UNIVERSITY OF JOHANNESBURG

PROGRAM	BACHELOR OF TECHNOLOGY *EXTRACTION METALLURGY*
SUBJECT	**NON-FERROUS EXTRACTION METALLURGY**
CODE	**MNF41-2**
DATE	JUNE EXAMINATION 10. June 2014
DURATION	(SESSION 1) 08:30 - 11:30
WEIGHT	40 : 60
TOTAL MARKS	187

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MODERATOR	MARCEL KALEMBA
NUMBER OF PAGES	4 PAGES AND A 2-PAGE ANNEXURE

INSTRUCTIONS

- First read carefully through all questions; only then
- Answer all questions in any sequence – but
- Please start answering each question on a new page
- You must clearly demonstrate how you arrived at a given answer, results alone are insufficient
- Finally: Check whether an answer makes sense; is the result likely?
- Calculators are permitted but nothing else because
- All data required for calculations are provided in the Annexure

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QUESTION 1 **[34]**

Non-ferrous mining and minerals

1.1. Name two countries in Africa that are known for their copper ore deposits; also name the specific areas in these countries where copper is in fact mined. However, which country produces most copper worldwide and where is it situated? (6)

1.2. Which companies in South Africa produce copper, lead, zinc and aluminium metal? Where are the plants located? Which plant in which neighbouring country produces refined zinc? (9)

1.3. Name the main minerals (one each), including their formulas, that are contained in ore bodies mined for copper, lead, zinc and aluminium (8)

1.4. Some non-ferrous minerals are sulfides, others oxides. But in which form are iron and gold present in their ore bodies? Name the main mineral for each of the latter cases. (3)

1.5. Consider two entirely different sulfur-containing feed materials, such as a flotation concentrate and battery scrap: describe what happens to sulfur in each case. Write the detailed process reactions and indicate the respective oxidation states of sulfur; briefly comment. (8)

QUESTION 2 **[34]**

Beneficiation

2.1 Define the term beneficiation in the context of extraction metallurgy (4)

2.2 Give examples to what extend the following South African products are already or could possibly be beneficiated: (30)

- Coal (two different ways of beneficiation)
- "Slag" from ilmenite smelting
- Refined lead metal
- Fluorite concentrate
- Iron blast furnace slag
- Waste gas from iron blast furnace and ferrochrome electric furnace
- Power plant fly ash
- Lead blast furnace slag (from Tsumeb or Kipushi – not available in South Africa)
- Refined aluminium metal
- Ferrochrome (two beneficiation steps)
- Chromite concentrate (exported to India)
- Sunshine and wind (God's products)

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QUESTION 3 [16]

Copper converting

Suppose 125 t of matte, with a matte grade of 44% Cu, is transferred from the furnace to the converter; calculate:

3.1 The stoichiometric amount of converted slag (assume this to be only fayalite) that is produced; result in t (6)

3.2 Suppose all sulfur contained in matte could be converted to sulfuric acid, how much acid would be obtained? Result in m^3 (4)

3.3 The length of the copper blow if the air blowing rate is 210 t/h and the oxygen efficiency 95%; result in minutes (6)

QUESTION 4 [16]

Energy consumption

Calculate and compare the specific electrical energy required to produce zinc and aluminium, respectively, by electrowinning. Result in kWh/t of metal.

For calculations you need:		Cell voltage E	Current efficiency η
for	Zinc	3.6 V	90%
for	Aluminium	4.6 V	85%

First develop the applicable formula for the specific energy requirement in general terms, starting with the Faraday equation. After having obtained your results, comment about the factors responsible for the difference.

QUESTION 5 [15]

Cementation reactions are widely used in metallurgical processes. Give three examples of such reactions: Write down the reaction equations and elaborate to which processes they refer.

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QUESTION 6 [12]

Environmental process problems

Briefly discuss one environmental problem associated with each of the following three process steps:

6.1 Copper converter blowing (4)

6.2 Zinc electrowinning (4)

6.3 Bauxite leaching (4)

QUESTION 7 [20]

Platinum

Discuss why electric arc furnaces have replaced reverberatory and blast furnaces in platinum smelting.

