Unit 7 reduction of metal oxide

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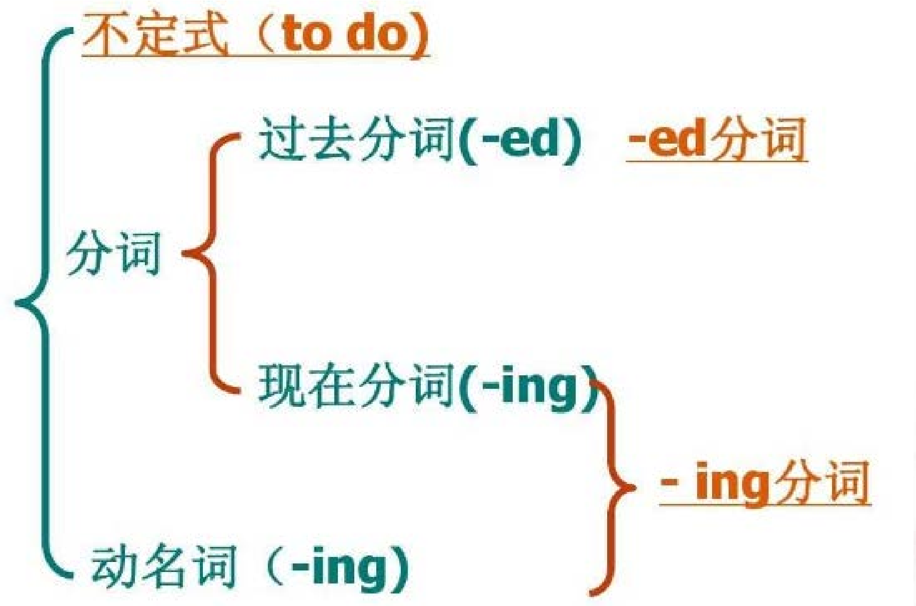
New words and expressions

- aluminothermic [əlju:maɪnə'θɜ:mɪk] 铝热法的
- carbon monoxide 一氧化碳
- contamination [kən͵tæmə'neɪʃən] 污染, 污染物
- dissociation [dɪ͵səʊsi'eɪʃn] 分解, 分离
- enthalpy [en'θælpɪ]焓, 热焓
- ferrotitanium [ferəʊtaɪ'teɪnɪəm] 钛铁
- ferroniobium [fe'rɒni:əʊbjəm] 铌铁
- ferrovanadium [ferəvə'neɪdɪəm] 钒铁
- ferrochromium [͵ferəʊ'krəʊmɪəm] 铬铁
- metallothermic reduction reactions [mɪtælə'θɜ:mɪk]金属热还原法
- monoxide 一氧化物
- reducing agent 还原剂
- reversing reaction 逆向反应
- standard thermodynamic condition 标准热力学条件

➢Stylistic features of EST（科技英语的文体特点）

□Non-Finite Verb（非谓语动词）



可对所修饰的词进行严格的说明和限定，同时保证行文简练、结构紧凑。

➢What can we learn?

- 1、What is reduction principle?
- 2、What are the reducing agents in common use?
- 3、The principle of “reduction with C, CO, H2， metal”.
- 4、What is the difference between C, CO and H2?

