GEO1-1112 Chemistry of the Earth I

EINDTOETS 2010

08 November 2010

Name _____ Student nummer _____

SECTION A: MULTIPLE CHOICE: **ANSWER ALL 14 QUESTIONS**
SECTION B: LONG QUESTIONS: **ANSWER 3 OUT OF 5 QUESTIONS**

NOTE: Physical constants and a periodic table are given at end of this exam paper

A. MULTIPLE CHOICE QUESTIONS

Answer all questions by placing a cross in the box against the correct answer

A1. Why do geochemists typically normalize trace element concentrations to *chondrite*?

- ☐ **A** Because some elements were anomalously unstable during nucleosynthesis (e.g. B, Be)
- ☐ **B** Because some elements were anomalously stable during nucleosynthesis (e.g. Fe)
- ☐ **C** Odd atomic number elements are more abundant than those with an even atomic number
- ☐ **D** Even atomic number elements are more abundant than those with an odd atomic number

A2. Which of the following processes accompanies β^+ decay?

- ☐ **A** Emission of an electron and conversion of a neutron to a proton
- ☐ **B** Emission of an electron and conversion of a proton to a neutron
- ☐ **C** Emission of He nucleii
- ☐ **D** Splitting of the nucleus into two daughter nucleii

A3. Which of the following radiogenic isotope pairs can be used for dating zircon ($(Zr,Hf)SiO_4$) crystals ?

- ☐ **A** ^{238}U-^{232}Th
- ☐ **B** ^{238}U-^{206}Pb
- ☐ **C** ^{238}U-^{176}Hf
- ☐ **D** ^{182}Hf-^{182}W

A4. Which of the following atoms contains 7 valence electrons

- ☐ **A** Li
- ☐ **B** N
- ☐ **C** Mn
- ☐ **D** Co

A5. Which of the following groups of elements fall into the *siderophile* group as defined by Goldschmidt?

- ☐ **A** Ca, Mg, Al
- ☐ **B** N, O, He
- ☐ **C** Sb, As, Cu
- ☐ **D** Co, Ni, Ge

A6. Which of the following parameters are represented in phase diagrams?

- ☐ **A** Pressure, Temperature, Composition
- ☐ **B** Mass, Density, Time
- ☐ **C** Pressure, Temperature, Time
- ☐ **D** Pressure, Temperature, Density

A7. 5 g dried calcite powder were reacted with 15% HCl (= 4 mol/l) for a minimum of 20 minutes producing a volume of 4.2 ml $CO_{2(g)}$. How many grams of calcite were there in the original sample?

- ☐ **A** 0.053
- ☐ **B** 0.105
- ☐ **C** 9.54
- ☐ **D** 18.75

A8. A sediment sample has a porosity of 35% with a total concentration of organic matter of 5%. The density of the organic matter is approximately 1.4 g/cm^3. The average density of the minerals present in the sediment is 2.7 g/cm^3. What is the volume (in cm^3) of a 100 g by dry mass sample of sediment?

- ☐ **A** 38.76
- ☐ **B** 54.13
- ☐ **C** 59.63
- ☐ **D** 107.2

A9. What is the average distance and of the electron from the nucleus in a helium ion (He^+) for the $2p$ orbital. a_0= 0.529 Å

- ☐ **A** 1.3 Å
- ☐ **B** 1.6 Å
- ☐ **C** 2.6 Å
- ☐ **D** 3.2 Å

A10. What is the ground state electron configuration for the element Aluminium (Al), atomic number 13

- ☐ **A** [Ne] $3s^3$
- ☐ **B** [Ar] $3s^2\ 2p^1$
- ☐ **C** [Ar] $3s^2\ 3p^1$
- ☐ **D** [Ar] $3s^2\ 4p^1$

A11. Which units are used to report $\delta^{18}O$ values?

- ☐ **A** %
- ☐ **B** ‰
- ☐ **C** ppm
- ☐ **D** ng g^{-1}

A12. What is the H-O-H bond angle in crystalline ice?

- ☐ **A** 90°
- ☐ **B** 104.5°
- ☐ **C** 107°
- ☐ **D** 109.5°

A13. Which of the following groups of elements would you expect to be insoluble during weathering and therefore useful for determining the origin of very old and altered rocks?

- ☐ **A** Na, K, Cs
- ☐ **B** Ca, Sr, Ba
- ☐ **C** Pb, Zn, Ni
- ☐ **D** Ti, Hf, Zr

A14. Which of the following analytical techniques would you use to measure the major element composition of a feldspar mineral?

