UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2005/2006

April/Mei 2006

EBB 335/3 – Pirometalurgi

Masa : 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi SEBELAS muka surat yang bercetak dan DUA muka surat LAMPIRAN sebelum anda memulakan peperiksaan.

Kertas soalan ini mengandungi TUJUH soalan.

Jawab LIMA soalan. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.

Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru.

Semua jawapan hendaklah dijawab dalam Bahasa Malaysia.

...2/-

1. [a] Adalah dikehendaki bahawa PbO dihapuskan daripada bijih yang mengandungi PbO, PbS dan $PbSO_4$ dengan cara menukarkannya kepada PbS atau $PbSO_4$ melalui tindakbalas dengan gas $SO_2 - O_2$. Walaupun tekanan O_2 di dalam gas boleh dilaraskan dalam lingkungan had yang lebar tetapi tekanan separa SO_2 mungkin tidak melebihi 0.5 atm. Kira suhu maksimum dimana ia boleh dijamin bahawa fasa PbO boleh dihapuskan. Gunakan data yang diberikan di **Lampiran**.

(60 markah)

*It is required that PbO be eliminated from an ore containing PbO, PbS, and $PbSO_4$ by converting it to PbS or $PbSO_4$ by reaction with an $SO_2 - O_2$ gas. Although the pressure of O_2 in the gas can vary within wide limits, the partial pressure of SO_2 may not be higher than 0.5 atm. Calculate the maximum temperature at which it can be guaranteed that the PbO phase will be eliminated. Use the data provided in the **Appendix**.*

(60 marks)

[b] Huraikan dengan jelas perbezaan yang berikut:

(a) Panggang pengoksidaan

(b) Panggang pengkloridaan

(c) Panggang pengsulfatan

(d) Panggang manis ("mati")

Sertakan masing-masing dengan contoh.

(40 markah)

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Describe clearly the differences of:

(a) *Oxidation roasting*

(b) *Chloridizing roasting*

(c) *Sulphating roasting*

(d) *Sweet ("dead") roasting*

Provide each with an example.

(40 marks)

2. [a] Gas daripada suatu retort untuk penurunan karbotermik ZnO mengandungi 50.3% Zn, 49.0% CO dan 0.7% CO_2.

(i) Kira peratusan Zn yang akan teroksida semula dengan CO_2.

(ii) Daripada data dalam **Lampiran**, kira suhu mula kondensasi dan juga suhu dimana kondensasi 99% lengkap. Jumlah tekanan ialah tetap = 1 atm dan pengoksidaan semula diandaikan sempurna sebelum kondensasi bermula.

(60 markah)

The gas from a retort for carbothermic reduction of ZnO contains 50.3 percent Zn, 49.0 percent CO, and 0.7 percent CO_2.

(i) *Calculate the percentage of zinc that will reoxidize by reaction with CO_2.*

(ii) *From data in the* ***Appendix****, calculate the temperature of initial condensation, as well as the temperature where condensation is 99 percent complete. The total pressure is constant = 1 atm, and reoxidation is assumed completed before condension starts.*

(60 marks)

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[b] Tunjukkan perbezaan-perbezaan di antara proses peleburan zink yang dilakukan di retort mengufuk New Jersey dan relau bagas peleburan Imperial. Masukkan suatu lakaran untuk setiap reaktor.

(40 markah)

Indicate the differences between the zinc smelting process carried out in the New Jersey vertical retort and in the Imperial Smelting blast furnace. Include a sketch of each reactor.

(40 marks)

3. [a] (i) Menggunakan data daripada **Lampiran**, kira tekanan oksigen keseimbangan untuk penukaran Cu_2S tulen ke Cu tulen pada 1300°C jika p_{SO_2} = 0.1 atm.

(ii) Kira aktiviti yang berkaitan untuk FeS di dalam 'matte' dan Fe di dalam logam jika aktiviti FeO di dalam jermang berbanding dengan cecair FeO lampan sejuk ialah 0.4.

(iii) Kira aktiviti-aktiviti berkaitan Fe_3O_4 (s) dan Cu_2O (l).

