BIRKBECK, UNIVERSITY OF LONDON

BSc EXAMINATION

SCHOOL OF SCIENCE

Department of Earth and Planetary Sciences

INTRODUCTION TO GEOCHEMISTRY

EASC038H4

15 credits

<date>

Time Allowed: 2 HOURS AND 45 MINUTES

INSTRUCTIONS

Answer THREE questions. [Candidates are advised to spend 40 minutes on each question, and to finish writing and begin the document upload process 2 hours after starting the exam. Use diagrams, equations and chemical reactions to support written answers wherever possible]

ALL QUESTIONS CARRY EQUAL MARKS

Candidates are provided with a Periodic Table of the Elements and an Equation bank on the final two pages.

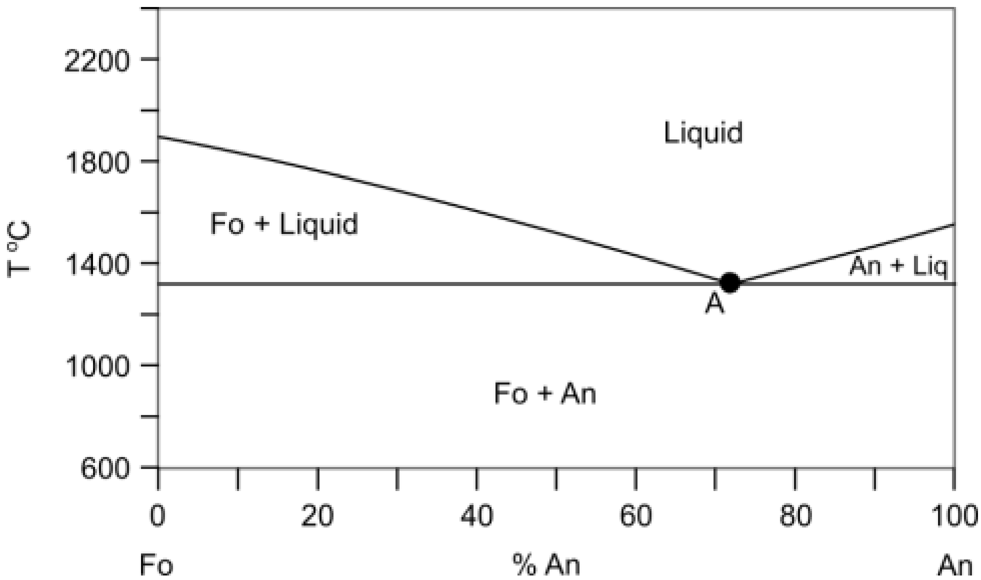
Candidates are permitted to use a scientific calculator, Excel, or similar means of carrying out calculations

Show all calculations and units in your answers.

You must type your answers, and it is recommended that you type out calculations. You may include sketch figures and hand-written calculations where appropriate, by uploading an image of your sketch and including this in your submitted document.

You **are not permitted** to include copied graphics or text from lecture notes in your answer.

Q1 Consider the following binary phase diagram for the system forsterite (Fo) – anorthite (An).



a) How many components does this system have? [5%]

b) Consider point A on this diagram (the eutectic). Answer the following:

i) How many phases coexist at this point? [5%]

ii) How many degrees of freedom are there at this point? [5%]

iii) Give your reason for the answer to (ii) above. [5%]

c) What is the melting temperature of pure:

i) forsterite; [5%]

ii) a mixture of forsterite and anorthite crystals in eutectic proportions. [5%]

d) Consider the heating and melting of a rock consisting of 60% forsterite and 40% anorthite crystals.

i) What is the composition of the first droplet of melt? [10%]

ii) With continued heating, which phase is exhausted first? [10%]

iii) At what temperature does the rock become fully molten? [10%]

e) At the eutectic in this system, the process of melting can be described with a chemical reaction: 7 Fo + 18 An = 25 liquid. Would you predict this reaction to be endothermic or exothermic, and why? [20%]

f) The volume change of this eutectic melting reaction is slightly positive (the liquid has a higher volume than the solid). If this reaction were plotted as a line on a diagram of temperature (on the x-axis) against pressure (on the y-axis), would you expect that line to have a positive or negative slope? You may wish to refer to either Le Chatelier's principle or the Clapeyron equation in your answer. [20%]

Q2
a) Describe how radioactive isotopes can be used to determine the age of geological materials, using the ^{87}Rb – ^{87}Sr system as an example. [70%]

b) Explain how an isotope evolution diagram works, using the system ^{87}Rb – ^{87}Sr as an example. [30%]

