



PROGRAM : NATIONAL DIPLOMA METALLURGY

SUBJECT : METALLURGICAL THERMODYNAMICS 2

CODE : THM21-2

DATE : WINTER SUPPLEMENTARY EXAMINATION 2019

DURATION : 3 Hours

WEIGHT : 40: 60

TOTAL MARKS : 84

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<u>MODERATOR</u>	: MR MARCEL KALEMBA	011 899 3124
<u>NUMBER OF PAGES</u>	: 3 PAGES AND 2 ANNEXURES	

INSTRUCTIONS

- First, read carefully through all questions.
- Answer all questions in any sequence.
- Please start answering each question on a new page.
- You must clearly demonstrate how you arrived at a given answer.
- Calculator permitted, but nothing else because all data required for calculations are provided in the Annexure.

Question 1

[28]

The reduction of chromite with coke is an important process to make ferrochrome.

- 1.1 Formulate the overall reaction. (2)
- 1.2 How much coke (in t) would you have to add for the reduction of 1 t of pure chromite?
Assume stoichiometric requirements and coke to be carbon. (4)
- 1.3 Estimate the volume of gas (in m³) that is produced by the reduction of 1 t of pure chromite (4)
- 1.4 If you were to completely combust the produced gas, how much energy (in MJ) would be generated? (4)
- 1.5 Determine whether the reduction of chromite is an exo- or endothermic process. (4)
- 1.6 As regards the change of entropy for the reaction, what could you predict?
Do not calculate yet but give a reason for your answer. (2)
- 1.7 Demonstrate that the reaction is not feasible at room temperature. (5)
- 1.8 Estimate the temperature at which the reaction becomes feasible (3)

Question 2

[10]

Calculate the change of entropy for the following transformations

- 2.1 Grey to white tin. (3)
- 2.2 Solid to liquid magnesium. (3)
- 2.3 Liquid magnesium to magnesium vapour. (3)
- 2.4 What do you think is the reason for the different entropy changes? (1)

Question 3

[10]

Consider an electric power station that, instead of coal, burns methane to raise steam which drives a turbine which a generator is coupled. Suppose 1000 m³/h of methane are combusted and 85% of the generated thermal energy forms the input (as superheated steam) to the turbine/generator set which operates as a Carnot machine with 45% efficiency to produce useful (electrical) energy. The steam is condensed and the water cooled to 50°C.

- 3.1 Calculate the output of useful (electrical) energy (in MW)
Remember: J/s = W (6)
- 3.2 Calculate the temperature of the steam before the turbine. (4)

Question 4

[10]

Consider the following set-up by which coal is burnt in order to make warm water:

- There are 2 m³ of water at 25°C .
- 15 kg of coal (assume this to be carbon) is burnt.
- Assume all thermal energy from combustion is taken up by the water.

Estimate the temperature that the water will attain.

(10)

Use the mean heat capacity of water

Question 5

[16]

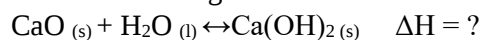
Consider the reduction of metal oxides to the respective metals by hydrogen gas:

- 5.1 Formulate the reaction and define the equilibrium constant K for the reduction of a metal oxide of the composition MO. **(4)**
- 5.2 Calculate and compare the equilibrium constants at 1000°C for manganese oxide (MnO) and cupric oxide (CuO). **(10)**
- 5.3 Based on the values of the equilibrium constants, what qualitative statement can you make as regards the usefulness of this reaction for the industrial production of the two metals? **(2)**

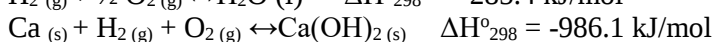
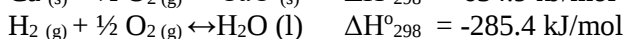
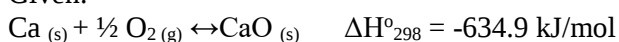
Question 6

[10]

6.1 Balance the following reaction and calculate its enthalpy

(4)

Given:



6.2 For the reaction: $\text{N}_{2(g)} + 3\text{H}_{2(g)} \leftrightarrow 2\text{NH}_{3(g)}$ $\Delta H = -92.0 \text{ kJ mol}^{-1}$

6.2.1 Determine the heat energy released when 2 moles of nitrogen reacts.

(3)

6.2.2 Determine the energy released when 0.50 mole of ammonia is formed.

(3)