- ☐ **A** Inductively coupled plasma atomic emission spectrometry (ICP-AES)
- ☐ **B** Inductively coupled plasma mass spectrometry (ICP-MS)
- ☐ **C** Gas Source mass spectrometry (GS-MS)
- ☐ **D** Electron microprobe microanalysis (EMPA)

PART B: ANSWER 3 OUT OF THE FOLLOWING 5 QUESTIONS

OPTION B1: Age of the Earth

(a) How would you accurately determine the age of the Earth?
In your answer give details about the rocks or minerals that could be investigated and the analytical methods that could be applied. Include information about the elements and isotopes involved in radioactive decay

[8 Marks]

(b) ^{238}U has a half life of 4.5 Ga and ^{235}U a half life of 0.7 Ga. Assuming that the two isotopes were to be found in a proportion of 1:1 at the time of formation of the Earth, use radioactive decay equations to calculate an age for the Earth. Assume the modern $^{235}U/^{238}U$ ratio to be 0.007.

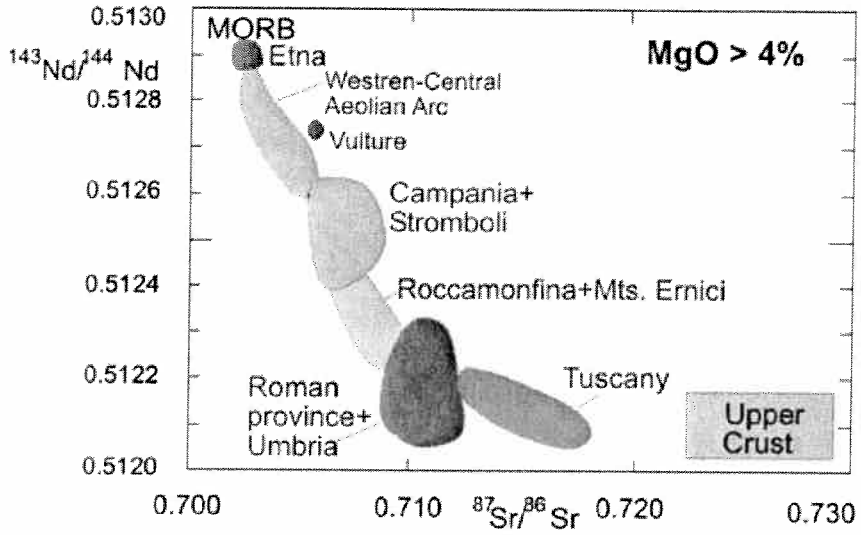
[8 Marks]

(c) What are the oldest dated objects in the solar system at the current time? How would you determine if there is a time gap between the origin of the solar system and the formation of the Earth? Which isotopes would be used to help determine these timescales?

[4 Marks]

OPTION B2: Radiogenic Isotopes in the crust

The figure below shows how strontium and neodymium isotope ratios vary within volcanic and magmatic rocks from central and southern Italy. The fields for mid-ocean ridge basalt (MORB) and typical upper crust are also given.



(a) Explain why radiogenic isotope ratios are better than major or trace elements for identifying the origin of the volcanic/magmatic rocks

[4 Marks]

(b) Give the names of the parent and daughter isotopes in both the Sr and Nd radiogenic decay systems

[4 Marks]

(c) Explain why the field for upper crust is in the bottom right hand corner of the diagram with relatively high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$. Tip: In your answer explain how the elements partition during the formation of the crust from the mantle, and show how this affects isotope ratios

[8 Marks]

(d) Do you think that the volcanic rocks were formed in the crust or the mantle, or both? Explain your answer

[4 Marks]

OPTION B3: Water

Water on the early Earth:

(a) What evidence do we have that liquid oceans were present on the surface of the Earth as early as 4000 to 4400 million years ago? In your answer explain which stable isotope system could be used, how the isotopes of this element are fractionated, in which rock or mineral it would be measured and how it deviates from what would be expected if liquid water was not present.

[8 Marks]

Water on the modern Earth. Ocean circulation:

(b) Describe as clearly as you can, how changes to the structure of liquid water causes water to sink to the bottom of the ocean in high latitude regions. Use diagrams in your answer to show clearly how changes in the structure are linked to density changes.