Q3 Limestone (calcite) dissolves in rainwater in the presence of carbonic acid according to the following reaction:

$$CaCO_{3(s)} + H_2CO_{3(aq)} = Ca^{2+}_{(aq)} + HCO_3^-{}_{(aq)}$$

a) Balance this equation. [10%]

b) Which term best describes this type of chemical weathering: dissolution, oxidation, or hydrolysis? [5%]

c) What is the origin of carbonic acid in natural waters? Write a reaction to describe this process. [15%]

d) At a given location, the reactants and products of this reaction are all found to co-exist and are assumed to be in equilibrium. In this situation:

i) What is the solvent? [5%]
ii) What is/are the solutes? [5%]
iii) Comment on the saturation of the solution with respect to calcite. [10%]

e) If 1 g of calcite were to dissolve in a kilogram of water, what would the concentration of Ca^{2+} ions in the solution be? Express your answer in molality, i.e. mol kg^{-1}. [35%]

f) A sample of rainwater contains 1.6×10^{-6} mol l^{-1} of H^+. What is its pH? [15%]

Q4
a) Give an illustrated account of ionic, covalent and metallic bonding, with examples of materials displaying each type of bonding. [75%]

b) Why are bonds in silicate minerals described as being neither pure ionic, nor pure covalent, and how can we predict how ionic or covalent a particular bond might be? [25%]

Q5

a) What is an exothermic reaction? Give an example of one. [15%]

b) What is entropy? [10%]

c) How is the concept of Gibbs free energy used to predict the feasibility of chemical reactions? [25%]

d) Why might a thermodynamically-feasible reaction not occur? [25%]

e) Explain why higher temperature will lead to a higher reaction rate. You may wish to refer to the Arrhenius equation. [25%]

Q6

a) What name is given to a positively-charged ion? [5%]

b) Define the following terms [15%]

- i) Ionisation energy;
- ii) Electronegativity;
- iii) Valence.

c) Why is water such an effective solvent of ionic crystals? [20%]

d) Water is present in the structure of some silicate minerals. The following reaction describes the hydration of forsterite (olivine) to serpentine:

$$Mg_2SiO_4\ [s] + SiO_2\ [aq] + H_2O\ [l] = Mg_3Si_2O_5(OH)_4\ [s]$$

- i) Balance this reaction. [15%]
- ii) Where on Earth might such a reaction occur? [10%]

e) Serpentine is a sheet silicate. Give a brief account of the structure of sheet silicates in terms of the arrangement and bonding of their $[SiO_4]^{4-}$ complex anions. [35%]

Equation Bank

$\Delta H = H_{products} - H_{reactants}$

$\Delta G = G_{products} - G_{reactants}$

$G = H - TS$

$\Delta G = \Delta H - T\Delta S$

$k = A\ e^{-Ea/RT}$

$\varphi + F = C + 2$

$\varphi + F = C + 1$

$J_i = -D_i\ dc_i/dx$

$N = N_0\, e^{-\lambda t}$

$\delta P/\delta T = \Delta S/\Delta V$

$\delta c_{product} / \delta T = \delta c_{reactant} / \delta T$

$J_i = -D_i\ \delta c_i / \delta x$

$K = [C]^c\ [D]^d\ [E]^e / [A]^a\ [B]^b$

$I = ½\ \Sigma\ m_i\ z_i^2$

$t_{½} = \ln 2 / \lambda$

$D = P\ (e^{\lambda t} - 1) + D_{initial}$ [approximates to:] $D = P * \lambda t + D_{initial}$

$^{87}Sr = {}^{87}Rb * (e^{\lambda t} - 1) + {}^{87}Sr_{initial}$ $^{87}Sr/^{86}Sr = {}^{87}Rb/^{86}Sr * \lambda t + {}^{87}Sr/^{86}Sr_{initial}$

$\delta y/\delta x = \lambda t$

$\delta_{sample} = ((R_{sample} - R_{standard}) / R_{sample}) *1000$

$T(°C) = T(K) - 273$

$pH = -\log[H^+_{(aq)}]$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.94	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.97	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium [97]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293
55 Cs Cesium 132.905	56 Ba Barium 137.327	57 La Lanthanum 138.905 *	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.997	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89 Ac Actinium [227] **	104 Rf Rutherfordium [267]	105 Db Dubnium [270]	106 Sg Seaborgium [269]	107 Bh Bohrium [270]	108 Hs Hassium [270]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [281]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [293]	118 Og Oganesson [294]

*Lanthanide series	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.967
**Actinide series	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]	103 Lr Lawrencium [262]