UNIVERSITY OF JOHANNESBURG

PROGRAM	:	**NATIONAL DIPLOMA METALLURGY**
SUBJECT	:	**METALLURGICAL THERMODYNAMICS 2**
CODE	:	**THM21-2**
DATE	:	**WINTER MAIN EXAMINATION 2019**
DURATION	:	**3 Hours**
WEIGHT	:	**40: 60**
TOTAL MARKS	:	**83**

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NUMBER OF PAGES	:	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 [10]

The new coal-fired Medupi power plant constructed near Ellisras, with a design capacity of 5 GW. Assuming an efficiency of 40% (Carnot efficiency), estimate the daily emission of carbon dioxide into the atmosphere (in t). (10)

Question 2 [25]

In an industrial process, the production of MnO from pyrolusite at 25 °C is required.

2.1 Formulate and balance the reaction in which pyrolusite is reduced to MnO with coke; (2)

2.1.1 Calculate the enthalpy change for the reaction under standard conditions. (3)

2.1.2 Calculate the entropy change for the reaction under standard conditions. (3)

2.1.3 Calculate the free energy change for this reduction reaction under standard conditions. (3)

2.2 Formulate and balance the reaction in which pyrolusite forms MnO by dissociation; (2)

2.2.1 Calculate the enthalpy change for the reaction under standard conditions. (3)

2.2.2 Calculate the entropy change for the reaction under standard conditions. (3)

2.2.3 Calculate the free energy change for this reduction reaction under standard conditions. (3)

2.3 Comment which of the two reactions is feasible and provide reasons. (3)

Question 3 [10]

3.1 The new tax is introduced in South Africa to encourage the buying of new "clean" automobiles, for cars exhausting over 120 g CO_2 / km. Calculate the carbon dioxide emitted per km for a car that consumes 8.6 ℓ / 100 km of gasoline ("petrol").
Assume "petrol" to be n-heptane, C_7H_{16}, with a density of 0.68 kg/ℓ, and complete combustion to CO_2 and H_2O. (5)

3.2 South African power plants usually burn coal to generate steam and then electrical energy. Establish the "environmental footprint" by calculating the ratio of g CO_2 produced per kWh electricity generated.
Assume coal to be carbon and a typical power plant efficiency of 33%. (5)

Question 4 [10]

Compare coal and natural gas as fuels for power stations and demonstrate which of the two is "cleaner" in respect to carbon dioxide produced per thermal energy generated (expressed as g CO_2 / kWh).

Assume coal to be carbon and natural gas to be methane. (10)

Question 5 [10]

A converter contains 100 t of molten chalcocite (Cu_2S), at a temperature of 1250°C. Estimate how many tons of cold copper scrap need to be added to reduce the temperature to 1150°C, in order to protect the refractory lining of the converter.

The temperature of the cold copper scrap is 25°C; assume this to be pure copper metal. (10)

Question 6 [18]

Demonstrate which of the following reduction reactions are feasible (possible) at 640°C:

6.1 The reduction of chromium (III) oxide with aluminium (metal) powder. (5)
6.2 The reduction of manganese (II) oxide with coke (carbon) to manganese metal. (5)
6.3 The reduction of iron (II) oxide, wüstite with hydrogen gas to iron metal. (5)
6.4 Estimate ΔG^o for each reaction and comment on the results. (3)

Good Luck!