[8 Marks]

(c) What is the main difference between circulation in a water ocean and a methane ocean (such as the one we might find on Titan). Describe changes in bonding and how this would affect ocean currents

[4 Marks]

OPTION B4: Analytical Techniques in Geochemistry

(a) Why is it important to measure both *major elements* and *trace elements* in most geochemical studies? In your answer give the definitions of a major and a trace element with as much detail as you can.

[6 Marks]

(b) What is an inductively coupled plasma mass spectrometer (ICP-MS) used for in a geochemical laboratory? In your answer explain

- how the sample is excited
- what kind of sample can be measured and on what scale
- what is measured: major elements, trace elements or isotopes

[6 Marks]

(c) A drinking water aquifer in *Noord Holland* has been contaminated with saline fluids, which may have come from seawater. You are working for an environmental consultancy and it is your job to investigate the contamination event.

- Which elements would you expect to be higher in concentration in seawater than in freshwater? Give as many elements as you can.

- Which analytical technique(s) could you use to determine the concentration of salts in groundwater samples taken from the aquifer?

- The saline fluids might also have been introduced by the excessive use of salt on a nearby road to prevent it from freezing in winter. The road salt comes from a salt mine in Italy. What geochemical tools could you use to distinguish the salt of seawater origin and the salt from the mine? (Tip: The salt is not pure NaCl and is contaminated with other elements and compounds including sulphate (SO_4^{2-}))

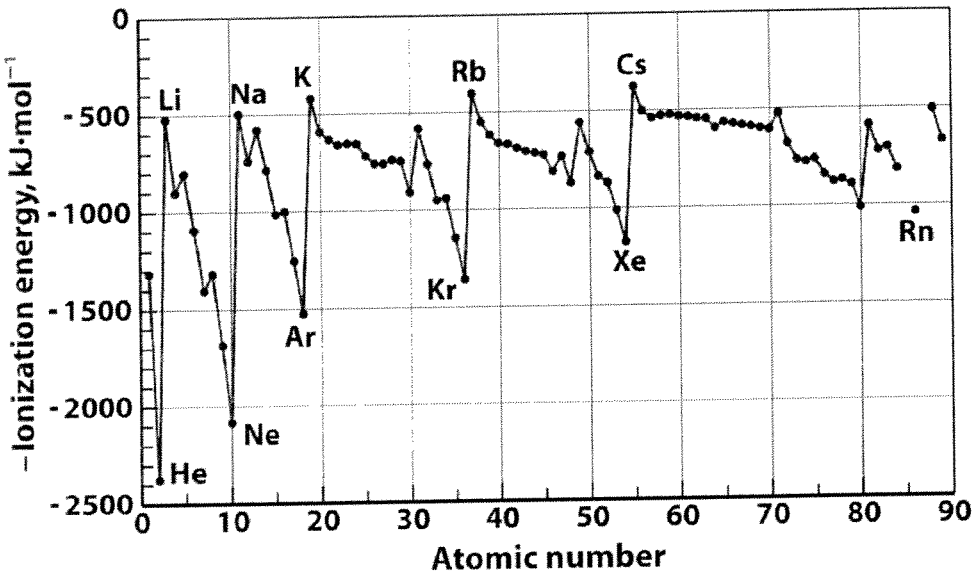
[8 Marks]

OPTION B5: Periodic Table

The modern periodic table explains the variation in many chemical properties of the elements from both a theoretical (quantum mechanical) and practical basis. Ionization energy can be both measured and predicted from the periodic table with excellent agreement.

(a) What is the definition of **ionization energy?** **[4 Marks]**

(b) The figure below shows how ionization energy varies with atomic number for the first 88 elements in the periodic table.



Why does ionization energy increase on going across the second period elements from Li to Ne? Give as much detail as you can about changes in forces and distances within the atom.

[6 Marks]

(c) Explain why the slope of the plot varies in steps between Cs and Rn

[6 Marks]

(d) Why is ionization energy not very useful as a property for describing the properties of solids and liquids at the Earth's surface? Which chemical property would be more useful in its place?

