an electron pair to a metal ion in a complex to form a coordinate bond

Neutral ligands



Anionic ligands

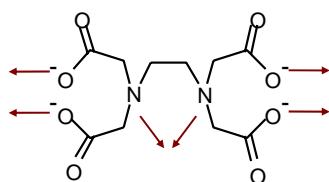


**Monodentate** ligands = "one tooth"  
one electron pair to donate  
monodentate ligands occupy one coordination site about the metal centre

**Denticity** = number of donor atoms with which one ligand can coordinate to a metal centre

## Polydentate Ligands

Hexadentate ligand



tetraanion of ethylenediaminetetraacetic acid, EDTA<sup>4-</sup>