	Substance				Enthalpy	Entropy	Heat Capacity			
	Name	Formula	State	Mol Mass	H^o_{298}	S^o_{298}	Temp Range	a	b	C_{mean}
				g/mol	J/mol	J/(mol K)	K		x 10^3	J/(mol K)
1	Acetylene	C_2H_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		Alliq	liq		10 711	39,8	933 - 2790			31,7
4	Aluminium oxide, *alumina*	Al_2O_3	sol	102,0	-1 675 274	50,9	298 - 800	58,2	83,5	101
5		Al_2O_3 hi					800 - 2327	112,2	12,7	133
6	Cadmium	Cd	sol	112,4		51,8	298 - 594	22,3	12,2	27,4
7		Cdliq	liq		6 192	62,2	594 - 1040			29,7
8		Cdgas	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, *lime*	CaO	sol	56,1	- 635 089	38,1	298 - 3200	46,0	6,0	56,0
12	Ca-carbonate, *calcite*	$CaCO_3$	sol	100,1	-1 206 921	92,9	298 - 1200	74,8	50,2	110
13	Carbon, *graphite*	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_2hi					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		Crliq	liq		16 900	31,6	2130 - 2945			39,3
19	Chromium(III)-oxide	Cr_2O_3	sol	152,0	-1 139 701	81,2	298 - 2603	114,8	11,2	131
20	Iron-chrome spinel *chromite*	$FeCr_2O_4$	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		Culiq	liq		13 138	42,8	1358 - 2843			32,8
23	Copper(I)-oxide, *cuprite*	Cu_2O	sol	143,1	- 170 707	92,3	298 - 1508	56,4	25,8	79,7
24		Cu2Oliq	liq		- 105 939	135,0	1508 - 2000			99,9
25	Copper(II)-oxide, *tenorite*	CuO	sol	79,5	- 156 063	42,6	298 - 1397	40,8	13,9	48,6
26	*Chalcopyrite*	$CuFeS_2$	sol	183,5	- 190 372	125,0	298 - 830	78,6	63,6	114
27	Cu(I)-sulfide, *chalcocite*	Cu_2S	sol	159,1	- 81 170	116,2	298 - 1400	47,9	97,2	85,7
28	Cu-Matte	Cu2Sliq	liq		- 68 325	125,3	1400 - 2000			89,7
29	Cu(II)-sulfide, *covellite*	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		Auliq	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		Feliq	liq		13 807	34,9	1811 - 3158			45,0
35	Iron(II) oxide, *wüstite*	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, *magnetite*	Fe_3O_4	sol	231,5	-1 118 383	146,1	298 - 1870	75,5	240,1	207
38	Iron-iron spinel Fe [Fe_2O_4]	Fe3O4liq	liq		- 980 311	220,0	1870 - 2000			213
39	Iron(III)-oxide, *hematite*	Fe_2O_3	sol	159,7	- 824 248	87,4	298 - 1700	78,1	99,8	142,0
40	Iron carbonate, *siderite*	$FeCO_3$	sol	115,9	- 740 568	92,9	298 - 800	48,7	112,1	106,0
41	Iron sulfide, *pyrrhotite*	FeS	sol	87,9	- 105 441	60,8	298 - 1465	31,0	63,0	68,0
42	Fe-Matte	FeSliq	liq		- 72 977	82,3	1465 - 3000			62,6
43	Iron sulfide, *pyrite*	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		Pbliq	liq		4 770	72,7	600 - 1200			29,7
46	Lead oxide, *litharge*	PbO	sol	223,2	- 218 062	68,7	298 - 1159	41,8	16,1	53,1
47		PbOliq	liq		- 192 540	90,7	1159 - 2000			65,0
48	Lead dioxide, *plattnerite*	PbO_2	sol	239,2	- 274 470	71,8	298 - 1200	58,9	20,4	73,4
49	Lead sulfide, *galena*	PbS	sol	239,3	- 98 634	91,3	298 - 1386	46,6	9,5	54,0
50		PbSliq	liq		- 79 806	104,9	1386 - 2000			66,9
51	Lead sulfate, *anglesite*	$PbSO_4$	sol	303,3	- 923 137	149,5	298 - 1139	66,5	110,0	144,0
52	Magnesium	Mg	sol	24,3		32,7	298 - 922	21,4	11,8	28,5
53		Mgliq	liq		8 954	42,4	922 - 1361			32,6
54		Mggas	gas		146 440	148,6	1361 - 2000			20,8
55	Mg-carbonate, *magnesite*	$MgCO_3$	sol	84,3	-1 095 798	65,7	298 - 700	47,8	99,0	94,0
56	Mg-oxide, *periklase*	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 $\times 10^3$	C_{mean} 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	85,8	298 - 700	58,1	85,4	106
60	Manganese(II)-oxide	MnO	sol	70,9	- 385 221	59,7	298 - 1500	42,9	10,9	52,3
61	Mn-dioxide, *pyrolusite*	MnO_2	sol	86,9	- 520 029	53,0	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, *red mercury*	HgO	sol	216,6	- 90 789	70,3	298 - 800	36,6	27,6	50,8
65	Mercury sulfide, *cinnabar*	HgS	sol	232,7	- 53 346	82,4	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	186,2	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	86,2	298 - 700	67,1	68,1	99,0
71	Nickel carbonyl	$Ni(CO)_4$	gas	170,8	- 602 910	410,6	298 - 2000	152,7	29,1	184,8
72	Nickel oxide	NiO	sol	74,7	- 239 701	38,0	298 - 2228	20,9	36,5	58,0
73	Nickel sulfide, *millerite*	NiS	sol	90,8	- 87 864	53,0	298 - 1249	36,5	27,4	51,0
74	Ni-sulfide, *heazlewoodite*	Ni_3S_2	sol	208,1	- 216 313	133,9	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	38,9	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	41,5	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_2O	sol	231,7	- 31 049	121,3	298 - 500	49,2	56,2	70,2
88	Slag, *calcium ortho silicate*	Ca_2SiO_4	sol	172,2	-2 315 216	120,8	298 - 2403	145,9	40,8	164
89		Ca2SiO4liq	liq		-2 244 000	170,8	2403 - 2800			209
90	Slag, *fayalite*	Fe_2SiO_4	sol	203,8	-1 479 902	145,2	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	248,2	50 - 500	30,8	31,9	39,0
96		SO2hi	hi				500 - 5000	52,5	3,0	60,7
97	*grey*	Sngr	sol		- 2 092	44,1	298 - 398	25,8		25,8
98	Tin *white*	Sn	sol	150,7		51,2	298 - 505	21,6	18,1	28,8
99		Snliq	liq		7 029	65,1	505 - 800			25,5
100	Tin dioxide, *cassiterite*	SnO_2	sol	150,7	- 577 631	49,0	298 - 1903	58,7	18,2	78,8
101	Water	Ice	sol		-279 850		< 273			37,0
102		H_2O	liq	18,0	- 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, *smithonite*	$ZnCO_3$	sol	125,4	- 812 780	82,4	298 - 500	38,9	138,1	93,0
108	Zinc oxide, *zincite*	ZnO	sol	81,4	- 350 460	43,6	298 - 2248	41,4	9,5	53,3
109	Zinc sulfide, *sphalerite*	ZnS	sol	97,4	- 201 669	57,7	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