(iv) Dalam arah manakah nilai-nilai tersebut di atas akan terkesan oleh:

I. aktiviti FeO lebih tinggi.

II. tekanan SO_2 lebih tinggi.

III. suhu rendah?

(60 markah)

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(i) *Using data in the **Appendix**, calculate the equilibrium oxygen pressure for conversion of pure* Cu_2S *to pure Cu at* 1300^oC *if* $p_{SO_2} = 0.1$ *atm.*

(ii) *Calculate the corresponding activities of FeS in the matte and Fe in the metal if the FeO activity in the slag, relative to supercooled liquid FeO, is 0.4.*

(iii) *Calculate the corresponding activities of* Fe_3O_4 *(s) and* Cu_2O *(l).*

(iv) *In which direction would the above values be affected by:*

I. *higher FeO activity*

II. *higher* SO_2 *pressure*

III. *lower temperature*

(60 marks)

[b] Di dalam peleburan kilat 'matte' untuk bijih-bijih sulfida, jelaskan perbezaan-perbezaan utama di antara proses-proses INCO dan Outokumpu berdasarkan yang berikut:

(i) Penggunaan tenaga.

(ii) Jumlah isipadu gas terbebas.

(iii) % SO_2 di dalam gas efluen.

(iv) Jumlah habuk yang hilang.

(v) Produktiviti.

Masukkan lakaran untuk setiap reaktor.

(40 markah)

In matte flash smelting of sulfide ores describe the major differences between the INCO and Outokumpu processes with respect to:

(i) *Energy consumption*

(ii) *Amount of the offgas volume*

(iii) *% SO_2 in the effluent gas*

(iv) *Amount of dust losses*

(v) *Productivity*

Include a sketch of each reactor

(40 marks)

4. [a] Dolomit bakar (MgO) mungkin diturunkan oleh tindakbalas karbotermik seperti berikut:

$$MgO\ (s) + C\ (s) = Mg\ (g) + CO\ (g)$$

(i) Kira ΔG_T^0 untuk tindakbalas ini pada 1300, 1500, 1700, 1900 dan 2100°C menggunakan data yang diberikan di dalam **Lampiran**.

(ii) Berapakah tekanan-tekanan keseimbangan untuk magnesium dan karbon monoksida pada setiap suhu ini?

(60 markah)

Burned dolomite (MgO) may be reduced by the carbothermic reaction as follows:

$$MgO\ (s) + C\ (s) = Mg\ (g) + CO\ (g)$$

(ii) *Calculate ΔG_T^0 for this reaction at 1300, 1500, 1700, 1900, and 2100°C using the data provided in the* ***Appendix****.*

(ii) *What are the equilibrium pressures of magnesium and carbon monoxide at each of these temperatures?*

(60 marks)

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[b] Huraikan dengan terperinci proses **Pidgeon** untuk pengekstrakan logam magnesium daripada dolomit bakar. Tunjukkan tindakbalas penurunan keseluruhan dan lakarkan reaktor yang digunakan dalam proses perindustrian.

(40 markah)

Describe in detail the ***Pidgeon*** *process for extracting magnesium metal from burned dolomite. Indicate the overall reduction reaction and sketch the reactor used in the industrial process.*

(40 marks)

5. [a] Kesemua fosforus daripada bahan - bahan mentah yang dimasukkan dalam relau bagas akhirnya menuju ke logam panas. Terangkan mengapakah keadaan ini berlaku berdasarkan prinsip-prinsip asasnya.

(30 markah)

All the phosphorus from the input raw materials of a blast furnace finally go to the hot metal. Explain why this happens from the fundamental principles.

(30 marks)

[b] Terangkan secara ringkas peranan $CaCO_3$ sebagai fluks di dalam relau bagas pembuatan besi.

(30 markah)

Explain in brief the role of $CaCO_3$ as a flux in blast furnace iron making.

(30 marks)

...8/-

[c] Dengan bantuan Teori Filem Pendua Whitman, terbitkan ungkapan umum untuk pemindahan sulfur melintasi sempadan antara cecair jermang dan cecair logam panas.

(40 markah)

With the help of Whitman's Two Film Theory, derive the general expression for sulphur transfer across the boundary between liquid slag and liquid hot metal.

