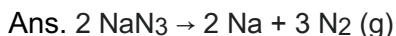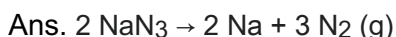1. Sodium azide (NaN_3) is an essential component of the safety airbags used in vehicles.

(a) Write down the balanced chemical reaction that causes the inflation of the airbag following a collision.

Ans. $2\ NaN_3 \rightarrow 2\ Na + 3\ N_2$ (g)

(b) If we need to inflate a 45.0 L airbag, how much sodium azide (in grams) should we use?

Ans. $2\ NaN_3 \rightarrow 2\ Na + 3\ N_2$ (g)

This balanced reaction shows 2 x 65.0 g (mol. Wt. of sodium azide) produces 22.4 x 3 L of N2
i.e., 67.2 L N2 is produced from 130.0 g of sodium azide
Hence, 45.0 L N2 production requires $= (45.0/67.2) \times 130.0\ g \approx 87.0$ g of sodium azide

(c) An equivalent amount of hazardous sodium is produced during this reaction. How is this sodium regulated so that it does not affect the passenger during the opening of the airbag?

Ans. $2\ NaN_3 \rightarrow 2\ Na + 3\ N_2$ (g)
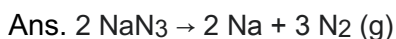
The reaction produces an equivalent amount of hazardous amounts of sodium during the thermal decomposition of sodium azide. This sodium can cause trouble to the passenger via direct exposure or via the formation of sodium hydroxide (after reacting with available moisture).

This issue is resolved by adding an adequate amount of potassium nitrate and silica.
The KNO3 oxidizes sodium to its corresponding oxide, which further reacts with silica to create benign silicate salts. Same fate follows for the potassium ion. The first step of the reaction produces extra N2 that aids the inflation of the airbag.

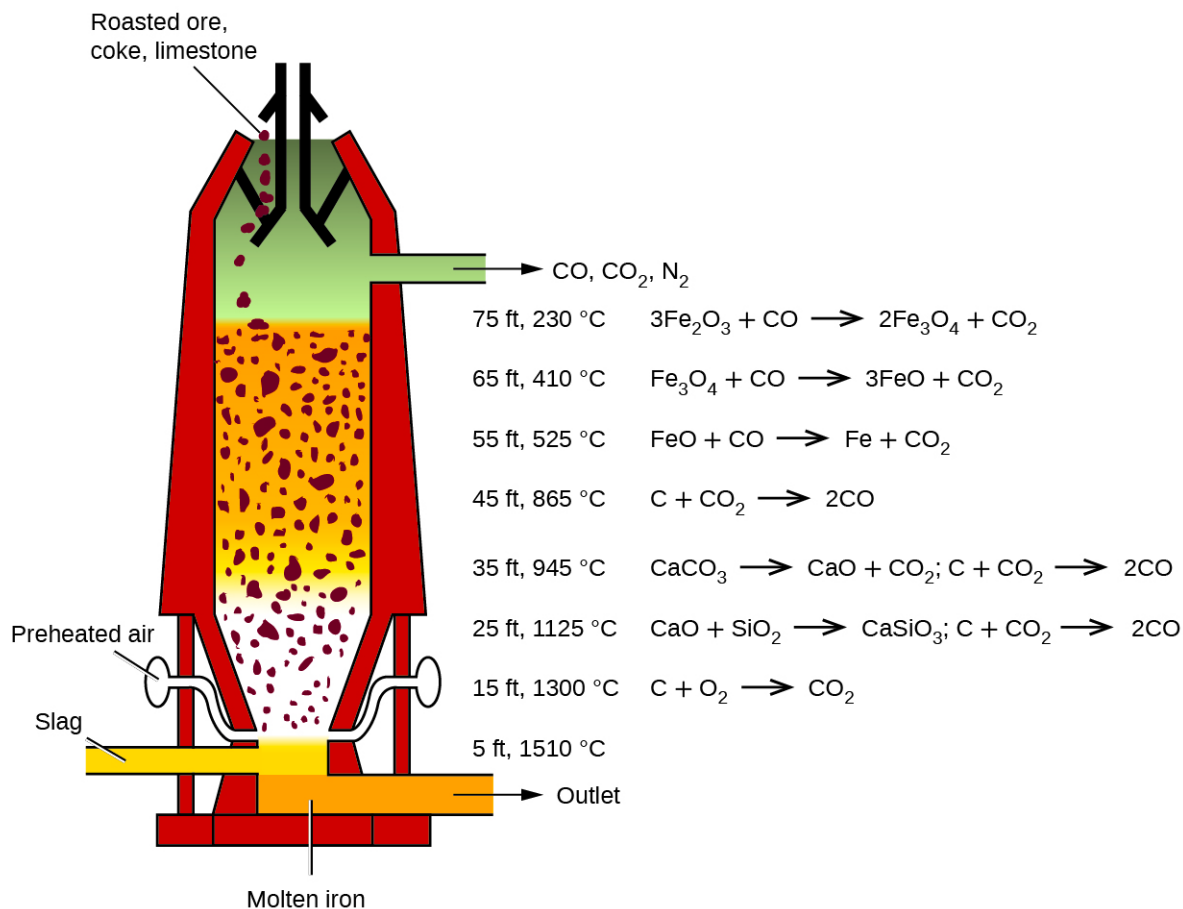$10\ Na + 2\ KNO_3 \rightarrow K_2O + 5\ Na_2O + N_2$ (g)

