Please mark X to indicate your tutorial section.
Failure to do so will result in a deduction of 5 marks.

TUT 01	
TUT 02	
TUT 03	
TUT 04	
TUT 05	
TUT 06	
TUT 07	
TUT 08	
TUT 09	
TUT 10	
TUT 11	
TUT 12	

UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

Final Exam

20 April 2015

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: G. Azimi, C Chin, T. Mirkovic, J. Nogami

NAME: ________________________________
Last First

STUDENT NO:________________________________

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all seven questions.
- All work is to be done on the pages of this booklet.
- When answering the questions **include all the steps** of your work on these pages and then **fill the answer in** the respective **boxes**. For additional space, you may use the back of the preceding page.
- Do not unstaple this exam booklet.
- A Formula Sheet and the periodic table are attached to the end of this exam booklet; if you wish, you may tear-off these sheets *only*.

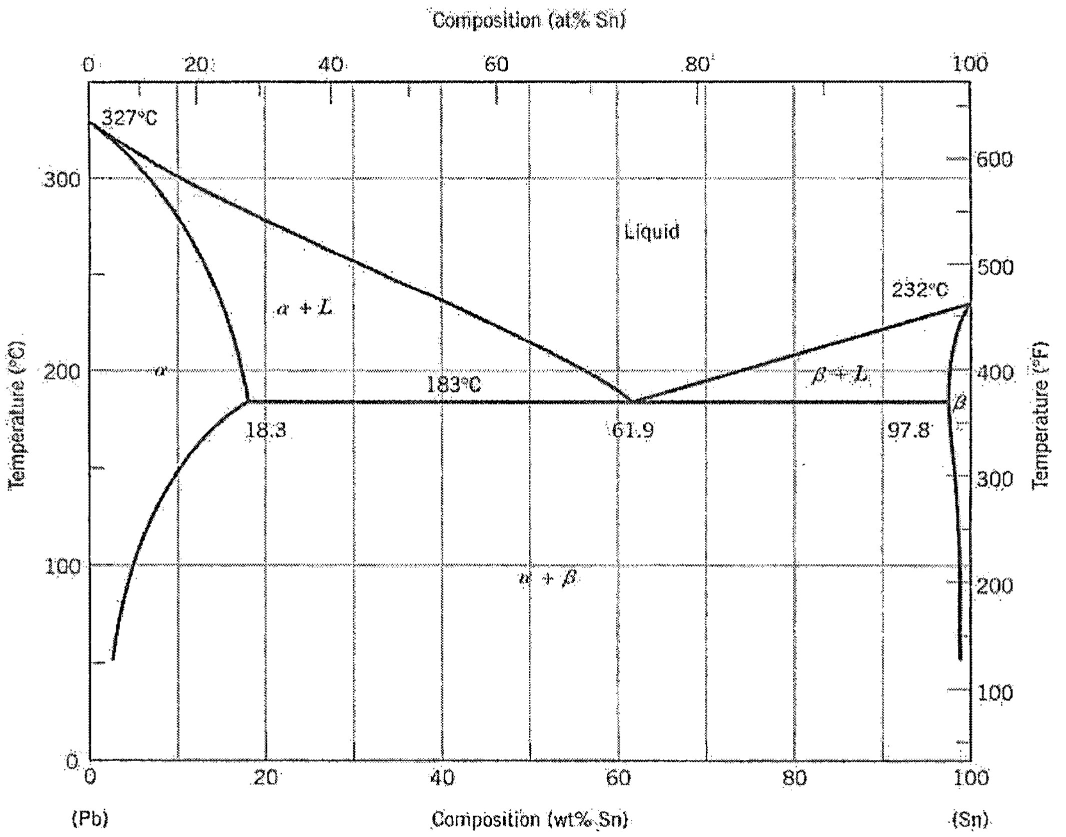
Q1	/20
Q2	/20
Q3	/20
Q4	/20
Q5	/20
Q6	/20
Q7	/20
Total	/140

Name: ______________________ Student No: ______________________

Problem 1. Binary Phase Diagrams

A phase diagram of tin and lead is shown below.

For Part 1a-1d, we examine the slow cooling of a 30 wt% Sn-70 wt% Pb mixture from the liquid phase to 150 °C.



Phase diagram of Sn and Pb

1a. What is the temperature at which the first solid phase is formed. [2 pts]

1b. What is the composition of the last drop of liquid in the alloy before complete solidification. [2 pts]

1c. Determine the i) phase(s), ii) their respective weight fractions, and iii) their composition(s) of the phases when the temperature reaches 150 °C.