- $\Delta G - T$ diagram

- Metal oxide

reduction ← H_2, CO, C, Metal

metal

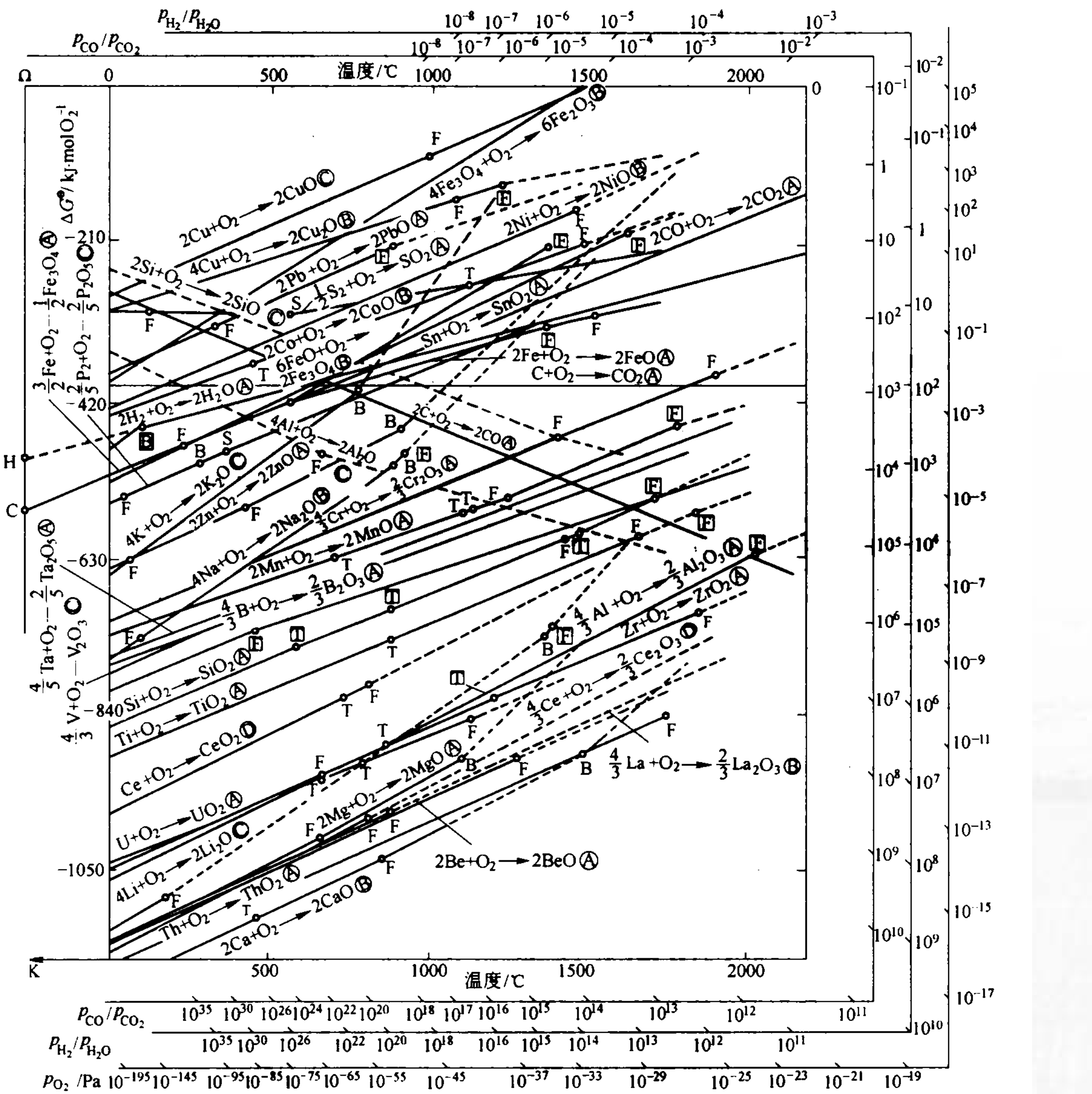
$$2M(s)+O_2(g)=2MO(s) \quad (7\text{-}1)$$

$$C(s)+O_2(g)=CO_2(g) \quad \Delta H^\ominus_{298}=-397\ \text{kJ} \quad (7\text{-}2)$$

$$2C(s)+O_2(g)=2CO(g) \quad \Delta H^\ominus_{298}=-222\ \text{kJ} \quad (7\text{-}3)$$

$$2CO(g)+O_2(g)=2CO_2(g) \quad \Delta H^\ominus_{298}=-572\ \text{kJ} \quad (7\text{-}4)$$

$$2H_2(g)+O_2(g)=2H_2O(g) \quad \Delta H^\ominus_{298}=-486\ \text{kJ} \quad (7\text{-}5)$$



- Metal oxides may be reduced to the metal by carbon, carbon monoxide, hydrogen or other metals which form more stable oxides (more negative ΔG for oxide formation) than the metal oxide to be reduced.
- If the oxides and reduced phases are assumed to be pure solids and MO is the hypothetical metal oxide required to be reduced, the reaction lines on the ΔG -T diagram can be used to assess the various reducing agents.

