28.1 General physical and chemical properties of transition elements

Learning outcomes

Candidates should be able to:

1. define a transition element as a d-block element which forms one or more stable ions with incomplete d orbitals
2. sketch the shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital
3. understand that transition elements have the following properties:
   (a) they have variable oxidation states
   (b) they behave as catalysts
   (c) they form complex ions
   (d) they form coloured compounds
4. explain why transition elements have variable oxidation states in terms of the similarity in energy of the 3d and the 4s sub-shells
5. explain why transition elements behave as catalysts in terms of having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with ligands
6. explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible

Initial assessment

1. List the full electron configurations for each of the elements titanium to copper

Introduction

The elements from scandium to zinc inclusive comprise the 3d block. The 3d sub-shell contains five orbitals, each able to accommodate two electrons, and so this block contains ten elements. The electronic configuration of scandium is $[Ar]3d^14s^2$, and that of zinc is $[Ar]3d^{10}4s^2$.

Apart from scandium and zinc, the other eight elements are known as the transition elements, because some of their properties show a gradual change (transition) from those of the reactive metal calcium in Group 2 to the much less reactive metal gallium in Group 13.

Transition elements are d-block elements that form one or more stable ions with incomplete d orbitals.

When transition elements form ions, their atoms lose electrons from the 4s sub-shell first, followed by 3d electrons.

2. Write down the electronic configuration of: i) a titanium atom (Ti) ii) a titanium ion (Ti^{2+})

   ……..

   ……..

3. Give the electronic configuration of an isolated Ti^{3+} ion.

   $1s^2$ [1]

4. Complete the shorthand electronic configurations of Fe and Fe^{3+}.

   Fe [Ar] .....

Fe^{3+} [Ar] ..... [1]

5. Complete the electronic configuration of an isolated gaseous Fe^{2+} ion.

   $1s^2$ ..... [1]

6. The most common oxidation states of cobalt are +2 and +3.
   Complete the electronic configurations of the following free ions.

   ● Co^{2+} [Ar]……

   ● Co^{3+} [Ar] …… [1]

7. Copper is a transition element.
   (a) (i) Complete the electronic configurations of a Cu^+ ion and a Cu^{2+} ion.

   Cu^+ ion: [Ar] .....

   Cu^{2+} ion: [Ar] .....

8. Complete the electrons in boxes diagram in Fig. 1.1 to show the electronic configuration of a copper(II) ion.

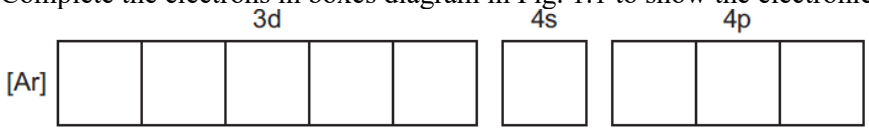


Fig. 1.1

9. Define transition element.

   ……

   ……

   …… [1]

10. Silver, Ag, is a metal in the d-block of the Periodic Table.
    Silver can form compounds containing either Ag^+ or Ag^{2+} ions.
    Explain why silver is a transition element.

    .....

    ..... [1]

11. The transition elements are able to form stable complexes with a wide range of molecules and ions.
    State the meaning of *transition element*.

    .....

    .....

    ..... [1]

12. Explain why scandium (which forms only one ion, Sc^{3+}) and zinc (which forms only one ion, Zn^{2+}) are not called transition elements.

They form some compounds containing ions with an incomplete d sub-shell.

They have variable oxidation states.

They can behave as catalysts.

They form complex ions.

They form coloured compounds.

The transition elements commonly have physical properties that are typical of most metals:

they have high melting points

they have high densities

they are hard and rigid, and so are useful as construction materials

they are good conductors of electricity and heat

13. Titanium is a transition element in Period 4. It is commonly found as TiO_2 in minerals.

Identify **two** typical properties of transition elements.

1 .....