$K_2O + Na_2O + 2\ SiO_2 \rightarrow K_2SiO_3 + Na_2SiO_3$
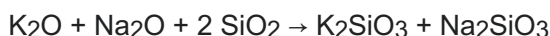
More about the interesting airbag chemistry can be found here:
https://www.youtube.com/watch?v=qCIes_xJdGo&ab_channel=Lesics

2. Blast furnace is regarded as the heart of the steel industry, where the iron ore is converted into molten iron. Here, a significant amount of coke is required for the operation of the furnace, which results in a huge carbon footprint for iron production.

(a) What is the specific chemical role of coke in this process?

Ans. The coke (or carbon) produces CO following its partial oxidation. This CO is the primary reducing agent of iron oxide ore as it sequentially reduces Ee2O3 to Fe3O4 to FeO and finally to Fe (liquid).

Roasted ore, coke, limestone

CO, CO_2, N_2

75 ft, 230 °C $\quad 3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$

65 ft, 410 °C $\quad Fe_3O_4 + CO \longrightarrow 3FeO + CO_2$

55 ft, 525 °C $\quad FeO + CO \longrightarrow Fe + CO_2$

45 ft, 865 °C $\quad C + CO_2 \longrightarrow 2CO$

35 ft, 945 °C $\quad CaCO_3 \longrightarrow CaO + CO_2; C + CO_2 \longrightarrow 2CO$

25 ft, 1125 °C $\quad CaO + SiO_2 \longrightarrow CaSiO_3; C + CO_2 \longrightarrow 2CO$

15 ft, 1300 °C $\quad C + O_2 \longrightarrow CO_2$

5 ft, 1510 °C

Preheated air
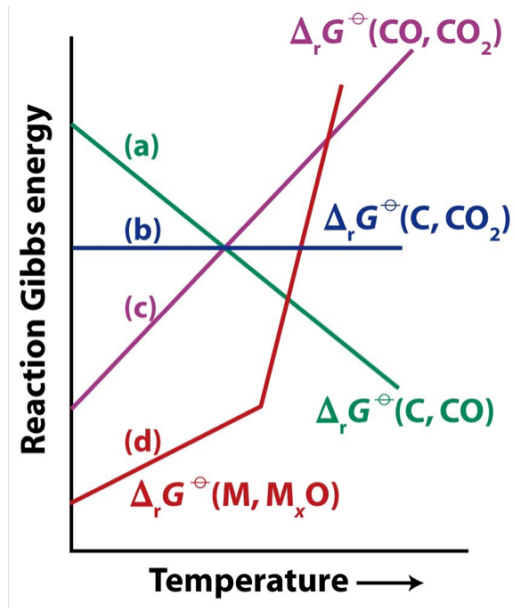
Slag

Outlet

Molten iron

Ref. https://chem.libretexts.org/
Video: https://www.youtube.com/watch?v=lr0xhtR5ssU&ab_channel=RecentGyan

