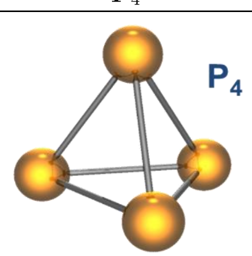
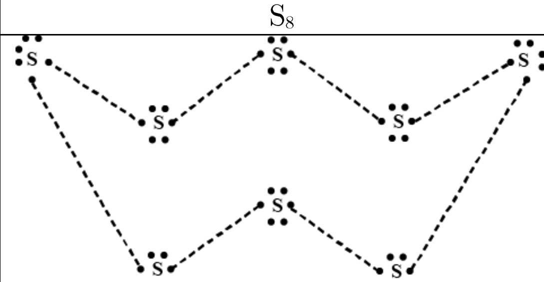
Patterns in the Chemical World

Is this revision??

Variation of properties from Li to Ar

	Li	Be	B	C	N	O	F	Ne
Chemical formula of elemental form	Li	Be	B	C	N_2	O_2	F_2	Ne
Type	Metal		Semi-metal	Non-metals				
Nature of bonding	Metallic bond		Covalent bond		Covalent bond (within molecule except Ne) + Van der waal's forces between molecules			
	Na	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
Chemical formula of elemental form	Na	Mg	Al	Si	P_4	S_8	Cl_2	Ne
Type	Metal			Semi-metal	Non-metals			
Nature of bonding	Metallic bond			Covalent bond	Covalent bond (within molecule except Ar) + Van der waal's forces between molecules			

Structures of phosphorus and sulphur. In reality both elements have several allotropes, the forms P_4 and S_8 are the typical (and most stable) forms of the two elements.

P_4	S_8
	

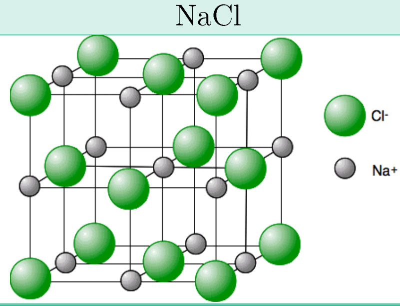
Relationships between structures and electrical conductivity

Type of structure	Types of bond(s) present	Electrical conductivity
Giant metallic structure	Metallic bond between metal ions and delocalized electrons	Can conduct electricity
Giant ionic structure	Ionic bonds between ions of opposite polarities of charge	Can conduct electricity in aqueous or molten state **only**
Simple molecular structure	Covalent bonds within molecules; Van der waal's forces between molecules	Cannot conduct electricity in any state
Giant covalent structure	Covalent bonds between atoms	Cannot conduct electricity (except graphite)

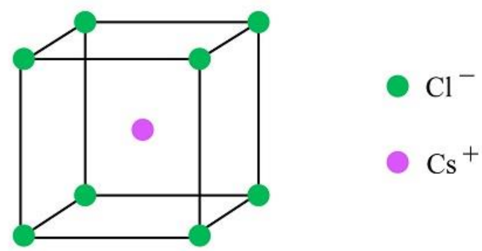
Drawing of the different structures

Giant ionic structure

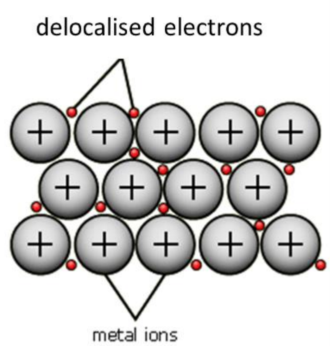
NaCl



CsCl

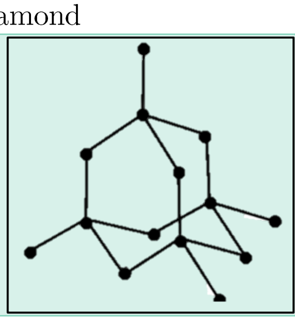


Giant metallic structure

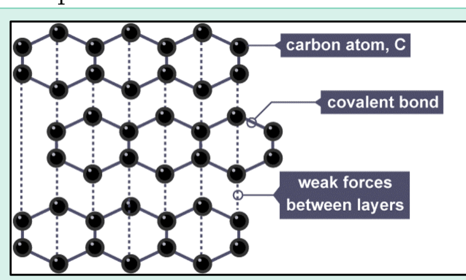


Giant covalent structure

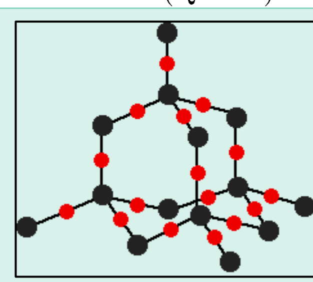
Diamond



Graphite



Silicon Dioxide (Quartz)