2 .....[1]

14. Vanadium is a transition element in Period 4 of the Periodic Table.
Vanadium shows typical chemical properties of transition elements, including variable oxidation states.
State two other typical chemical properties of transition elements.

1. …….....

2. …….....[1]

- The melting and boiling points of the transition elements are generally much higher than those of the s- and p-block elements.
- This indicates that not only the 4s electrons but also the 3d electrons are involved in the metallic bonding.
- The conductivities of the transition elements are similar to those of calcium (29.2 mS m−1); the conductivity of copper is particularly high.
- The metallic radii tend to decrease across the block as the increasing nuclear charge attracts the outer electrons more strongly. There are minor variations to this trend.
- There is no obvious trend in the M2+ ionic radii, but the M3+ ionic radii tend to decrease across the block as the nuclear charge increases and attracts the electrons more strongly.

3. Compare the melting point and density of iron with those of calcium, an s-block element in the fourth period.

melting point .....

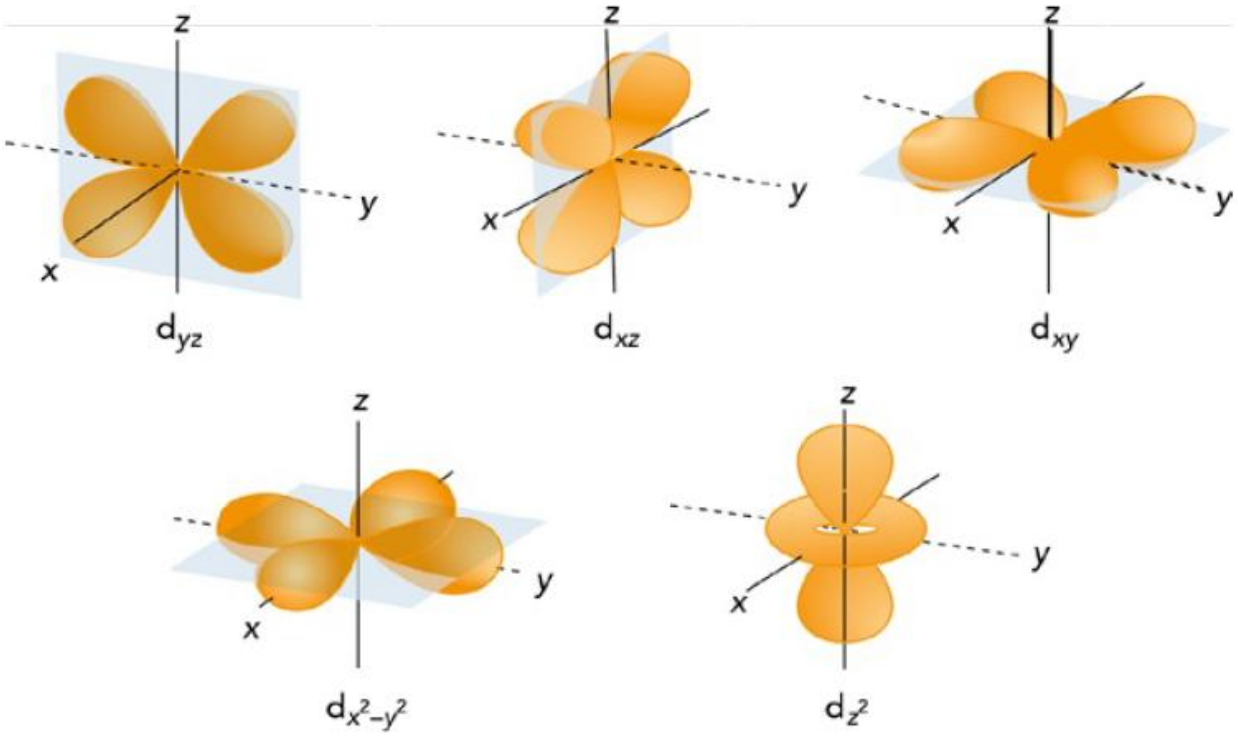
density ..... [1]

4. State how the melting point and density of iron compare to those of calcium.

.....