(40 marks)

6. [a] Anggapkan bahawa satu relau bagas besi menghasilkan logam panas berkomposisi Fe = 92.8%, C = 3.8%, Si = 2.1%, P = 0.9%, Mn = 0.4%. Bijih yang dianalisis terdiri daripada Fe_2O_3 = 78.0%, SiO_2 = 8.4%, MnO = 0.6%, Al_2O_3 = 5.0%, P_2O_5 = 1.7%, MgO = 1.2%, H_2O = 5.1%. Fluks yang diperlukan hanya 25% daripada berat bijih dan analisis fluk mengandungi $CaCO_3$ = 96%, $MgCO_3$ = 2%, SiO_2 = 2%. Penggunaan kok adalah 900 kg/thm dan mengandungi C = 88%, SiO_2 = 9%, Al_2O_3 = 1%, H_2O = 2%. Gas yang terbebas terdiri dari dua bahagian CO kepada satu bahagian CO_2. Anggapkan bahawa 99.5% besi telah dihasilkan dan hanya 0.5% keluar sebagai jermang. Kirakan:

(i) Berat bijih yang diperlukan.

(ii) Berat jermang yang dihasilkan dan komposisinya.

(iii) Isipadu dan peratus komposisi bagi gas relau bagas.

(60 markah)

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Assume that an iron blast furnace produces hot metal of composition Fe = 92.8%, C = 3.8%, Si = 2.1%, P = 0.9%, Mn = 0.4%. The ore has the analysis of Fe_2O_3 = 78.0%, SiO_2 = 8.4%, MnO = 0.6%, Al_2O_3 = 5.0%, P_2O_5 = 1.7%, MgO = 1.2%, H_2O = 5.1%. The flux needed is 25% of the weight of ore and has the analysis of $CaCO_3$ = 96%, $MgCO_3$ = 2%, SiO_2 = 2%. Coke consumption is 900 kg/thm and contains C = 88%, SiO_2 = 9%, Al_2O_3 = 1%, H_2O = 2%. The gases carry 2 parts of CO to 1 part of CO_2. Assume that 99.5% of the iron is reduced and only 0.5% goes to the slag. Calculate:

(i) The weight of ore required.

(ii) The weight of slag made and its composition.

(iii) The volume and the percentage composition of the blast furnace gas.

(60 marks)

[b] Tuliskan nota pendek bagi (mana-mana 2) berikut:

(i) Kealkalian jermang.

(ii) Peranan kok dalam sesebuah relau bagas besi.

(iii) Masalah-masalah yang dikaitkan dengan kehadiran Na_2O dan K_2O di dalam relau bagas bahan-bahan mentah.

(40 markah)

Write short notes on (any two):

(i) Basicity of slag.

(ii) Role of coke in an iron blast furnace.

(iii) Problems associated with the presence of Na_2O and K_2O in the blast furnace raw materials.

(40 marks)

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7. Jawab mana-mana empat daripada berikut:

Answer any four from the following:

[a] Nyatakan prinsip-prinsip penyahgasan keluli dalam penyahgas RH.

(20 markah)

Outline the principles of degassing of steel in a RH degasser.

(20 marks)

[b] Bincangkan masalah pengoksidaan semula DRI dan terangkan secara ringkas bagaimana untuk mengatasi masalah tersebut.

(20 markah)

Discuss the problem of reoxidation of DRI and mention in brief how to overcome the problem.

(20 marks)

[c] Nyatakan langkah-langkah pemprosesan utama yang berkaitan dalam proses HyL untuk penghasilan DRI.

(20 markah)

Outline the major process steps associated in the HyL process for producing DRI.

(20 marks)

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[d] Tunjukkan secara skema helaian aliran proses bagi proses COREX yang menunjukkan semua masukan dan keluaran.

(20 markah)

Schematically show the process flowsheet of the COREX process indicating the inputs and outputs.

(20 marks)

[e] Nyatakan prinsip-prinsip proses LD yang menunjukkan tindakbalas-tindakbalas utama yang terlibat.

(20 markah)

Outline the principles of LD process indicating the major reactions involved.

(20 marks)

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LAMPIRAN

SELECTION STANDARD GIBBS ENERGIES

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$S_4(g) = 2\ S_2$	62 800	115.5	25–1700
$S_6(g) = 3\ S_2$	276 000	305	25–1700
$S_8(g) = 4\ S_2$	400 000	450	25–1700
$SO(g) = \frac{1}{2}\ S_2 + \frac{1}{2}\ O_2$	57 800	−5.0	445–2000
$SO_2 = \frac{1}{2}\ S_2 + O_2$	362 000	72.7	445–2000
$SO_3(g) = \frac{1}{2}\ S_2 + \frac{3}{2}\ O_2$	458 000	163.3	445–2000
$S = S(l)$	1715	4.44	115 m
$S(l) = \frac{1}{2}\ S_2$	58 600	68.3	115– 445 b
$S_2 = 2\ S(g)$	469 300	161.3	25–1700