Checkpoint

1. Explain why the melting point of diamond is higher than that of P.

2. Explain why solid sodium chloride cannot conduct electricity while solid sodium can conduct electricity.

3. Arrange Mg, Si, Cl and Ar in decreasing order of boiling point, explain your answer by making appropriate comparisons between their bonding and structures.

Properties of oxides of third period elements

	Na	**Mg**	**Al**	Si	P	S	Cl
Group	I	II	III	IV	V	VI	VII
Chemical formula of oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	OCl_2
Nature of bonding	Ionic bond			Covalent bond			
Structure of oxide	Giant ionic structure			Giant covalent	Simple molecular structure		
Acid-base property	Basic		Amphoteric	Acidic			

Basic oxides

Na_2O and MgO are called basic oxides because they react like a base. They react with water to form alkalis.

	Na_2O	**MgO**
Reaction with water	$Na_2O_{s} + H_2O_{l} \rightarrow 2NaOH_{aq}$	$MgO_{s} + H_2O_{l} \rightarrow Mg(OH)_{2\ aq}$
Reaction with acid (e.g. HCl)	$Na_2O_{s} + 2HCl_{aq} \rightarrow 2NaCl_{aq} + H_2O_{l}$	$MgO_{s} + 2HCl_{aq} \rightarrow MgCl_{2\ aq} + H_2O_{l}$

Acidic oxides

The covalent oxides are acidic as they can react with alkalis and neutralize them. Some of them can also dissolve in water to form acids.

- SiO_2
  - Reaction with alkalis:
    $SiO_{2(s)} + 2NaOH_{aq} \rightarrow Na_2SiO_{3(aq)} + H_2O_{l}$
  - SiO_2 **does not dissolve in water**
- P_4O_{10}
  - Reaction with alkalis:
    $P_4O_{10(s)} + 12NaOH_{aq} \rightarrow 4Na_3PO_{4(aq)} + 6H_2O_{l}$
  - Reaction with water:
    $$P_4O_{10(s)} + 6H_2O_{l} \rightarrow 4H_3PO_{4\ aq}$$
  - Phosphoric acid is produced
- SO_2
  - Reaction with alkalis:
  $SO_{2\ g} + 2NaOH_{aq} \rightarrow Na_2SO_{3\ aq} + H_2O_{l}$

- Reaction with water:
  $SO_{2(g)} + H_2O_{(l)} \rightleftharpoons H_2SO_{3(aq)}$
- Sulphurous acid is produced

- OCl_2
  - Reaction with alkali:
    $OCl_{2(g)} + 2NaOH_{(aq)} \rightarrow 2NaOCl_{(aq)} + H_2O_{(l)}$
  - Reaction with water
    $OCl_{2(g)} + H_2O_{(l)} \rightleftharpoons 2HOCl_{(aq)}$
  - Hypochlorous acid is produced

Amphoteric oxides

Al_2O_3 is considered *amphoteric* as it has **both** acid and basic properties. In other words, it can react like an acid or a base. Al_2O_3 does not dissolve in water.

Base: $6HCl_{(aq)} + Al_2O_{3(s)} \rightarrow 2AlCl_{3(aq)} + 3H_2O_{(l)}$
Acid: $2NaOH_{(aq)} + Al_2O_{3(s)} + 3H_2O_{(l)} \rightarrow 2Na[Al(OH)_4]_{(aq)}$

Checkpoint

1. Answer the following questions
   a. Write the equation for the reaction between sodium oxide and water. State the type of bonding present in sodium oxide

   b. With an aid of a chemical equation, explain whether P_4O_{10} is acidic, basic or amphoteric

   c. Relate the acid-base character of the oxides in (a) and (b) to the variation in metallic character of the elements in Period 3 of the Periodic table (sodium to argon).

   d. Show why sulphur dioxide is an acidic gas with the aid of a chemical equation

e. Al_2O_3 is said to be amphoteric, what does it mean by being 'amphoteric', explain your answer and include relevant chemical equations.