Can you use the Ellingham diagram to support your answer of Q2(a)?

Ans. The C to CO conversion and CO to CO2 conversion runs in opposite directions in the Ellingham diagram. (mention the entropy factor difference).

The conversion of Fe2O3 to Fe conversion slope is in between them and creates a region below 1073 K (highlighted in blue) where CO2 is stable compared to Fe2O3. Hence, in this region, CO reduces Fe2O3 to Fe, while producing CO2 as a product. Beyond that temperature region, CO will be unable to reduce Fe2O3.
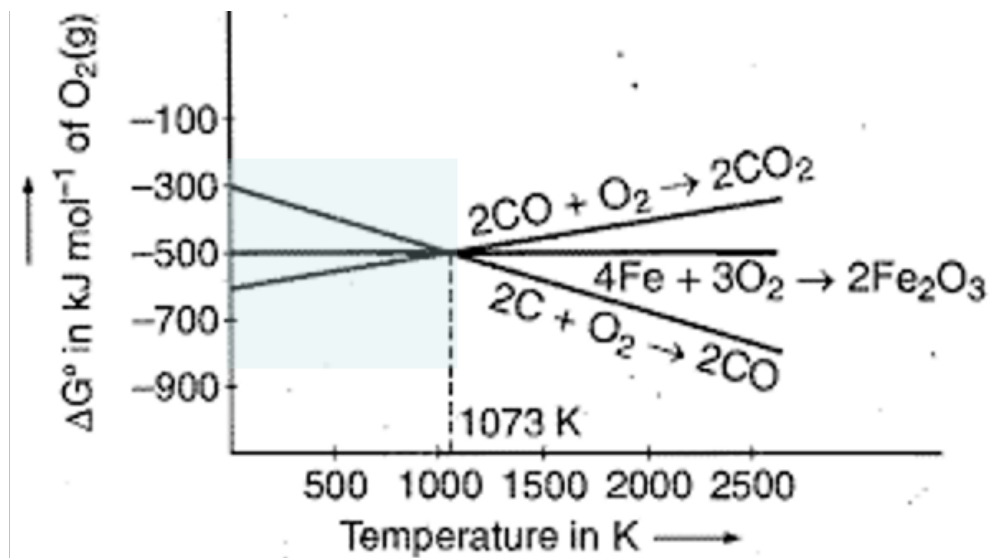
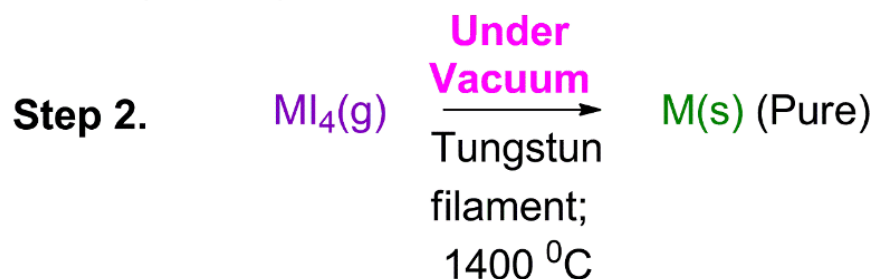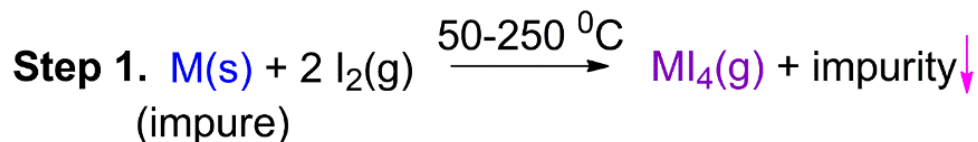(b) $CaCO_3$ is also added in the blast furnace. Is this addition really necessary for good quality iron production?