- It can be seen that if a sufficiently high temperature is achieved any metal oxide may be reduced with carbon according to the reaction:

$$2MO(s)+C(s) = 2M(s)+CO_2(g) \text{ below } 650^\circ C \quad (7\text{-}6)$$

$$MO(s)+C(s) = M(s)+CO(g) \text{ above } 650^\circ C \quad (7\text{-}7)$$

- As the minimum reduction temperature rises above 1800°C , the cost of reduction with carbon increases substantially. This is due to the problem of providing refractory materials that can cope with these high temperatures and the increased reactivity of the metal with its environment resulting in increased contamination. For these reasons, iron, manganese, chromium, tin, lead, and zinc are the main metal oxides reduced with carbon.

- Under standard thermodynamic conditions CO gas will reduce all the oxides above the $6FeO+O_2 \rightarrow 2Fe_3O_4$ reaction line and, as stated above, is normally achieved with an evolution of heat for the less stable oxides, e. g. Fe. Thus, reduction of most metal oxides with carbon is endothermic due to the smaller exothermic nature of reaction (7−3) compared with reaction (7−4) while reduction of FeO and less stable oxides with CO is exothermic; the enthalpy values become more positive in each case with increasing stability of the oxide.
- Changing the partial pressures of CO, CO_2 and O_2 will alter the position of the reaction lines on the diagram. If the CO / CO_2 ratio is increased the $2CO+O_2 \rightarrow 2CO_2$ reaction line will be lowered (more negative ΔG) allowing other metal oxides, e. g. ZnO, to be reduced with CO.

后置定语

- Reduction of metal oxides with CO is the most favorable reaction at the lower temperatures (below 700℃) in the blast furnace while above this temperature reduction with C is thermodynamically favorable. However, due to the high CO / CO_2 ratios, the $2CO+O_2 \rightarrow 2CO_2$ reaction line is lowered and the improved reaction kinetics associated with the gas-solid reaction(7 - 8) compared with the solid-solid reaction(7 - 7), reduction of metal oxides with CO takes place at higher temperatures than 700 ℃ in the blast furnace.
- At the onset of slag formation, the surface of the metal oxide will be covered with a layer of liquid slag which will prevent contact with carbon monoxide (CO is insoluble in liquid slags). The only method available for reduction at this stage is for the solid coke to penetrate the slag layer and provide a solid coke—solid metal oxide reaction according to reaction (7-7). Thus, although predominantly indirect reduction of metal oxides with coke takes place in the blast furnace there is also some direct reduction.

Compared with 与。。。比较
associated with：与。。。相关联

Reduction with CO

- Reduction of metal oxides with hydrogen is of less importance industrially than C or CO. The lower enthalpy value for the reaction $2H_2 + O_2 \rightarrow H_2O$ results in less exothermic reduction of metal oxides with hydrogen than with carbon monoxide; most metal oxides being reduced endothermically. Examination of reaction(7−2), reaction (7−3), reaction (7−5) indicates that H_2 is a better reducing agent of metal oxides than carbon at the lower temperature(below 650°C). From the same thermodynamic reasoning, CO should be a better reducing agent than H_2 below 800°C and H_2 better than CO above 800°C. However, due to its increasing diffusivity, hydrogen is often superior to CO below 800°C in the reduction of metal oxides while, due to improved reduction kinetics, CO is a more effective reducing agent above 800°C. In certain cases, CO and H_2 are added as joint reducing agents.

	Comparing H_2 and C		Comparing H_2 and CO	
	H_2	C	CO	H_2
thermodynamic	<650℃	>650℃	<800℃	>800℃
kinetics			>800℃	<800℃

$MO+2C \rightarrow MC+CO$ Which needs another reducing agent other than carbon, CO

- a metal oxide is reduced with another metal which forms a more stable oxide. These are called metallothermic reduction reactions and are normally used when the metal to be extracted forms stable carbides（Ti, Cr, Nb）on reduction with carbon.
- These reactions never go to completion, leaving some residual unreacted reducing agent in the final metal product together with some unreduced metal oxide in the oxide or slag phase.
- Metallothermic reductions are normally exothermic, the stronger the reducing agent the more exothermic the reaction.

$3MO+2Al \rightarrow 3M+Al_2O_3$ Exothermic, Al and M are present in the product

$2MO+Si \rightarrow 2M+SiO_2$ exothermic

Reducing agent	T	Metal oxide
C	>650	Fe, Mn, Cr, Sn, Pb, Zn
CO	>800	Cu, Pb
H_2	<800	Fe, Cu, Pb
metal	High T	Stable oxide

- **Homework**

Choose and describe a typical ……

THANKS

End

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