[2 pts] Phase(s):

[2 pts] Weight Fraction(s):

[2 pts] Composition(s) of each phase:

Name: ______________________________ Student No: ________________________

1d. What is the minimum weight fraction of β in the mixture containing only solid phases that can be formed from the 30 wt% Sn-70 wt% Pb during the cooling process (from liquid phase to 150 °C)? [2 pts]

1e. Consider cooling a second sample with 75% Sn from the liquid phase to 100°C.

i) Sketch the microstructure at T = 184°C. Label all of the phases present. [2 pts]

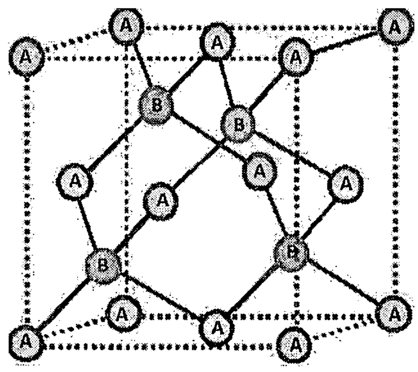
ii) Sketch the microstructure at T = 182°C. Label all of the phases present. [2pts]

iii) At T = 182°C, calculate the weight fractions of the solid solution and the eutectic phase. [4 pts]

Name: ______________________________ Student No: ______________________________

Problem 2: Crystal Structures

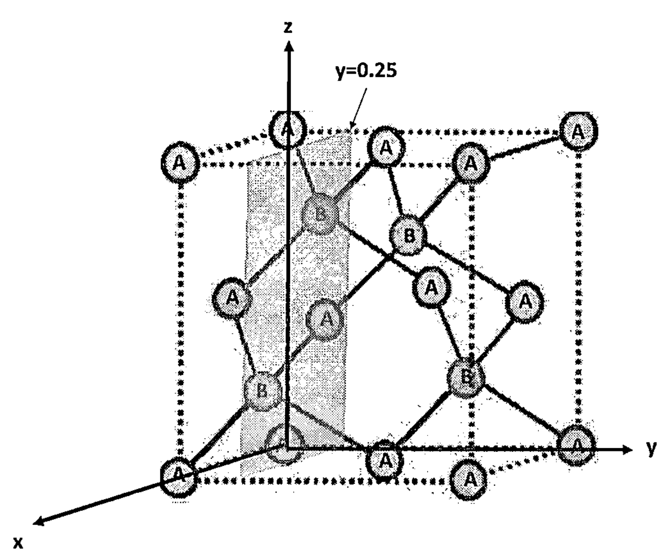
The crystal structure of Mercury(II) Telluride ($Hg^{2+}Te^{2-}$) is shown below. The radius of Mercury(II) ion is 116 pm and that of the Telluride ion is 211 pm.



2a. Name the crystal structure. ______________________________ [2 pts]

2b. The coordination number of atom A in the figure is ______________________________ [2 pts]

2c. The Planar (Miller) Indices of the plane highlighted below are: [2 pts]



2d. The planar density (PD) is defined as:

$$PD = \frac{number\ of\ atoms\ centered\ on\ a\ plane}{area\ of\ plane}$$

Determine the planar density of the plane in Part 2c, in atom nm^{-2}. [4 pts]

Name: ________________________________ Student No: ___________________________

2e. Determine the theoretical density of HgTe, in g cm^{-3}. [6 pts]

2f. As the ionic radius for cation-to-anion increases, the appropriate crystal structures change from (select the correct answer): [4 pts]

a. Sodium chloride, cesium chloride, zincblende
b. Cesium chloride, zincblende, sodium chloride
c. Zincblende, sodium chloride, cesium chloride
d. Cesium chloride, sodium chloride, zincblende