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
Graphite = Diamond	1440	−4.48	29– 900
$C = C(g)$	713 500	155.5	1750–3800 s
$CH_4(g) = C + 2\ H_2$	91 040	110.7	500–2000
$CO = C + \frac{1}{2}\ O_2$	110 540	−89.35	−150– 500
$CO = C + \frac{1}{2}\ O_2$	114 400	−85.77	500–2000
$CO_2 = C + O_2$	395 350	−0.54	500–2000
$CO_2 = C + O_2$	393 500	−2.88	−50– 500
$COS(g) = C + \frac{1}{2}\ O_2 + \frac{1}{2}\ S_2$	202 800	−9.96	500–2000
$CS(g) = C + \frac{1}{2}\ S_2$	−163 000	−88	25–2000
$CS_2(g) = C + S_2$	11 400	−6.5	25–2000

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$2\ PbO \cdot SiO_2 = 2\ PbO \cdot SiO_2(l)$	51 050	50.3	743 m
$2\ PbO \cdot SiO_2(l) = 2\ PbO(l) + SiO_2$	33 500	−6.7	885–1500
$PbO \cdot SiO_2 = PbO \cdot SiO_2(l)$	26 000	25.1	764 m
$PbO \cdot SiO_2 = PbO(l) + SiO_2$	25 100	1.26	885–1500
$Pb = Pb(l)$	4810	8.0	327 m
$Pb(l) = Pb(g)$	182 000	90.1	327–1746 b
$PbO = PbO(l)$	27 500	23.7	886 m
$PbO(l) = Pb(l) + \frac{1}{2}\ O_2$	181 000	68.0	886–1535 b
$Pb_3O_4 = 3\ Pb(l) + 2\ O_2$	702 500	370	328–1200
$PbO_2 = Pb(l) + O_2$	272 000	194	328– 900
$PbS = Pb(l) + \frac{1}{2}\ S_2$	163 000	88.0	328–1113 m
$PbO \cdot B_2O_3 = PbO(l) + B_2O_3(l)$	102 500	33.0	885–1535
$PbO \cdot 2\ B_2O_3 = PbO(l) + 2\ B_2O_3(l)$	166 500	79.5	885–1535
$PbSO_4 = PbO + SO_2 + \frac{1}{2}\ O_2$	401 000	262	25–1090 m

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$Cu = Cu(l)$	13 050	9.62	1085 m
$Cu(l) = Cu(g)$	308 200	108.9	1085–2570 b
$Cu_2O = Cu_2O(l)$	56 820	37.66	1244 m
$Cu_2O = 2\ Cu + \frac{1}{2}\ O_2$	168 400	71.25	25–1085
$Cu_2O(l) = 2\ Cu(l) + \frac{1}{2}\ O_2$	119 000	39.5	1236–2000
$CuO = Cu + \frac{1}{2}\ O_2$	152 300	85.4	25–1085
$Cu_2S_\gamma = 2\ Cu + \frac{1}{2}\ S_2$	140 700	43.3	25– 435
$Cu_2S_\beta = 2\ Cu + \frac{1}{2}\ S_2$	132 000	30.8	435–1129 m
$Cu_2S = Cu_2S(l)$	9000	6.40	1129 m
$Cu_{1.738}S_\beta = 1.738\ Cu + \frac{1}{2}\ S_2$	113 600	26.6	435– 620
$CuS = Cu + \frac{1}{2}\ S_2$	115 600	76.0	25– 430