2. DSE 2022 Q13
   Describe the acid-base properties of the products formed (if any) when the following oxides are added to water separately. Chemical equations are NOT required. (5 marks)

Transition metals and their properties

Transition elements refer to the elements that are not a part of a main group. Most of these elements are metals, hence they are also commonly called transition metals. These elements have a few typical properties.

- Higher melting and boiling point that main group elements
- Multiple oxidation states
- Catalytic properties
- Coloured ions (when dissolved in aqueous solutions)

Most transition metals have higher boiling points than normal metals because more electrons can become delocalized and hence increase the strength of the metallic bonds between the metal ions and sea of delocalized electrons. The details of this are not covered in DSE, so the property of higher boiling point is rarely assessed. (Not seen yet)

Multiple oxidation states

Most transition metals can have multiple oxidation states because their partially filled third electron shell allows for different ways to form stable ions (i.e. different oxidation states)

Manganese

Compound	Oxidation number exhibited
MnO_2	+4
$MnCl_2$	+2
$KMnO_4$	+7

Iron

Compound	Oxidation number exhibited
FeO	+2
Fe_2O_3	+3

Vanadium

Compound	Oxidation number exhibited
VO	+2
V_2O_3	+3
VC	+4
$VOCl_3$	+5

Catalytic properties

This property mostly arises from the fact that transition metals can take up multiple oxidation states, they can go back and forth between the states to help catalyse reactions. **Catalysts increase the rate of reaction while remaining chemically unchanged after the reaction.**

Material	Process catalysed
Fe	Haber process (450°C, 200 atm, finely divided Fe) $N_2 + 3H_2 \rightleftharpoons 2NH_3$
$Cu/ZnO/Al_2O_3$	Methanol formation (250°C, 50-100 atm, $Cu/ZnO/Al_2O_3$) $CO + 2H_2 \rightarrow CH_3OH$
NiO	Steam methane reforming (700°C-1000°C, 10-20 atm, Ni) $CH_4 + H_2O \rightleftharpoons CO + 3H_2$
Pt/Rh	Catalytic converter
Pt/Ni/Pd	Catalytic hydrogenation of alkenes

Mechanism of catalysts:

This usually will not be assessed but it can be useful to understand how transition metals catalyse reactions. Take the reaction between persulphate ions ($S_2O_8^{2-}$) and iodide ions as an example.

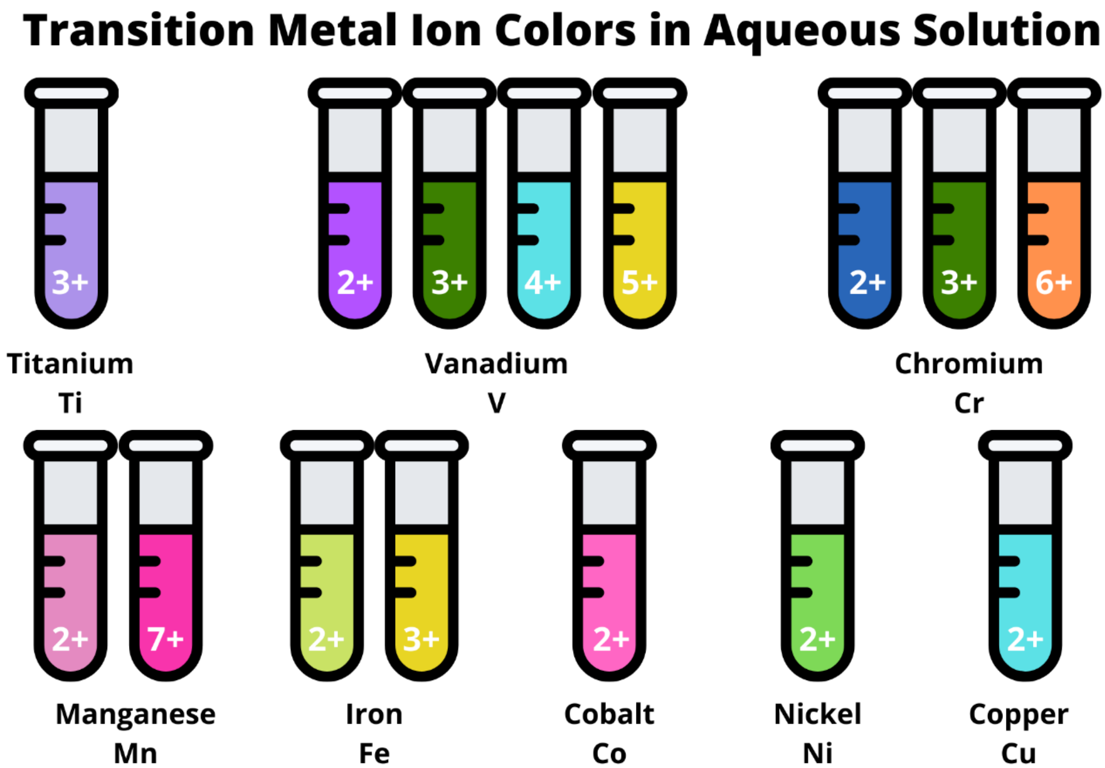
$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2$$