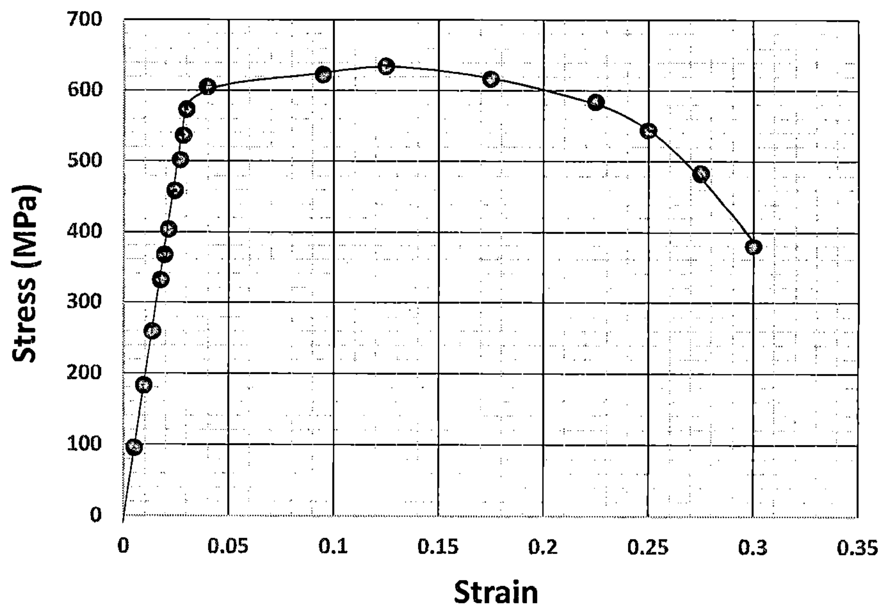
Name: ______________________________ Student No: ________________________

Problem 3: Mechanical Properties

You are evaluating a bronze alloy specimen with a cross-sectional area of 500 mm^2 and length of 6 mm.

You are given:

1) stress-strain behavior (see figure below) and
2) the Poisson's ratio for this material is 0.30



Stress-strain behavior of a bronze alloy specimen.

3a. What is the maximum load (in N) that can be sustained by the specimen? [2pts]

3b. What is the maximum load (in N) that can be applied to the bronze alloy specimen without plastic deformation? [2 pts]

3c. Determine the specimen cross-sectional area when the specimen is pulled in tension with a force of 200 000 N. [4 pts]

Name: ______________________________ Student No: ________________________

3d. What is the ductility, in percent of elongation? [4 pts]

3e. How do you determine the toughness of this sample? [2 pts]

3f Calculate the toughness of the sample. [2pts]

3g. Select the correct answer: [4 pts]

i. Brittle materials generally never exhibit higher tensile strengths than ductile materials
ii. During plastic deformation, the bonds between original atom neighbors are broken and new bonds are formed.
iii. Ceramics typically absorb large amount of energy than metal before their catastrophic fracture.
iv. When porosity increases, the flexural strength also increases accordingly.

Name: ______________________________ Student No: ________________________

Problem 4: Equilibrium and $\Delta G°$

4(a) A 1-L vessel intially contains 0.2 M $CH_4(g)$ and 0.8 M $H_2S(g)$ at 973 K. Assume the process given below reaches equilibrium when 30% of the $CH_4(g)$ reacts with the $H_2S(g)$ to produce $H_2(g)$ and $CS_2(g)$ products, according to:

$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2\ (g)$

Calculate the equilibrium constants (K_c and K_p) and $\Delta G°$ for this reaction at 973 K [6 pts].

4(b) Calculate K_c for the following related chemical equations at 973 K [4 pts].

$4H_2S\ (g) + 2CH_4\ (g) \rightleftharpoons 8H_2\ (g) + 2CS_2\ (g)$

$4H_2\ (g) + CS_2\ (g) \rightleftharpoons 2H_2S\ (g) + CH_4\ (g)$

Name: ______________________________ Student No: ______________________________

4(c) If K_p for the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2\ (g)$" is 3.02×10^{-5} at 25°C, and also using the results from part a), calculate $\Delta H°_{reaction}$ (assumption: $\Delta H°_{reaction}$ is independent of temperature) [6 pts].

4(d) How would the equilibrium position change, if the following actions are performed on the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2(g)$" system? Circle the correct response [4 pts].

1) Addition of iron mixed with metal oxides catalyst	*move to right*	*move to left*	*doesn't shift*
2) Decreasing temperature	*move to right*	*move to left*	*doesn't shift*
3) Increasing the volume of the vessel	*move to right*	*move to left*	*doesn't shift*
4) Increasing the partial pressure of $CS_2(g)$	*move to right*	*move to left*	*doesn't shift*

Name: ______________________________ Student No: __________________________

Problem 5: Thermodynamics

One mole of an ideal diatomic gas is compressed from an initial pressure and temperature of 1 bar and 300 K to a final pressure of 4 bar in three different reversible process paths given below. For each path, calculate w, q, ΔU, ΔH, and ΔS for the process.

