Introduction to the transition metals

The IUPAC definition of a transition metal is an element with an incomplete d sub-level in atoms or ions

these characteristics include
- **complex formation,**
- **formation of coloured ions,**
- **variable oxidation state**
- **catalytic activity.**

Electronic structure of d-block elements

The electronic structure of the d-block has some complications. As mentioned earlier, conventionally we say that 4s fills before 3d and so we write them in that order. There is, however, disagreement in the scientific community about whether this is true.
If you look at the electronic structures below you will see both Chromium and copper have an unusual arrangement in having a half filled 4s sub shell.
You will also see that when d block elements form ions they lose the 4s electrons first.
You may find if you research different reasons for these observations. It may well be many of the reasons are false and we have to accept that some things in chemistry don't neatly follow patterns we can explain.

Sc $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^1$
Ti $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^2$
V $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^3$
Cr $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^1 3d^5$
Mn $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^5$
Fe $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^6$
Co $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^7$
Ni $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^8$
Cu $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^1 3d^{10}$
Zn $1s^2 2s^2 2p^6 3s^2 3p^6\ 4s^2 3d^{10}$

→ When forming ions lose 4s before 3d

Sc^{3+} [Ar] $4s^0 3d^0$
Ti^{3+} [Ar] $4s^0 3d^1$
V^{3+} [Ar] $4s^0 3d^2$
Cr^{3+} [Ar] $4s^0 3d^3$
Mn^{2+} [Ar] $4s^0 3d^5$
Fe^{3+} [Ar] $4s^0 3d^5$
Co^{2+} [Ar] $4s^0 3d^7$
Ni^{2+} [Ar] $4s^0 3d^8$
Cu^{2+} [Ar] $4s^0 3d^9$
Zn^{2+} [Ar] $4s^0 3d^{10}$

1	**H**																	**He**
2	**Li**	**Be**											**B**	**C**	**N**	**O**	**F**	**Ne**
3	**Na**	**Mg**											**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
4	**K** $4s^1$	**Ca** $4s^2$	**Sc** $3d^1$	**Ti** $3d^2$	**V** $3d^3$	**Cr** $4s^1$ $3d^5$	**Mn** $3d^5$	**Fe** $3d^6$	**Co** $3d^7$	**Ni** $3d^8$	**Cu** $4s^1$ $3d^{10}$	**Zn** $3d^{10}$	**Ga** $4p^1$	**Ge** $4p^2$	**As** $4p^3$	**Se** $4p^4$	**Br** $4p^5$	**Kr** $4p^6$

Forming ions

When transition metals form ions they lose the 4s electrons before the 3d

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

Cu^+ $1s^2 2s^2 2p^6 3s^2 3p^6\ 3d^{10}$

Cu^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6\ 3d^9$

One explanation for this is the 3d sub-shell is lower in energy than the 4s when electrons start filling the 3d sub-shell. When electrons are removed they are therefore first taken from the 4s.

Why is Zn not a transition metal?

Zn can only form a +2 ion. In this ion the Zn^{2+} has a **complete** d orbital and so does not meet the criteria of having an incomplete d orbital in one of its ions or atoms.

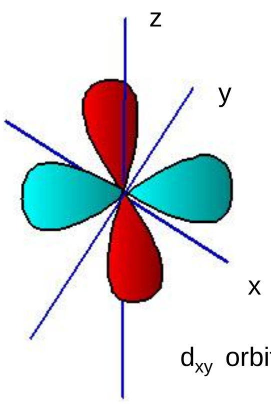
Zn is excluded from the transition metals because it does not share the common properties associated with them. Zinc only has one oxidation state and only forms white compounds.

Sc a transition metal?

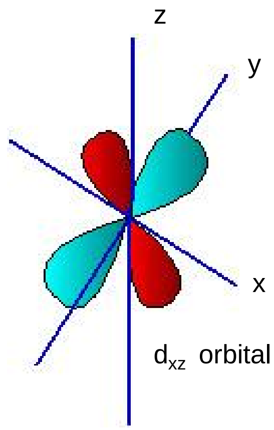
Some A-level syllabi use a slightly different definition of a transition metal. This definition is for an element with an incomplete d sub-level ions.

With this definition Scandium is not a transition metal. Sc can only form a +3 ion. In this ion the Sc^{3+} has an empty d orbital and so does not meet the criteria of having an incomplete d orbital in one of its ions. With the IUPAC definition it does fit as it has an incomplete 3d sub shell in its atom.