Normally the reaction proceeds quite slowly but using Fe as a catalyst can speed things up. The two ions on the reactant side are both negatively charged, a lot (kinetic) energy is required to overcome the electrostatic repulsion force.

$$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2SO_4^{2-} + 2Fe^{3+}$$
$$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$$

Notice how at the end of the two reactions, iron is present as Fe^{2+}, meaning that it remained chemically unchanged throughout the reaction. This is a good example of how the variable oxidation states of transition metals can help to catalyse reactions (redox in this case).

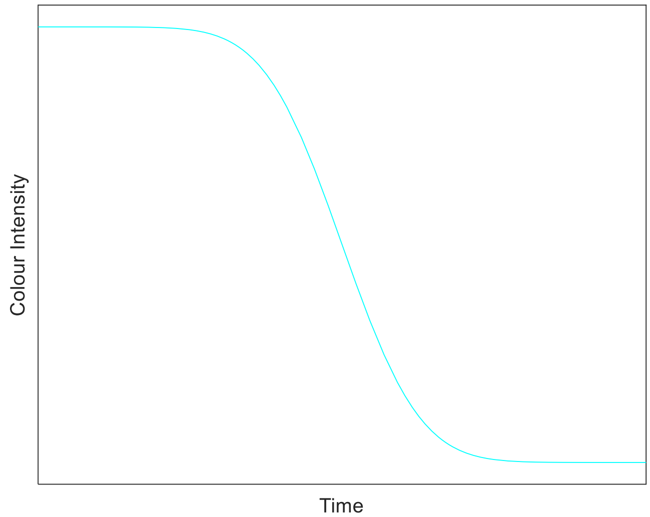
Coloured ions



Checkpoint

DSE 2017 Q14

At 60°C, MnO_4^-(aq) reacts with $C_2O_4^{2-}$(aq) in an acidic medium to give Mn^{2+}(aq), CO_2(aq) and H_2O(l). The graph below shows the variation of the colour intensity of the reaction mixture with time.



Based on the information above, write the chemical equation for the reaction and illustrate THREE characteristics of transition metals exhibited by manganese.

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$ x 2

$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$ x 5

$$2\mathrm{MnO_4^-} + 16\mathrm{H^+} + 5\mathrm{C_2O_4^{2-}} \rightarrow 2\mathrm{Mn^{2+}} + 8\mathrm{H_2O} + 10\mathrm{CO_2}$$

Multiple oxidation states

Mn has an oxidation number of +7 in MnO_4^-, but it has an oxidation number of +2 in Mn^{2+}.

Catalytic properties

The rate of reaction is proportional to the slope of the colour intensity curve against time. The slope increases as the reaction progresses. This indicates that the rate of reaction is higher after the reaction has progressed by a bit due to the presence of a catalyst, which in this case, is the product of the reaction, Mn^{2+}. Hence, Mn can catalyse chemical reactions and exhibits the catalytic properties of transitional metals.

(Mn remains chemically unchanged after the catalytic process.)

Coloured ions (when dissolved in aqueous solutions)

Colour intensity decreases with time since MnO_4^- is purple in colour while the product, Mn^{2+} is colourless (very pale pink), so manganese ions are coloured when dissolved in water.