(a) the process is adiabatic [7 pts].

(b) the process takes place at constant volume [7 pts].

(c) the process takes place isothermally [6 pts].

Name: ________________________________ Student No: ____________________________

Problem 6: Electrochemistry

A voltaic cell with Ni/Ni^{2+} and Co/Co^{2+} half-cells has the following initial concentrations: $[Ni^{2+}]=0.80$ M; $[Co^{2+}] = 0.20$ M.

Standard Reduction Potentials at 25 °C

$Co^{2+}(aq) + 2e^- \rightarrow Co(s)$ $E° = -0.28$ V

$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ $E° = -0.25$ V

(a) Write the overall reaction that occurs spontaneously under standard conditions and circle the reducing agent in the equation. **[3 pts]**

(b) Write the cell notation for the voltaic cell that incorporates the above reaction. **[2 pts]**

(c) What is the initial E_{cell}? **[3 pts]**

(d) What is $[Ni^{2+}]$ when E_{cell} reaches 0.03 V? **[4 pts]**

(e) What are equilibrium concentrations of the ions? **[5 pts]**

(f) If the cell was run from the initial conditions to equilibrium at 10A, how many hours will it take to reach equilibrium? Assume 1L volume in each half cell. **[3 pts]**

Name: ______________________ Student No: ______________________

Problem 7: Electrical Properties

Assume that Indium contributes three free electrons per atom to electrical conduction. The density of In is 7.31 g/cm^3 and its resistivity is 8.37×10^{-8} $\Omega \cdot m$.

(a) What is the electron mobility of indium? [10 pts]

(b) How long would an In wire of 0.1 mm diameter have to be to have a resistance of 50 Ω ? [4 pts]

Name: ______________________________ Student No: ______________________

(c) Silicon has the following properties:

	E_g	n_i	μ_e	μ_h
units	eV	m^{-3}	$m^2/V\cdot s$	$m^2/V\cdot s$
Si	1.10	1.3×10^{16}	0.135	0.045

Calculate the conductivity of intrinsic Silicon. [4 pts]

(d) Which of the following statements is true? Circle the correct answer. [2 pts]

- Electrons and holes contribute equally to conductivity in intrinsic Si
- Electrons contribute more than holes to conductivity in intrinsic Si
- Holes contribute more than electrons to conductivity in intrinsic Si

Name: ______________________ Student No: ______________________

FORMULAE & CONSTANTS (You may tear this sheet off.)

$R = 8.3145\ \text{J·K}^{-1}\ \text{mol}^{-1} = 0.0820574587\ \text{L·atm·K}^{-1}\ \text{mol}^{-1} = 0.083145\ \text{L·bar·K}^{-1}\text{·mol}^{-1}$

1 atm = 101.325 kPa = 1.01325 bar = 14.696 psi = 760 Torr = 760 mmHg

$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$ $k = 8.62 \times 10^{-5}$ eV/K 1 eV = 1.60×10^{-19} J

$T(\text{K}) = T(^\circ\text{C}) + 273.15$ K F = 9.6485309×10^4 C mole^{-1} e = $1.60217733 \times 10^{-19}$ C

STP: 273.15K, 1 atm ***SATP***: 298.15K, 1 bar 1L atm = 101.325 J

Mechanical properties

$$E = \frac{\sigma}{\varepsilon} \quad \sigma = \frac{F}{A} \quad \epsilon = \frac{\Delta l}{l} \quad \tau = \frac{F}{A} \quad \tau = G\gamma \quad U_r = \frac{1}{2}\sigma_Y \varepsilon_Y \quad \%\text{CW} = \left(\frac{A_0 - A_d}{A_0}\right) \times 100 \quad G = E/(2(1+\nu))$$

$$\nu = -\frac{\epsilon_L}{\epsilon} = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

Electrical properties

$$V = IR \quad \rho = \frac{RA}{l} \quad \sigma = \frac{1}{\rho} \quad v_d = \mu_e E \quad \sigma = n|e|\mu_e$$

$$\sigma = n|e|\mu_e + p|e|\mu_h$$

Electrochemistry

$$E = E^o - \frac{RT}{nF}\ln Q \qquad E = E^o - \frac{0.0592}{n}\log Q \quad \text{at } 25^\circ\text{C} \qquad I = \frac{nC}{t}$$