QUESTION 8 [20]

Gold

Discuss why CIP circuits have replaced the filtration – lead zinc process in many gold plants.

QUESTION 9 [20]

Uranium

Discuss the 5 factors affecting the efficiency of acid leaching of uranium.

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)
Acetylene	C_2H_2	gas	26.0	226 731	201.0	298 - 3000	50.2	14.2	72.9
Aluminium	Al	sol	27.0		28.3	298 - 933	19.8	14.4	28.5
	Alliq	liq		10 711	39.8	933 - 2790			31.7
Aluminium oxide, *alumina*	Al_2O_3	sol	102.0	-1 675 274	50.9	298 - 800	58.2	83.5	101
	Al_2O_3 hi					800 - 2327	112.2	12.7	133
Cadmium	Cd	sol	112.4		51.8	298 - 594	22.3	12.2	27.4
	Cdliq	liq		6 192	62.2	594 - 1040			29.7
	Cdgas	gas		111 796	167.7	1040 - 1500			20.8
Cadmium carbonate	$CdCO_3$	sol	172.4	- 751 865	92.5	298 - 600	43.1	131.8	99.9
Cadmium oxide	CdO	sol	128.4	- 258 990	54.8	298 - 1500	43.0	9.7	51.5
Calcium oxide, *lime*	CaO	sol	56.1	- 635 089	38.1	298 - 3200	46.0	6.0	56.0
Ca-carbonate, *calcite*	$CaCO_3$	sol	100.1	-1 206 921	92.9	298 - 1200	74.8	50.2	110
Carbon, *graphite*	C	sol	12.0		5.7	298 - 1100	4.9	17.2	16.3
Carbon monoxide	CO	gas	28.0	- 110 541	197.7	298 - 5000	30.9	1.9	33.0
Carbon dioxide	CO_2	gas	44.0	- 393 505	213.8	298 - 500	26.0	37.2	35.6
	CO_2hi					500 - 5000	51.9	3.0	60.1
Chromium	Cr	sol	52.0		23.6	298 - 2130	20.3	12.1	30.0
	Crliq	liq		16 900	31.6	2130 - 2945			39.3
Chromium(III)-oxide	Cr_2O_3	sol	152.0	-1 139 701	81.2	298 - 2603	114.8	11.2	131
Iron-chrome spinel *chromite*	$FeCr_2O_4$	sol	223.8	-1 458 124	142.0	298 - 2123	140.1	35.5	183
Copper	Cu	sol	63.5		33.2	298 - 1358	22.0	7.4	28.0
	Culiq	liq		13 138	42.8	1358 - 2843			32.8
Copper(I)-oxide, *cuprite*	Cu_2O	sol	143.1	- 170 707	92.3	298 - 1508	56.4	25.8	79.7
	Cu2Oliq	liq		- 105 939	135.0	1508 - 2000			99.9
Copper(II)-oxide, *tenorite*	CuO	sol	79.5	- 156 063	42.6	298 - 1397	40.8	13.9	48.6
Chalcopyrite	$CuFeS_2$	sol	183.5	- 190 372	125.0	298 - 830	78.6	63.6	114
Cu(I)-sulfide, *chalcocite*	Cu_2S	sol	159.1	- 81 170	116.2	298 - 1400	47.9	97.2	85.7
Cu-Matte	Cu2Sliq	liq		- 68 325	125.3	1400 - 2000			89.7
Cu(II)-sulfide, *covellite*	CuS	sol	95.6	- 53 095	66.5	298 - 1300	44.4	11.0	53.0
Gold	Au	sol	197.0		47.5	298 - 1336	24.0	4.4	26.7
	Auliq	liq		12 552	56.9	1336 - 3130			31.0
Hydrogen	H_2	gas	2.0		130.7	298 - 5000	28.2	2.7	35.0
Iron	Fe	sol	55.8		27.3	298 - 1811	23.1	16.0	38.7
	Feliq	liq		13 807	34.9	1811 - 3158			45.0
Iron(II)-oxide, *wüstite*	FeO	sol	71.8	- 267 270	57.6	298 - 1650	47.9	10.7	58.0