Substance					Enthalpy	Entropy	Heat Capacity				
Name	Formula	State	Mol Mass		H ⁰ ₂₉₈	S ⁰ ₂₉₈	Temp Range		a	b	C _{mean}
			g/mol		J/mol	J/(mol K)	K		x 10 ³ J/(mol K)		
1	Acetylene	C ₂ H ₂	gas	26,0	226 731	201,0	298	- 3000	50,2	14,2	72,9
2	Aluminium	Al	sol	27,0		28,3	298	- 933	19,8	14,4	28,5
3		Al _{liq}	liq		10 711	39,8	933	- 2790			31,7
4	Aluminium oxide, <i>alumina</i>	Al ₂ O ₃	sol	102,0	-1 675 274	50,9	298	- 800	58,2	83,5	101
5		Al ₂ O ₃ hi					800	- 2327	112,2	12,7	133
6		Cd	sol	112,4		51,8	298	- 594	22,3	12,2	27,4
7	Cadmium	Cd _{liq}	liq		6 192	62,2	594	- 1040			29,7
8		Cd _{gas}	gas		111 796	167,7	1040	- 1500			20,8
9	Cadmium carbonate	CdCO ₃	sol	172,4	- 751 865	92,5	298	- 600	43,1	131,8	99,9
10	Cadmium oxide	CdO	sol	128,4	- 258 990	54,8	298	- 1500	43,0	9,7	51,5
11	Calcium oxide, <i>lime</i>	CaO	sol	56,1	- 635 089	38,1	298	- 3200	46,0	6,0	56,0
12	Ca-carbonate, <i>calcite</i>	CaCO ₃	sol	100,1	-1 206 921	92,9	298	- 1200	74,8	50,2	110
13	Carbon, <i>graphite</i>	C	sol	12,0		5,7	298	- 1100	4,9	17,2	16,3
14	Carbon monoxide	CO	gas	28,0	- 110 541	197,7	298	- 5000	30,9	1,9	33,0
15	Carbon dioxide	CO ₂	gas	44,0	- 393 505	213,8	298	- 500	26,0	37,2	35,6
16		CO ₂ hi					500	- 5000	51,9	3,0	60,1
17	Chromium	Cr	sol	52,0		23,6	298	- 2130	20,3	12,1	30,0
18		Cr _{liq}	liq		16 900	31,6	2130	- 2945			39,3
19	Chromium(III)-oxide	Cr ₂ O ₃	sol	152,0	-1 139 701	81,2	298	- 2603	114,8	11,2	131
20	Iron-chrome spinel <i>chromite</i>	FeCr ₂ O ₄	sol	223,8	-1 458 124	142,0	298	- 2123	140,1	35,5	183
21	Copper	Cu	sol	63,5		33,2	298	- 1358	22,0	7,4	28,0
22		Cu _{liq}	liq		13 138	42,8	1358	- 2843			32,8
23	Copper(I)-oxide, <i>cuprite</i>	Cu ₂ O	sol	143,1	- 170 707	92,3	298	- 1508	56,4	25,8	79,7
24		Cu ₂ O _{liq}	liq		- 105 939	135,0	1508	- 2000			99,9
25	Copper(II)-oxide, <i>tenorite</i>	CuO	sol	79,5	- 156 063	42,6	298	- 1397	40,8	13,9	48,6
26	<i>Chalcopyrite</i>	CuFeS ₂	sol	183,5	- 190 372	125,0	298	- 830	78,6	63,6	114
27	Cu(I)-sulfide, <i>chalcocite</i>	Cu ₂ S	sol	159,1	- 81 170	116,2	298	- 1400	47,9	97,2	85,7