Ideal gas equation of state: $PV = nRT$

First law, closed systems

$\Delta U = q + w$ $dU = dq + dw$

$dw = -P_{ext}dV$

$dU = nC_{v,m}dT$

$H \equiv U + PV$

$dH = nC_{p,m}dT$

For ideal gases, $C_{p,m} = C_{v,m} + R$

Solids, Liquids, $C_{p,m} = C_{v,m}$

$G \equiv H - TS$

$$dS \equiv \frac{dQ_{reversible}}{T}$$

For a process at constant temperature

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

For an isothermal reversible process (ideal gas):

$$W_{rev} = -\int_{V_1}^{V_2} \frac{nRT}{V} dV = -nRT \ln\frac{V_2}{V_1} = -nRT \ln\frac{P_1}{P_2}$$

Adiabatic reversible process (ideal gas):

$$P_1V_1^\gamma = P_2V_2^\gamma$$

$$T_1V_1^{(\gamma-1)} = T_2V_2^{(\gamma-1)} \quad T_1P_1^{[(1-\gamma)/\gamma]} = T_2P_2^{[(1-\gamma)/\gamma]} \quad \left(\frac{\overline{C}_P}{\overline{C}_V}\right) = \gamma$$

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{-R/\overline{C_v}} \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/\overline{C_p}}$$

υ_i: stoichiometric coefficient

Assuming no phase change, constant C_p

$\Delta H^\circ_{rxn} = \Sigma\upsilon_i{*}\Delta H^\circ_{f,i} + \Delta C_p{*}(T - 25^\circ C)$

$\Delta C_p = \Sigma\upsilon_i{*}C_{p,i}$

For solids or liquids:

Phase transition $\Delta S_{trans} = \dfrac{\Delta H_{trans}}{T_{trans}}$

$$\Delta S^\circ(T_2) = \Delta S^\circ(T_1) + \int_{T_1}^{T_2} \Delta C_P \frac{dT}{T}$$

$\Delta S = nR\ln\dfrac{V_f}{V_i}$ (isothermal)

$\Delta S = nC_V\ln\dfrac{T_f}{T_i}$ (change in T at const V)

$\Delta S = nC_p\ln\dfrac{T_f}{T_i}$ (change in T at const P)

Standard entropy of reaction $\Delta S^\circ_{rxn} = \Sigma\upsilon_i{*}S_m{^\circ}_i$

$$\Delta S = n\overline{C_p}\ln\left(\frac{T_2}{T_1}\right) - nR\ln\left(\frac{P_2}{P_1}\right) \qquad \Delta S = n\overline{C_v}\ln\left(\frac{T_2}{T_1}\right) + nR\ln\left(\frac{V_2}{V_1}\right)$$

Standard free energy of a reaction: $\Delta G^\circ_{rxn} = \Sigma\, \upsilon_i{*}\Delta G^\circ_{f,i}$ or $\Delta G^\circ_{rxn} = \Delta H^\circ_{rxn} - T\Delta S^\circ_{rxn}$

$\Delta G^\circ = -RT\ln K$

$$\ln\left(\frac{K_p(T_1)}{K_p(T_2)}\right) = -\frac{\Delta H^o_{reaction}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

(assuming $\Delta H^o_{reaction}$ independent of T)

Name: ____________________ Student No: ____________________

Total free energy of the reaction aA +bB => cC +dD

$\Delta G_{rxn} = \Delta G_{rxn}^{\varnothing} + RT\ln(Q)$

where

$where\ Q = \left[\frac{a_C^c a_D^d}{a_A^a a_B^b}\right]$ where a= activity

$\Delta G_{rxn} = \Delta G_{rxn}^{\varnothing} + RT\ln(Q_P)$,

$$Q_p = \frac{\left(\frac{P_C}{P^o}\right)^c \left(\frac{P_D}{P^o}\right)^d}{\left(\frac{P_A}{P^o}\right)^a \left(\frac{P_B}{P^o}\right)^b}$$

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/

GROUP NUMBERS IUPAC RECOMMENDATION (1985) — 13; GROUP NUMBERS CHEMICAL ABSTRACT SERVICE (1986) — IIIA

ATOMIC NUMBER — 5; RELATIVE ATOMIC MASS (1) — 10.811; SYMBOL — B; ELEMENT NAME — BORON

PERIOD	GROUP 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNILIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM				

Copyright © 1998-2002 EniG. (eni@ktf-split.hr)

LANTHANIDE

PERIOD															
6	57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

PERIOD															
7	89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@nettlinx.com)