		liq		- 243 212	72.2	1650 - 3687			68.2
Iron(II)(III)-oxide, *magnetite*	Fe_3O_4	sol	231.5	-1 118 383	146.1	298 - 1870	75.5	240.1	207
Iron-iron spinel Fe [Fe_2O_4]	Fe3O4liq	liq		- 980 311	220.0	1870 - 2000			213
Iron(III)-oxide, *hematite*	Fe_2O_3	sol	159.7	- 824 248	87.4	298 - 1700	78.1	99.8	142.0
Iron carbonate, *siderite*	$FeCO_3$	sol	115.9	- 740 568	92.9	298 - 800	48.7	112.1	106.0
Iron sulfide, *pyrrhotite*	FeS	sol	87.9	- 105 441	60.8	298 - 1465	31.0	63.0	68.0
Fe-Matte	FeSliq	liq		- 72 977	82.3	1465 - 3000			62.6
Iron sulfide, *pyrite*	FeS_2	sol	120.0	- 171 544	52.9	298 - 1000	56.0	27.8	73.0
Lead	Pb	sol	207.2		64.8	298 - 600	24.2	8.7	28.1
	Pbliq	liq		4 770	72.7	600 - 1200			29.7
Lead oxide, *litharge*	PbO	sol	223.2	- 218 062	68.7	298 - 1159	41.8	16.1	53.1
	PbOliq	liq		- 192 540	90.7	1159 - 2000			65.0
Lead dioxide, *plattnerite*	PbO_2	sol	239.2	- 274 470	71.8	298 - 1200	58.9	20.4	73.4
Lead sulfide, *galena*	PbS	sol	239.3	- 98 634	91.3	298 - 1386	46.6	9.5	54.0
	PbSliq	liq		- 79 806	104.9	1386 - 2000			66.9
Lead sulfate, *anglesite*	$PbSO_4$	sol	303.3	- 923 137	149.5	298 - 1139	66.5	110.0	144.0
Magnesium	Mg	sol	24.3		32.7	298 - 922	21.4	11.8	28.5
	Mgliq	liq		8 954	42.4	922 - 1361			32.6
	Mggas	gas		146 440	148.6	1361 - 2000			20.8
Mg-carbonate, *magnesite*	$MgCO_3$	sol	84.3	-1 095 798	65.7	298 - 700	47.8	99.0	94.0
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	H^o_{298}	S^o_{298}	Temp Range	a	b	C_{mean}
			g/mol	J/mol	J/(mol K)	K		$x10^3$	J/(mol K)
Manganese	Mn	sol	54.9		32.0	298 - 1517	20.7	18.7	28.6
	Mnliq	liq		12 100	40.0	1517 - 2332			46.0
Manganese carbonate	$MnCO_3$	sol	114.9	- 894 100	85.8	298 - 700	58.1	85.4	106
Manganese oxide	MnO	sol	70.9	- 385 221	59.7	298 - 1500	42.9	10.9	52.3
Mn-dioxide, *pyrolusite*	MnO_2	sol	86.9	- 520 029	53.0	298 - 523	35.1	66.0	62.9
Mercury (quicksilver)	Hg	liq	200.6		75.9	298 - 630	28.4	-2.1	27.4
	Hggas	gas		61 291	174.8	630 - 3000			20.8
Mercury oxide, *red mercury*	HgO	sol	216.6	- 90 789	70.3	298 - 800	36.6	27.6	50.8
Mercury sulfide, *cinnabar*	HgS	sol	232.7	- 53 346	82.4	298 - 1098	43.9	15.4	53.5
	HgSgas	gas		127 194	254.2	1098 - 2000	36.6	0.5	37.1
Methane	CH_4	gas	16.0	- 74 873	186.2	298 - 1000	19.3	54.8	54.3
Nickel	Ni	sol	58.7		29.9	298 - 1728	19.1	23.5	33.0
	Niliq	liq		17 472	40.0	1728 - 3187			43.1
Nickel carbonate	$NiCO_3$	sol	118.7	- 694 544	86.2	298 - 700	67.1	68.1	99.0
Nickel carbonyl	$Ni(CO)_4$	gas	170.8	- 602 910	410.6	298 - 2000	152.7	29.1	184.8