..... [1]

shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital



5. Sketch the shape of a $3d_{xy}$ orbital in Fig. 2.1. [2]

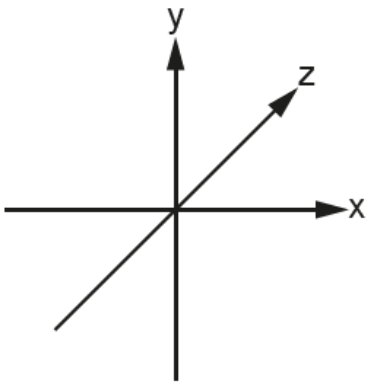
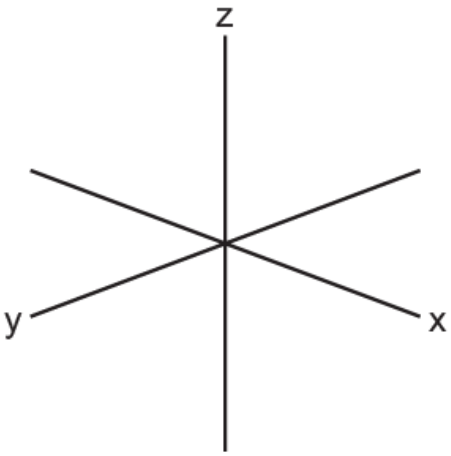


Fig. 2.1

6. Sketch the shape of a $3d_{z2}$ orbital. [1]



7. There are five different 3d orbitals.
Sketch the shape of a $3d_{z2}$ orbital in Fig. 1.2.

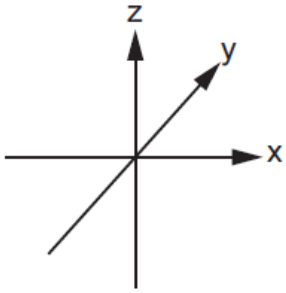
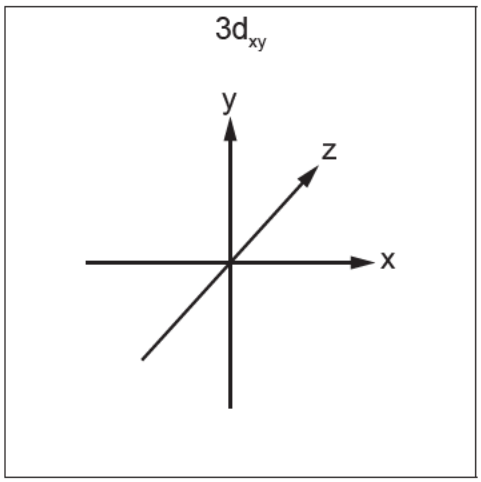
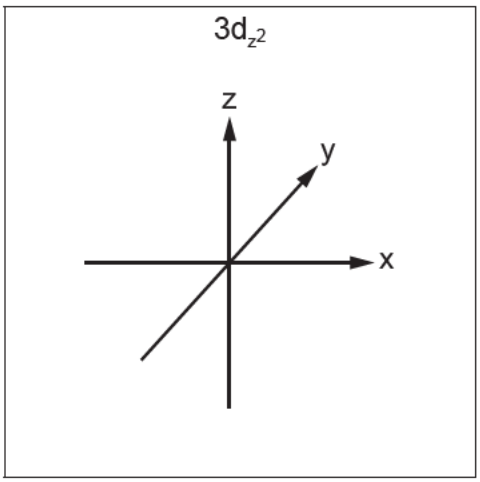


Fig. 1.2

8. A transition element is a d-block element which forms one or more stable ions with incomplete d-orbitals.
(a) Two of the 3d orbitals are the 3dxy orbital and the 3dz2 orbital.
Sketch the shapes of these two orbitals.