Ans. CaCO3 decomposes to CaO (and CO2) under the heat in the blast furnace. This CaO reacts with SiO2 present in the ore and creates CaSiO3, which is a solid and floats over molten iron to create the slag. Thus, CaCO3 purifies the iron.
The appropriate reactions are shown in Q.(a)

3. The Arkel-de Boer process has been developed for purifying titanium (Ti).

(a) Describe the basic chemistry behind the process?

Ans. Producing volatile metal complexes and using the aspect for purification.

Step 1. $M(s) + 2\ I_2(g) \xrightarrow{50\text{-}250\ ^0C} MI_4(g) + impurity\downarrow$
(impure)

Step 2. $MI_4(g) \xrightarrow[\substack{Tungstun \\ filament; \\ 1400\ ^0C}]{\textbf{Under Vacuum}} M(s)$ (Pure)

MI_4	MP (^{0}C)	BP (^{0}C)
Ti	150	377
Zr	499	600

Where M = **Ti, Zr**, Hf, V, Th

(b) Do you think Kroll's method is better for purifying Ti compared to the Arkel-de Boer process?

Ans. Kroll's process:

$$TiCl_4(g) + 2\ Mg\ (l) \xrightarrow{800\text{-}850\ ^0C} Ti(s) + 2\ MgCl_2(l)$$
$$\text{(pure)}$$
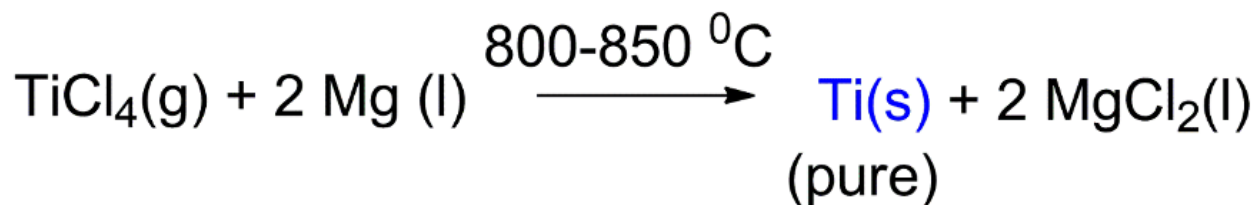
Advantages:

i. Low operational temperature, ii. No need of initial metal reduction
iii. Less costly

4. Addition of aluminum (Al) foil in acidic water results in H_2 production. However, the addition of silver (Ag) doesn't display the same reaction. Can you explain this observation with the concept of the standard reduction potential.
   Following are the standard reduction potential of the two metals vs. standard hydrogen electrode (SHE):
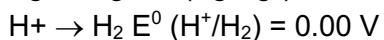 E^0 (Al^{+3}/Al) = -1.66 V
   E^0 (Ag^+/Ag) = +0.80 V

Ans.
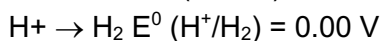
Al $\rightarrow$ Al^{3+} E^0 (Al/Al^{+3}) = +1.66 V
H+ $\rightarrow$ H_2 E^0 (H^+/H_2) = 0.00 V
E value of full reaction = +1.66 V (Gibbs Free Energy negative, spontaneous)

Ag $\rightarrow$ Ag^+ E^0 (Ag/Ag^+) = -0.80 V
H+ $\rightarrow$ H_2 E^0 (H^+/H_2) = 0.00 V
E value of full reaction = -0.80 V (Gibbs Free Energy positive, non-spontaneous)