

THE PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

THIRD YEAR MINERAL PROCESSING ENGINEERING

MP344 - PYROMETALLURGY

FIRST SEMESTER EXAMINATION

TUESDAY 15th JUNE 2021 – 12:50 PM

TIME ALLOWED – 3 HOURS

INFORMATION FOR STUDENTS

1. You have 10 minutes to read the paper. You **MUST NOT** begin writing during that time.
2. **Attempt ALL questions.** Write all answers in the answer booklet provided.
3. Write your **NAME** and **STUDENT NUMBER** clearly on the **ANSWER BOOKLET**. Do this **NOW**.
4. **NO MOBILE PHONES AND LAPTOPS ARE ALLOWED IN THE EXAMINATION ROOM.**

Marking Scheme:

All question carry equal marks. Total mark is 100.

Question 1

- (a) Determine the feasibility of reducing NiO by vanadium at 1000 °C. Show equations for the process. Refer to Figure 1.0 to answer this question.
- (b) Show by aid of a diagram the shaft furnace operation. Discuss the processes in each zone.
- (c) Discuss with an aid of a diagram the temperature of gas and solid during calcination of limestone in a coke-fired shaft furnace.
- (d) Show by equations the following processes:
 - i. magnetizing roasting
 - ii. sintering roasting

Question 2

- (a) Discuss with the aid of a diagram the Blast Furnace operation for pig iron production. Explain the processes within the Blast Furnace.
- (b) A Blast Furnace burden contains 160 kg Fe₂O₃, 54 kg SiO₂, 20 kg Al₂O₃, 100 kg CaCO₃ and 78 kg C. For the smelting of the above burden 266 Nm³ of air is used. The hot metal produced contains 4 % C and 1 % Si, the balance being iron, and it is assumed that all the iron in the burden enters the hot metal. The remaining oxides form a slag, whereas CO₂ from the limestone is expelled and mixes with the furnace gas. Carbon in the gas is partly as CO₂ and CO and there is no free oxygen.
 - i. Calculate the weight of the hot metal as well as the weight and composition of the slag.
 - ii. Calculate the volume and composition of the furnace gas, all for the above basis.

Note: Refer to Figure 2.0 for calculations.

Question 3

- (a) Design a flow sheet to produce 99.9 % Cu from Ok Tedi deposit of copper grade 1 – 2 % Cu. Assays of the tails report 0.1 – 0.2 % Cu whilst the Cu concentrate reported 20 – 30 % Cu. Slag to the waste is 0.3 – 1 % Cu with the Cu matte records 50 – 70 % Cu. Hence, slag from the refinery is re - circulated back to the matte smelting. Blister copper assayed 98 % Cu and at the cathodes with 99.5 % Cu. Finally, the waste electrolyte contains Ni, Cr, Co etc. and the noble metals (Au, Ag and Pt) are collected at the anode.

Note: Indicate flow of material, addition of fluxes and air, exit of volatile substances and wastes. Show all unit processes involved in the flow sheet.

- (b) A copper concentrate contains 20 %Cu and 40 % S. The ore minerals are CuFeS_2 and FeS_2 , the remaining gangue is SiO_2 .
- i. Calculate the number of moles of Fe, Cu, S, and SiO_2 in 1 kg of concentrate.
 - ii. The concentrate (25 °C) is flash smelted with oxygen enriched air (25 °C) to give a matte with 40 % Cu. All the oxygen in the blast is consumed. The matte is assumed to be a mixture of stoichiometric Cu_2S and FeS . The slag is stoichiometric Fe_2SiO_4 . Calculate the number of moles of Cu_2S and FeS in the matte and of FeO and SiO_2 in the slag.
 - iii. Calculate the necessary addition of SiO_2 as well as the total O_2 in the blast, all per kilogram of concentrate.

Question 4

- (a) Which furnace smelt the copper concentrates to produce copper matte? Explain the operation of this furnace.
- (b) Discuss the process in (a) by a chemical equation.
- (c) Study Figure 3.0 and answer the following questions:-
 - i. Discuss the composition of an acid slag and explain how it produces high viscous melt.
 - ii. Give the properties of the Blast furnace slag and discuss its formation with regards to temperature and chemical composition.
 - iii. Why are the following properties important in valuing refractory materials?
 - Melting point.
 - Resistance towards molten slags and metals.
 - Resistance to oxidation and reduction.