28	Cu-Matte	Cu ₂ S _{liq}	liq		- 68 325	125,3	1400	- 2000			89,7
29	Cu(II)-sulfide, <i>covellite</i>	CuS	sol	95,6	- 53 095	66,5	298	- 1300	44,4	11,0	53,0
30	Gold	Au	sol	197,0		47,5	298	- 1336	24,0	4,4	26,7
31		Au _{liq}	liq		12 552	56,9	1336	- 3130			31,0
32	Hydrogen	H ₂	gas	2,0		130,7	298	- 5000	28,2	2,7	35,0
33	Iron	Fe	sol	55,8		27,3	298	- 1811	23,1	16,0	38,7
34		Fe _{liq}	liq		13 807	34,9	1811	- 3158			45,0
35	Iron(II) oxide, <i>wüstite</i>	FeO	sol	71,8	- 267 270	57,6	298	- 1650	47,9	10,7	58,0
36			liq		- 243 212	72,2	1650	- 3687			68,2
37	Iron(II)(III) oxide, <i>magnetite</i>	Fe ₃ O ₄	sol	231,5	-1 118 383	146,1	298	- 1870	75,5	240,1	207
38	Iron-iron spinel Fe [Fe ₂ O ₄]	Fe ₃ O ₄ liq	liq		- 980 311	220,0	1870	- 2000			213
39	Iron(III)-oxide, <i>hematite</i>	Fe ₂ O ₃	sol	159,7	- 824 248	87,4	298	- 1700	78,1	99,8	142,0
40	Iron carbonate, <i>siderite</i>	FeCO ₃	sol	115,9	- 740 568	92,9	298	- 800	48,7	112,1	106,0
41	Iron sulfide, <i>pyrrhotite</i>	FeS	sol	87,9	- 105 441	60,8	298	- 1465	31,0	63,0	68,0
42	Fe-Matte	FeS _{liq}	liq		- 72 977	82,3	1465	- 3000			62,6
43	Iron sulfide, <i>pyrite</i>	FeS ₂	sol	120,0	- 171 544	52,9	298	- 1000	56,0	27,8	73,0
44	Lead	Pb	sol	207,2		64,8	298	- 600	24,2	8,7	28,1
45		Pb _{liq}	liq		4 770	72,7	600	- 1200			29,7
46	Lead oxide, <i>litharge</i>	PbO	sol	223,2	- 218 062	68,7	298	- 1159	41,8	16,1	53,1
47		PbO _{liq}	liq		- 192 540	90,7	1159	- 2000			65,0
48	Lead dioxide, <i>plattnerite</i>	PbO ₂	sol	239,2	- 274 470	71,8	298	- 1200	58,9	20,4	73,4
49	Lead sulfide, <i>galena</i>	PbS	sol	239,3	- 98 634	91,3	298	- 1386	46,6	9,5	54,0
50		PbS _{liq}	liq		- 79 806	104,9	1386	- 2000			66,9
51	Lead sulfate, <i>anglesite</i>	PbSO ₄	sol	303,3	- 923 137	149,5	298	- 1139	66,5	110,0	144,0
52		Mg	sol	24,3		32,7	298	- 922	21,4	11,8	28,5
53	Magnesium	Mg _{liq}	liq		8 954	42,4	922	- 1361			32,6
54		Mg _{gas}	gas		146 440	148,6	1361	- 2000			20,8
55	Mg-carbonate, <i>magnesite</i>	MgCO ₃	sol	84,3	-1 095 798	65,7	298	- 700	47,8	99,0	94,0
56	Mg-oxide, <i>periklase</i>	MgO	sol	40,3	- 601 241	26,9	298	- 3105	42,8	6,0	53,0