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$CuFeS_2 = Cu + Fe + S_2$	278 600	115	557– 700
$Cu_2O \cdot Fe_2O_3 = Cu_2O + Fe_2O_3$	37 700	19.0	25–1100
$CuSO_4 = \frac{1}{2}\ CuO \cdot CuSO_4 + \frac{1}{2}\ SO_2 + \frac{1}{4}\ O_2$	152 600	136	400– 800
$CuO \cdot CuSO_4 = 2\ CuO + SO_2 + \frac{1}{2}\ O_2$	297 000	250	500– 900
$Fe_\delta = Fe(l)$	13 800	7.61	1536 m
$Fe(l) = Fe(g)$	363 600	116.0	1536–2860 b
$Fe_{0.947}O = Fe_{0.947}O(l)$	31 340	19.0	1370 m
$Fe_{0.947}O = 0.947\ Fe + \frac{1}{2}\ O_2$	263 700	64.4	25–1370 m
$FeO(l) = Fe(l) + \frac{1}{2}\ O_2$	256 000	54.7	1371–2000
$Fe_3O_4 = 3\ Fe + 2\ O_2$	1 100 000	307	25–1597 m
$Fe_2O_3 = 2\ Fe + \frac{3}{2}\ O_2$	814 000	251	25–1500
$FeS = Fe_\gamma + \frac{1}{2}\ S_2$	164 000	61.0	988–1190 m
$FeS_2 = FeS + \frac{1}{2}\ S_2$	182 000	188	630– 760
$Fe_2(SO_4)_3 = Fe_2O_3 + 3\ SO_2 + \frac{3}{2}\ O_2$	772 000	724	400– 800
$Fe_2(SO_4)_3 = 2\ FeSO_4 + SO_2 + O_2$	396 000	352	430– 630
$FeSO_4 = \frac{1}{2}\ Fe_2O_3 + SO_2 + \frac{1}{4}\ O_2$	203 500	202.3	500– 630
$2\ FeO \cdot SiO_2 = 2\ FeO \cdot SiO_2(l)$	92 050	61.7	1220 m
$2\ FeO \cdot SiO_2 = 2\ FeO + SiO_2$	36 200	21.0	25–1220 m
$Zn = Zn(l)$	7320	10.6	420 m
$Zn(l) = Zn(g)$	118 000	100.3	420– 907 b
$ZnO = Zn(g) + \frac{1}{2}\ O_2$	460 240	190.4	907–1700
$ZnS = Zn(l) + \frac{1}{2}\ S_2$	278 000	108	420– 907
$ZnS(g) = Zn(g) + \frac{1}{2}\ S_2$	−5020	30.5	1182 b–1700
$ZnO \cdot Fe_2O_3 = ZnO + Fe_2O_3$	9620	3.8	25– 700
$ZnSO_4 = ZnO + SO_2 + \frac{1}{2}\ O_2$	328 000	267	25– 700

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$Mg = Mg(l)$	8960	9.71	650 m
$Mg(l) = Mg(g)$	129 600	95.1	650–1093 b
$MgSO_4 = MgO + SO_2 + \frac{1}{2}\ O_2$	371 000	261	670–1050
$2\ MgO \cdot SiO_2 = 2\ MgO \cdot SiO_2(l)$	71 100	32.6	1898 m
$2\ MgO \cdot SiO_2 = 2\ MgO + SiO_2$	67 200	4.31	25–1898 m
$MgO \cdot SiO_2 = MgO \cdot SiO_2(l)$	75 300	40.6	1577 m
$MgO \cdot SiO_2 = MgO + SiO_2$	41 100	6.1	25–1577 m
$MgO = Mg + \frac{1}{2}\ O_2$	601 000	107.6	25– 650
$MgO = Mg(g) + \frac{1}{2}\ O_2$	730 000	204	1090–2000
$MgS = Mg + \frac{1}{2}\ S_2$	410 000	94.4	25– 650
$MgS = Mg(g) + \frac{1}{2}\ S_2$	540 000	193	1090–1700
$MgO \cdot Al_2O_3 = MgO + Al_2O_3$	35 600	−2.09	25–1400
$MgCO_3 = MgO + CO_2$	116 000	173.4	25– 402 d

APPENDIX

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$2\ PbO\cdot SiO_2(l) = 2\ PbO(l) + SiO_2$	33 500	−6.7	885-1500
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$CuO = Cu + \frac{1}{2}\ O_2$	152 300	85.4	25-1085
$Cu_2S_\gamma = 2\ Cu + \frac{1}{2}\ S_2$	140 700	43.3	25- 435
$Cu_2S_\beta = 2\ Cu + \frac{1}{2}\ S_2$	132 000	30.8	435-1129 m
$Cu_2S = Cu_2S(l)$	9000	6.40	1129 m
$Cu_{1.738}S_\mu = 1.738\ Cu + \frac{1}{2}\ S_2$	113 600	26.6	435- 620
$CuS = Cu + \frac{1}{2}\ S_2$	115 600	76.0	25- 430