[4 Marks]

Physical Constants

Avogadro's number	$N_A = 6.022 \times 10^{23}$ atoms mol^{-1}
Bohr radius	$a_0 = 0.529$ Å $= 5.29 \times 10^{-11}$ m
Charge on an electron	$e = 1.602 \times 10^{-19}$ C
Mass of an electron	$m_e = 9.109 \times 10^{-31}$ kg
Permittivity of a vacuum	$\varepsilon_0 = 8.854 \times 10^{-12}$ $C^2 J^{-1} m^{-1}$
Planck's constant	$h = 6.62 \times 10^{-34}$ Js^{-1}
Speed of Light in a vacuum	$c = 2.998 \times 10^{8}$ ms^{-1}
Universal gas constant	$R = 8.314$ $Jmol^{-1}K^{-1}$

Key Equations

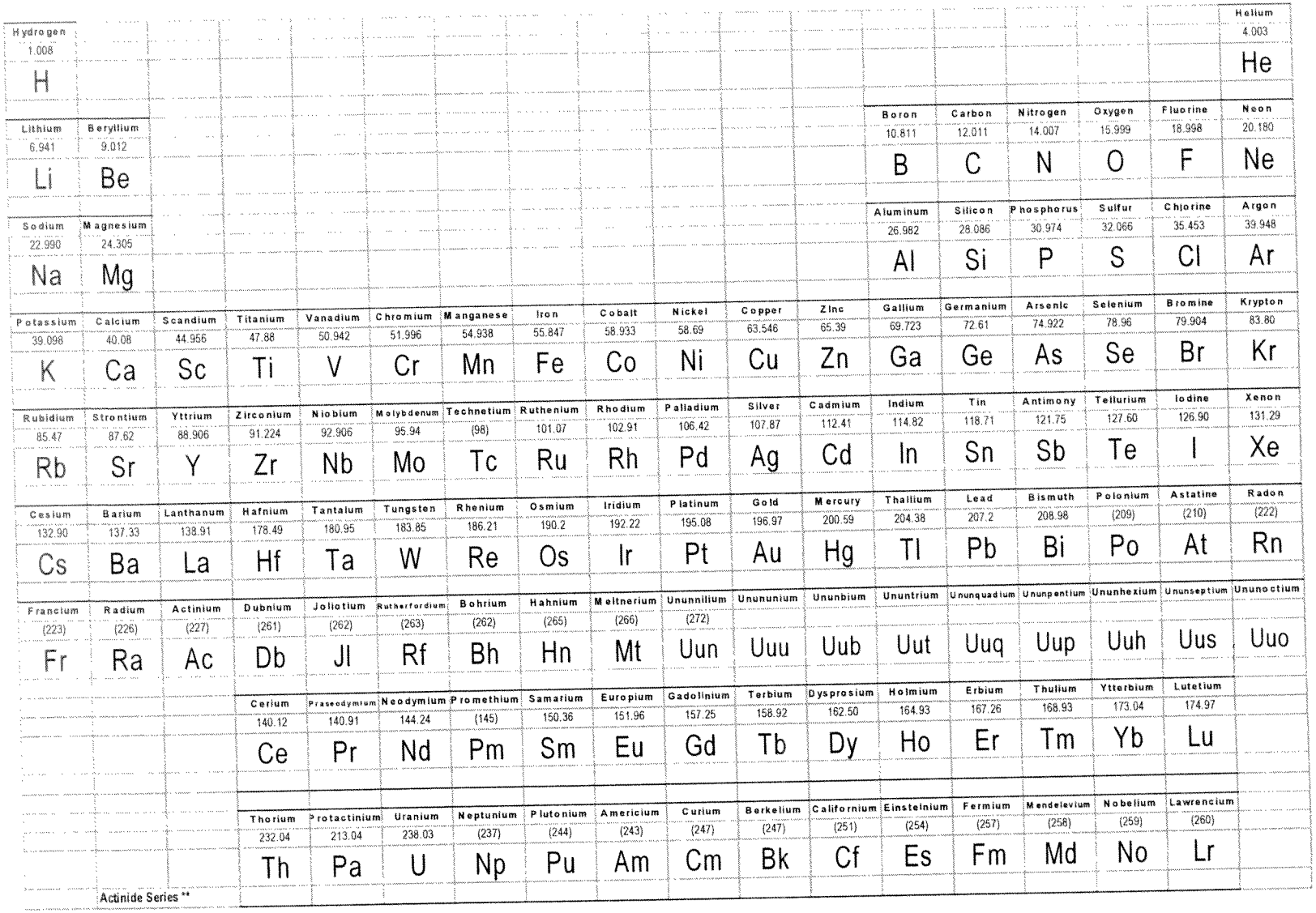
$$F(r) = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} \qquad r_n = \frac{\varepsilon_0 n^2 h^2}{\pi Z e^2 m_e} = \frac{n^2}{Z} a_0 \qquad v = (3.29 \times 10^{15}\, s^{-1}) Z^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$$V(r) = \frac{q_1 q_2}{4\pi\varepsilon_0 r} \qquad r = \frac{n^2 a_0}{Z} \left\{ 1 + \frac{1}{2} \left[1 - \frac{l(l+1)}{n^2} \right] \right\}$$

$$E_n = \frac{-Z^2 e^4 m_e}{8\varepsilon_0^2 n^2 h^2} = -(2.18 \times 10^{-18}\, J) \frac{Z^2}{n^2}$$