Nickel oxide	NiO	sol	74.7	- 239 701	38.0	298 - 2228	20.9	36.5	58.0
Nickel sulfide, *millerite*	NiS	sol	90.8	- 87 864	53.0	298 - 1249	36.5	27.4	51.0
Ni-sulfide, *heazlewoodite*	Ni_3S_2	sol	208.1	- 216 313	133.9	298 - 1062			150
Nitrogen	N_2	gas	28.0		191.6	298 - 1600	28.0	3.1	30.8
Octane (n-octane)	C_8H_{18}	liq	114.2	- 250 000	360.0	298 - 400			254.0
Oxygen	O_2	gas	32.0		205.1	298 - 5000	31.9	2.5	38.3
Palladium	Pd	sol	106.4		37.8	298 - 1825	24.2	6.4	29.4
Palladium oxide	PdO	sol	122.4	- 115 478	38.9	298 - 1200	21.0	34.7	45.6
Platinum	Pt	sol	195.1		41.6	298 - 2045	24.3	5.4	30.4
	Ptliq	liq		19 665	51.3	2045 - 4096			34.7
Silicon	Si	sol	28.1		18.8	298 - 1685	19.7	6.1	25.5
	Siliq	liq		50 208	48.6	1685 - 3504			27.2
Silica	SiO_2	sol	60.1	- 910 857	41.5	298 - 1996	29.2	56.8	65.0
	SiO2liq	liq		- 901 292	49.3	1996 - 3000			85.8
Silver	Ag	sol	107.9		42.7	298 - 1234	24.3	2.5	28.0
	Agliq	liq		11 297	51.8	1234 - 2433			33.5
Silver oxide	Ag_2O	sol	231.7	- 31 049	121.3	298 - 500	49.2	56.2	70.2
Slag, *calcium ortho silicate*	Ca_2SiO_4	sol	172.2	-2 315 216	120.8	298 - 2403	145.9	40.8	164
	Ca2SiO4liq	liq		-2 244 000	170.8	2403 - 2800			209
Slag, *fayalite*	Fe_2SiO_4	sol	203.8	-1 479 902	145.2	298 - 1490	125.5	60.6	153
	Fe2SiO4liq	liq		-1 387 728	61.9	1490 - 1700			241
Sulfur	S	sol	32.1		32.1	298 - 388	16.8	20.1	23.0
	Sliq	liq		2 122	37.6	388 - 882	30.0	6.8	34.1
	S2gas	gas		128 599	228.2	882 - 5000	35.2	1.9	40.2
Sulfur dioxide	SO_2	gas	64.1	- 296 813	248.2	50 - 500	30.8	31.9	39.0
	SO2hi	hi				500 - 5000	52.5	3.0	60.7
Tin *grey*	Sngr	sol		- 2 092	44.1	298 - 398	25.8		25.8
Tin *white*	Sn	sol	150.7		51.2	298 - 505	21.6	18.1	28.8
	Snliq	liq		7 029	65.1	505 - 800			25.5
Tin dioxide, *cassiterite*	SnO_2	sol	150.7	- 577 631	49.0	298 - 1903	58.7	18.2	78.8
Water	Ice	sol		-279 850		< 273			37.0
	H_2O	liq	18.0	- 285 830	69.9	298 - 373	73.0	7.9	75.5
	H2Ogas	gas		- 241 827	188.8	373 - 1600	30.1	10.0	38.5
Zinc	Zn	sol	65.4		41.6	298 - 693	22.2	10.5	27.1
	Znliq	liq		7 322	52.2	693 - 1 180			31.4
	Zngas	gas		130 415	161.0	1 180 - 2 000			20.8
Zinc carbonate, *smithonite*	$ZnCO_3$	sol	125.4	- 812 780	82.4	298 - 500	38.9	138.1	93.0
Zinc oxide, *zincite*	ZnO	sol	81.4	- 350 460	43.6	298 - 2248	41.4	9.5	53.3
Zinc sulfide, *sphalerite*	ZnS	sol	97.4	- 201 669	57.7	298 - 1293	44.7	10.6	52.8

Oxygen in air o_{av} = **21.0%** by volume o_{am} = **23.2%** by mass

Density of 98% H_2SO_4 d_{acid} = **1.84** m^3/t Faraday const F = **26.8** Ah/mol