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$CuFeS_2 = Cu + Fe + S_2$	278 600	115	557- 700
$Cu_2O\cdot Fe_2O_3 = Cu_2O + Fe_2O_3$	37 700	19.0	25-1100
$CuSO_4 = \frac{1}{2}\ CuO\cdot CuSO_4 + \frac{1}{2}\ SO_2 + \frac{1}{4}\ O_2$	152 600	136	400- 800
$CuO\cdot CuSO_4 = 2\ CuO + SO_2 + \frac{1}{2}\ O_2$	297 000	250	500- 900
$Fe_\delta = Fe(l)$	13 800	7.61	1536 m
$Fe(l) = Fe(g)$	363 600	116.0	1536-2860 b
$Fe_{0.947}O = Fe_{0.947}O(l)$	31 340	19.0	1370 m
$Fe_{0.947}O = 0.947\ Fe + \frac{1}{2}\ O_2$	263 700	64.4	25-1370 m
$FeO(l) = Fe(l) + \frac{1}{2}\ O_2$	256 000	54.7	1371-2000
$Fe_3O_4 = 3\ Fe + 2\ O_2$	1 100 000	307	25-1597 m
$Fe_2O_3 = 2\ Fe + \frac{3}{2}\ O_2$	814 000	251	25-1500
$FeS = Fe_\gamma + \frac{1}{2}\ S_2$	164 000	61.0	988-1190 m
$FeS_2 = FeS + \frac{1}{2}\ S_2$	182 000	188	630- 760
$Fe_2(SO_4)_3 = Fe_2O_3 + 3\ SO_2 + \frac{3}{2}\ O_2$	772 000	724	400- 800
$Fe_2(SO_4)_3 = 2\ FeSO_4 + SO_2 + O_2$	396 000	352	430- 630
$FeSO_4 = \frac{1}{2}\ Fe_2O_3 + SO_2 + \frac{1}{4}\ O_2$	203 500	202.3	500- 630
$2\ FeO\cdot SiO_2 = 2\ FeO\cdot SiO_2(l)$	92 050	61.7	1220 m
$2\ FeO\cdot SiO_2 = 2\ FeO + SiO_2$	36 200	21.0	25-1220 m
$Zn = Zn(l)$	7320	10.6	420 m
$Zn(l) = Zn(g)$	118 000	100.3	420- 907 b
$ZnO = Zn(g) + \frac{1}{2}\ O_2$	460 240	190.4	907-1700
$ZnS = Zn(l) + \frac{1}{2}\ S_2$	278 000	108	420- 907
$ZnS(g) = Zn(g) + \frac{1}{2}\ S_2$	−5020	30.5	1182 b-1700
$ZnO\cdot Fe_2O_3 = ZnO + Fe_2O_3$	9620	3.8	25- 700
$ZnSO_4 = ZnO + SO_2 + \frac{1}{2}\ O_2$	328 000	267	25- 700

Reaction	$\overline{\Delta H^0}$ (joule)	$\overline{\Delta S^0}$ (joule)	Range (°C)
$Mg = Mg(l)$	8960	9.71	650 m
$Mg(l) = Mg(g)$	129 600	95.1	650-1093 b
$MgSO_4 = MgO + SO_2 + \frac{1}{2}\ O_2$	371 000	261	670-1050
$2\ MgO\cdot SiO_2 = 2\ MgO\cdot SiO_2(l)$	71 100	32.6	1898 m
$2\ MgO\cdot SiO_2 = 2\ MgO + SiO_2$	67 200	4.31	25-1898 m
$MgO\cdot SiO_2 = MgO\cdot SiO_2(l)$	75 300	40.6	1577 m
$MgO\cdot SiO_2 = MgO + SiO_2$	41 100	6.1	25-1577 m
$MgO = Mg + \frac{1}{2}\ O_2$	601 000	107.6	25- 650
$MgO = Mg(g) + \frac{1}{2}\ O_2$	730 000	204	1090-2000
$MgS = Mg + \frac{1}{2}\ S_2$	410 000	94.4	25- 650
$MgS = Mg(g) + \frac{1}{2}\ S_2$	540 000	193	1090-1700
$MgO\cdot Al_2O_3 = MgO + Al_2O_3$	35 600	−2.09	25-1400
$MgCO_3 = MgO + CO_2$	116 000	173.4	25- 402 d