$4 + 2 \left(1 - \frac{4+2}{4} \right) =$

$4 + 2 - 3 = 3$



Hydrogen 1.008 H																	Helium 4.003 He
Lithium 6.941 Li	Beryllium 9.012 Be											Boron 10.811 B	Carbon 12.011 C	Nitrogen 14.007 N	Oxygen 15.999 O	Fluorine 18.998 F	Neon 20.180 Ne
Sodium 22.990 Na	Magnesium 24.305 Mg											Aluminum 26.982 Al	Silicon 28.086 Si	Phosphorus 30.974 P	Sulfur 32.066 S	Chlorine 35.453 Cl	Argon 39.948 Ar
Potassium 39.098 K	Calcium 40.08 Ca	Scandium 44.956 Sc	Titanium 47.88 Ti	Vanadium 50.942 V	Chromium 51.996 Cr	Manganese 54.938 Mn	Iron 55.847 Fe	Cobalt 58.933 Co	Nickel 58.69 Ni	Copper 63.546 Cu	Zinc 65.39 Zn	Gallium 69.723 Ga	Germanium 72.61 Ge	Arsenic 74.922 As	Selenium 78.96 Se	Bromine 79.904 Br	Krypton 83.80 Kr
Rubidium 85.47 Rb	Strontium 87.62 Sr	Yttrium 88.906 Y	Zirconium 91.224 Zr	Niobium 92.906 Nb	Molybdenum 95.94 Mo	Technetium (98) Tc	Ruthenium 101.07 Ru	Rhodium 102.91 Rh	Palladium 106.42 Pd	Silver 107.87 Ag	Cadmium 112.41 Cd	Indium 114.82 In	Tin 118.71 Sn	Antimony 121.75 Sb	Tellurium 127.60 Te	Iodine 126.90 I	Xenon 131.29 Xe
Cesium 132.90 Cs	Barium 137.33 Ba	Lanthanum 138.91 La	Hafnium 178.49 Hf	Tantalum 180.95 Ta	Tungsten 183.85 W	Rhenium 186.21 Re	Osmium 190.2 Os	Iridium 192.22 Ir	Platinum 195.08 Pt	Gold 196.97 Au	Mercury 200.59 Hg	Thallium 204.38 Tl	Lead 207.2 Pb	Bismuth 208.98 Bi	Polonium (209) Po	Astatine (210) At	Radon (222) Rn
Francium (223) Fr	Radium (226) Ra	Actinium (227) Ac	Dubnium (261) Db	Joliotium (262) Jl	Rutherfordium (263) Rf	Bohrium (262) Bh	Hahnium (265) Hn	Meitnerium (266) Mt	Ununnilium (272) Uun	Unununium Uuu	Ununbium Uub	Ununtrium Uut	Ununquadium Uuq	Ununpentium Uup	Ununhexium Uuh	Ununseptium Uus	Ununoctium Uuo
			Cerium 140.12 Ce	Praseodymium 140.91 Pr	Neodymium 144.24 Nd	Promethium (145) Pm	Samarium 150.36 Sm	Europium 151.96 Eu	Gadolinium 157.25 Gd	Terbium 158.92 Tb	Dysprosium 162.50 Dy	Holmium 164.93 Ho	Erbium 167.26 Er	Thulium 168.93 Tm	Ytterbium 173.04 Yb	Lutetium 174.97 Lu	
	Actinide Series **		Thorium 232.04 Th	Protactinium 213.04 Pa	Uranium 238.03 U	Neptunium (237) Np	Plutonium (244) Pu	Americium (243) Am	Curium (247) Cm	Berkelium (247) Bk	Californium (251) Cf	Einsteinium (254) Es	Fermium (257) Fm	Mendelevium (258) Md	Nobelium (259) No	Lawrencium (260) Lr	