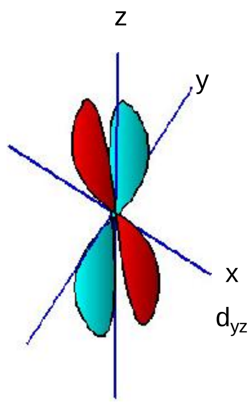
Shapes of the 3d orbitals



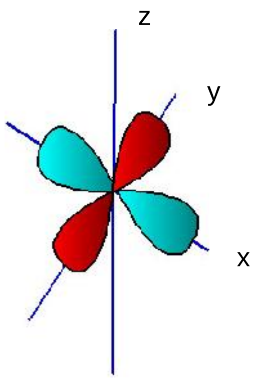
d_{xy} orbital



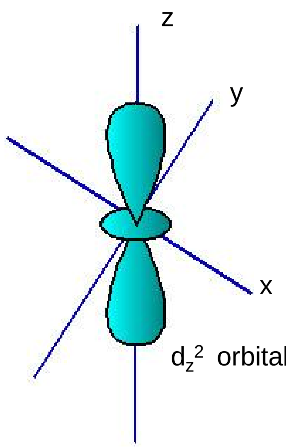
d_{xz} orbital



d_{yz} orbital



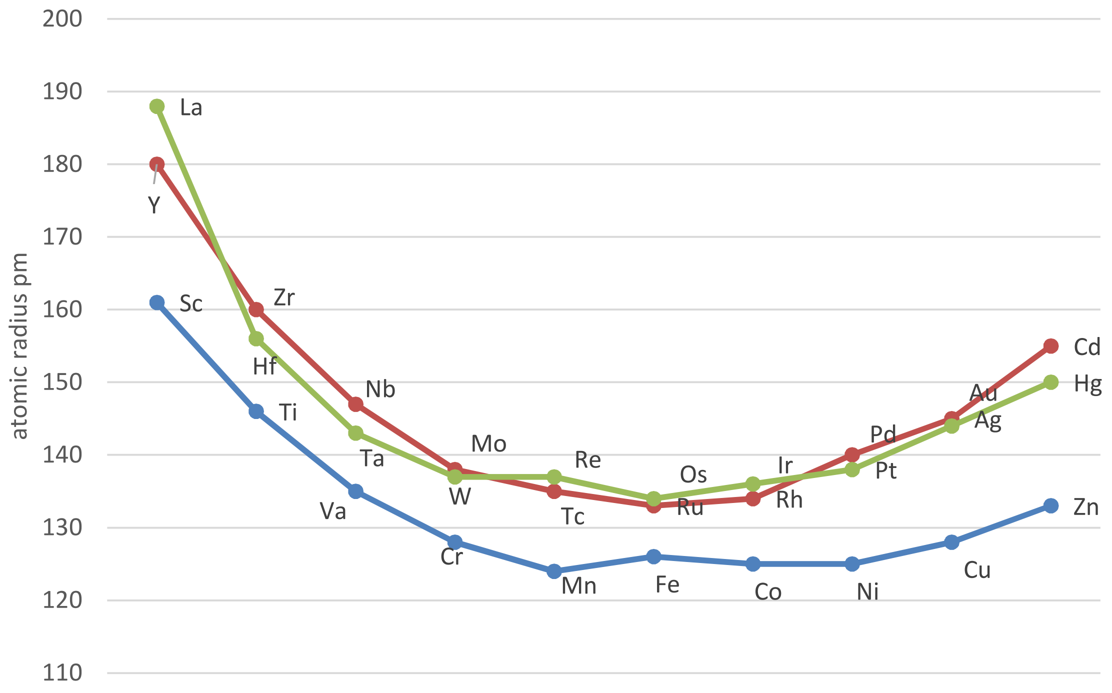
$d_{x^2-y^2}$ orbital



d_{z^2} orbital

Physical properties of Transition metals

Atomic Radii Of The *d*-Block Elements



Transition metals are:
•Dense metals
•Have high melting point and Boiling points
•Tend to be hard and durable
•Have high tensile strength
•High electrical conductivity
•Malleable

Properties derive from strong metallic bonding

Transition metals can release electrons into the pool of mobile electrons from both outer and inner shells.

Strong metallic bonds are formed between the delocalised electrons and the positive metal ions.

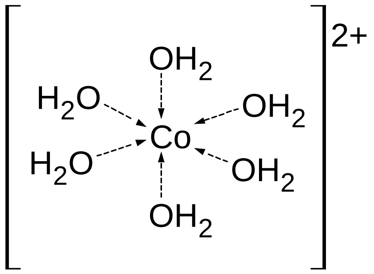
Chemical properties of transition metals

They form **coloured ions.**

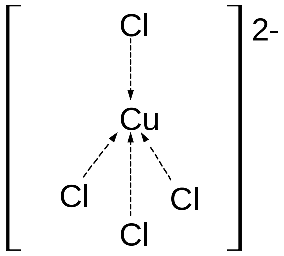
The photo shows some coloured vanadium compounds

They **form complexes** (ligands form co-ordinate bonds to the metal ion).

$[Co(H_2O)_6]^{2+}$



$[CuCl_4]^{2-}$



They exhibit variable oxidation states.

Transition metals form various oxidation states. They are able to donate and receive electrons and are able to oxidize and reduce. This is because they have many electrons of similar energy in their valence- shell orbital . The 4s + 3d orbitals have similar energies. The energy differences between the oxidation states are small.

Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
+3	+4	+5	+6	+7	+6	+5	+4	+3	+2
	+3	+4	+5	+6	+5	+4	+3	+2	
	+2	+3	+4	+5	+4	+3	+2	+1	
	+1	+2	+3	+4	+3	+2	+1		
		+1	+2	+3	+2	+1			
			+1	+2	+1				
				+1					

General trends

- Relative stability of +2 state with respect to +3 state increases across the period
- Compounds with high oxidation states tend to be oxidising agents e.g MnO_4^-
- Compounds with low oxidation states are often reducing agents e.g V^{2+} & Fe^{2+}

The diagram above shows the different oxidation states the transition metals can form. The ones shaded red are the most common ones.

They show **catalytic activity**.

e.g.

	Ni	margarine production
	V_2O_5	making SO_3 for H_2SO_4
	Fe	Haber process to make NH_3
	Pt, Pd	catalytic converters