Substance				Enthalpy	Entropy	Heat Capacity			
Name	Formula	State	Mol Mass g/mol	H ^o ₂₉₈ J/mol	S ^o ₂₉₈ J/(mol K)	Temp Range K	a	b	C _{mean} x 10 ³ J/(mol K)
57	Manganese	Mn	sol	54,9	32,0	298 - 1517	20,7	18,7	28,6
58		Mnliq	liq	12 100	40,0	1517 - 2332			46,0
59	Manganese carbonate	MnCO ₃	sol	114,9	- 894 100	298 - 700	58,1	85,4	106
60	Manganese(II)-oxide	MnO	sol	70,9	- 385 221	298 - 1500	42,9	10,9	52,3
61	Mn-dioxide, <i>pyrolusite</i>	MnO ₂	sol	86,9	- 520 029	298 - 523	35,1	66,0	62,9
62	Mercury (quicksilver)	Hg	liq	200,6	75,9	298 - 630	28,4	-2,1	27,4
63		Hggas	gas	61 291	174,8	630 - 3000			20,8
64	Mercury oxide, <i>red mercury</i>	HgO	sol	216,6	- 90 789	298 - 800	36,6	27,6	50,8
65	Mercury sulfide, <i>cinnabar</i>	HgS	sol	232,7	- 53 346	298 - 1098	43,9	15,4	53,5
66		HgSgas	gas	127 194	254,2	1098 - 2000	36,6	0,5	37,1
67	Methane	CH ₄	gas	16,0	- 74 873	298 - 1000	19,3	54,8	54,3
68	Nickel	Ni	sol	58,7	29,9	298 - 1728	19,1	23,5	33,0
69		Niliq	liq	17 472	40,0	1728 - 3187			43,1
70	Nickel carbonate	NiCO ₃	sol	118,7	- 694 544	298 - 700	67,1	68,1	99,0
71	Nickel carbonyl	Ni(CO) ₄	gas	170,8	- 602 910	298 - 2000	152,7	29,1	184,8
72	Nickel oxide	NiO	sol	74,7	- 239 701	298 - 2228	20,9	36,5	58,0
73	Nickel sulfide, <i>millerite</i>	NiS	sol	90,8	- 87 864	298 - 1249	36,5	27,4	51,0
74	Ni-sulfide, <i>heazlewoodite</i>	Ni ₃ S ₂	sol	208,1	- 216 313	298 - 1062			150
75	Nitrogen	N ₂	gas	28,0	191,6	298 - 1600	28,0	3,1	30,8
76	Oxygen	O ₂	gas	32,0	205,1	298 - 5000	31,9	2,5	38,3
77	Palladium	Pd	sol	106,4	37,8	298 - 1825	24,2	6,4	29,4
78	Palladium oxide	PdO	sol	122,4	- 115 478	298 - 1200	21,0	34,7	45,6
79	Platinum	Pt	sol	195,1	41,6	298 - 2045	24,3	5,4	30,4
80		Ptliq	liq	19 665	51,3	2045 - 4096			34,7
81	Silicon	Si	sol	28,1	18,8	298 - 1685	19,7	6,1	25,5
82		Siliq	liq	50 208	48,6	1685 - 3504			27,2
83	Silica	SiO ₂	sol	60,1	- 910 857	298 - 1996	29,2	56,8	65,0
84		SiO2liq	liq	- 901 292	49,3	1996 - 3000			85,8
85	Silver	Ag	sol	107,9	42,7	298 - 1234	24,3	2,5	28,0
86		Agliq	liq	11 297	51,8	1234 - 2433			33,5
87	Silver oxide	Ag ₂ O	sol	231,7	- 31 049	298 - 500	49,2	56,2	70,2
88	Slag, <i>calcium ortho silicate</i>	Ca ₂ SiO ₄	sol	172,2	-2 315 216	298 - 2403	145,9	40,8	164
89		Ca2SiO4liq	liq	-2 244 000	170,8	2403 - 2800			209
90	Slag, <i>fayalite</i>	Fe ₂ SiO ₄	sol	203,8	-1 479 902	298 - 1490	125,5	60,6	153
91		Fe2SiO4liq	liq	-1 387 728	61,9	1490 - 1700			241
92	Sulfur	S	sol	32,1	32,1	298 - 388	16,8	20,1	23,0
93		Sliq	liq	2 122	37,6	388 - 882	30,0	6,8	34,1
94		S2gas	gas	128 599	228,2	882 - 5000	35,2	1,9	40,2
95	Sulfur dioxide	SO ₂	gas	64,1	- 296 813	50 - 500	30,8	31,9	39,0
96		SO2hi	hi			500 - 5000	52,5	3,0	60,7
97	<i>grey</i>	Sngr	sol	- 2 092	44,1	298 - 398	25,8		25,8
98	<i>white</i>	Sn	sol		51,2	298 - 505	21,6	18,1	28,8
99		Snliq	liq	7 029	65,1	505 - 800			25,5
100	Tin dioxide, <i>cassiterite</i>	SnO ₂	sol	150,7	- 577 631	298 - 1903	58,7	18,2	78,8
101	Water	Ice	sol	-279 850		< 273			37,0
102		H ₂ O	liq	- 285 830	69,9	298 - 373	73,0	7,9	75,5
103		H2Ogas	gas	- 241 827	188,8	373 - 1600	30,1	10,0	38,5
104	Zinc	Zn	sol	65,4	41,6	298 - 693	22,2	10,5	27,1
105		Znliq	liq	7 322	52,2	693 - 1 180			31,4
106		Zngas	gas	130 415	161,0	1 180 - 2 000			20,8
107	Zinc carbonate, <i>smithonite</i>	ZnCO ₃	sol	125,4	- 812 780	298 - 500	38,9	138,1	93,0
108	Zinc oxide, <i>zincite</i>	ZnO	sol	81,4	- 350 460	298 - 2248	41,4	9,5	53,3
109	Zinc sulfide, <i>sphalerite</i>	ZnS	sol	97,4	- 201 669	298 - 1293	44,7	10,6	52,8
110									
111	Useful figures	Mole volume	V _{mol} =	22,4 L/mol	Gas constant	R =	8,31 J/(mol K)		
112		Temperature	0°C =	273 K	O ₂ in air	ξ =	21,0% by vol		