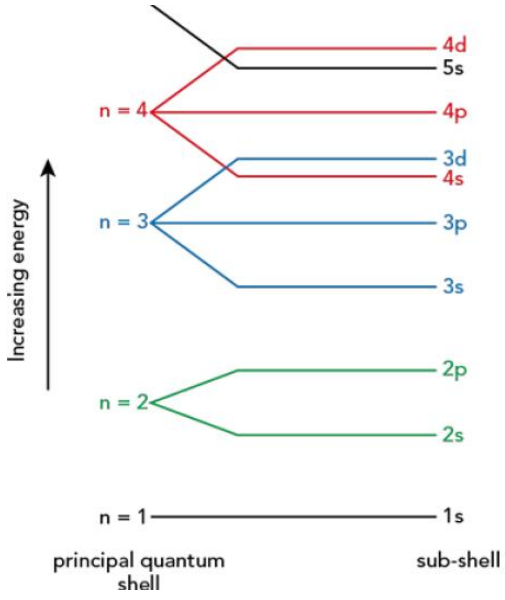


[1]

Variable oxidation states

Note down compounds of various common first row transition elements, and the oxidation states in these compounds.

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



9. Explain why the maximum oxidation state of manganese is +7.

10. The oxidation number of manganese can vary. What is its oxidation number in the following compounds?
    a. MnO_2 b. MnO_4

11. Deduce the oxidation states of iron in:

    $[Fe(CN)_6]^{4-}$ ..... $[Fe(CN)_5NO]^{2-}$. ..... [1]

12. Concentrated acidified H_2O_2 can react with V^{2+} to form red VO_2^{3+} ions.
    VO_2^{3+} contains vanadium combined with the peroxide anion, O_2^{2-}.
    Deduce the oxidation state of vanadium in VO_2^{3+}.

    ..... [1]

13. Deduce the oxidation numbers of chromium in $(NH_4)_2Cr_2O_7$ and in Cr_2O_3.

    $(NH_4)_2Cr_2O_7$ ..... Cr_2O_3 …… [1]

14. [MnC*l* 4]2– is a complex ion.
    Deduce the oxidation state of manganese in [MnC*l* 4]2–.

    oxidation state = ... [1]

15. Give the formulae of two oxides of iron. State the oxidation number of iron in each compound.

    .....

    ..... [1]

16. Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.
    Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

    ..... [1]

17. Copper can form stable complexes in the +1 and +2 oxidation states.
    Explain why transition elements have variable oxidation states.

    .....

    ..... [1]

18. Iron is a transition metal in Group 8 of the Periodic Table.
    Explain why iron has variable oxidation states.

    .....

    .....

    ..... [1]

vacant d orbitals that are energetically accessible and can form dative bonds with *ligands*

19. Explain why transition elements form complexes.

.....

..... [1]

20. **(a)** The most common zinc mineral contains zinc(II) sulfide, ZnS.
(i) Complete the electrons in boxes diagram in Fig. 1.1 to show the electronic configuration of a zinc(II) ion. [1]

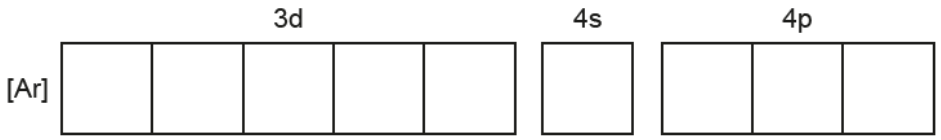


Fig. 1.1

(ii) Explain why transition elements can form complex ions.

…….....

…….....[1]

21. Transition metal atoms and transition metal ions form complexes by combining with ligands.
(a) Explain why transition elements form complex ions. [1]

Transition elements as catalysts

having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with ligands

22. Catalysts may be homogeneous or heterogeneous.
Platinum is a transition element. Explain why transition elements behave as catalysts.

…….....

…….....

…….....[1]

23. Transition elements behave as catalysts and can form complex ions.
Explain why transition elements behave as catalysts. [2]

*****This is not a complete note. It is just to guide you. It is recommended to study the prescribed textbooks along with this material. *****