- (d) Study Figure 4.0 and answer the following questions:-
- i. Which substance is independent of temperature?
 - ii. Which substances are less stable at higher temperatures?
 - iii. Give reasons why coke & coal are not viable on industrial scale.
 - iv. Which product of carbon is more stable at a higher temperature?
 - v. Explain why most of the organic compounds are not reducible by carbon.

END OF PAPER

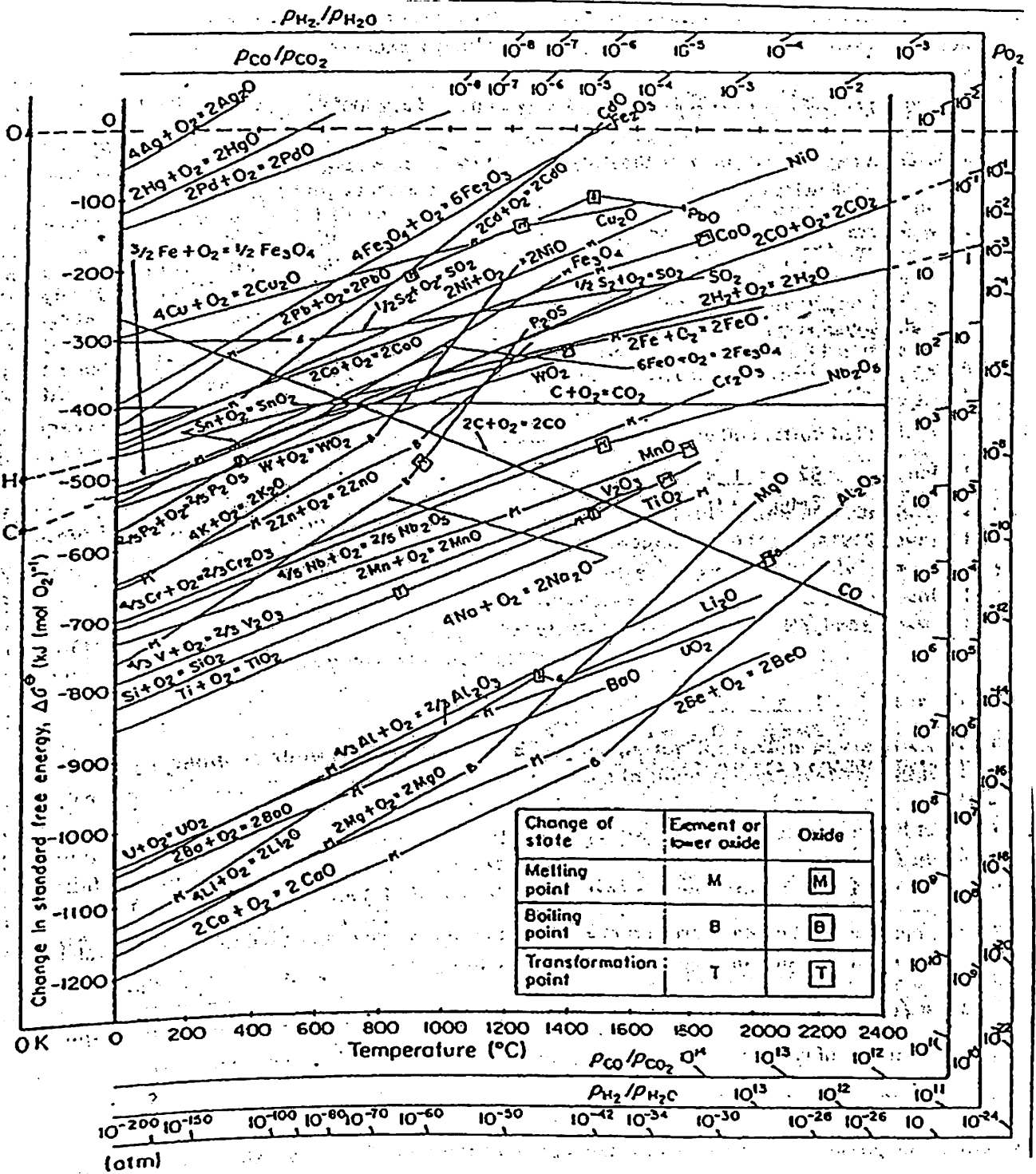


Figure 1.0 $\Delta G^\circ - T$ diagram for the formation of oxides. For equilibrium P_{O_2} , P_{CO}/P_{CO_2} and P_{H_2}/P_{H_2O} values use points O, C and H respectively on the ΔG° axis at 0 K.

Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 84.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (209)	86 Rn Radon 222.02
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.06	71 Lu Lutetium 174.97			
89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium (254)	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium (262)			

- | | | | | | | | | | |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|
| Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Metalloid | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|

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Figure 2.0 Periodic Table of Elements

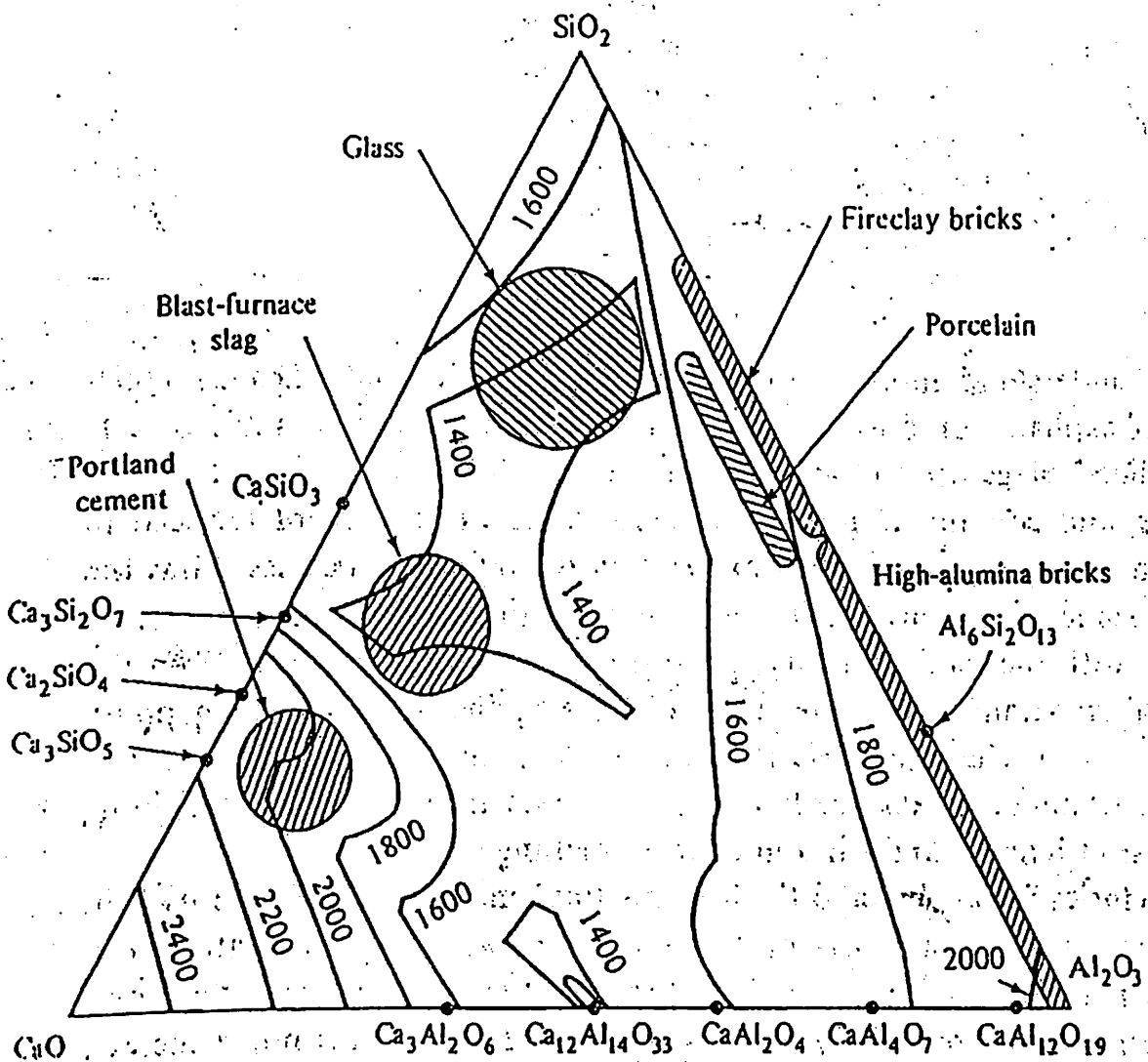


Figure 3.0 Liquidus isotherms in the SiO_2 - CaO - Al_2O_3 system

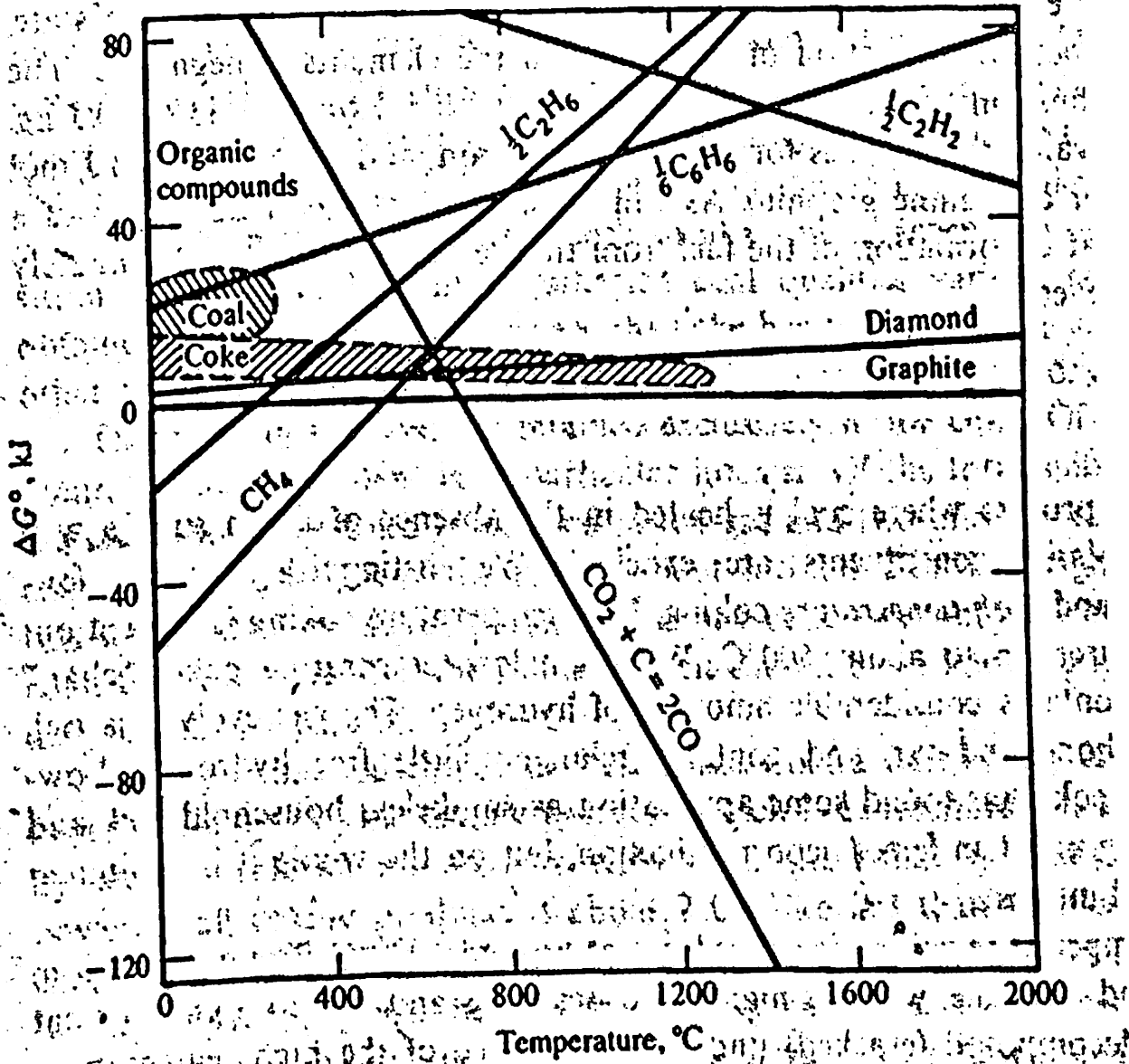


Figure 4.0 Standard Gibbs energy of formation, per mole of carbon, of various carbon compounds relative to graphite.