Q1	/15
Q2	/15
Q3	/16
Q4	/15
Q5	/15
Q6	/20
Q7	/15
Q8	/10
	/121

UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION

APRIL 2013

First Year

APS 104S
INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B
Examiners: *T. Bender, N. P. Kherani, T. Mirkovic*

Duration: 2 hour 30 minutes

NAME: ____
Last First

STUDENT NO:____

INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all 8 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 **write the answer in** the respective **boxes** where provided. 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*.

QUESTION 1 [15 marks]

Part I. A sample of zinc metal reacts completely with an excess of hydrochloric acid:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

The reaction is run at 273 K and 1.0 atm.

(a) [4 marks] Calculate the work done by the reaction if 19.8 g of zinc is reacted. (Neglect volume changes other than the change in gas volume)

(b) [5 marks] If the above reaction is exothermic, determine if the following are positive, negative, or zero (circle the correct response) :

ΔU:	+ve	-ve	0
ΔH:	+ve	-ve	0
q:	+ve	-ve	0
ΔS:	+ve	-ve	0
ΔG:	+ve	-ve	0

(c) [2 marks] In a second experiment, the reaction in (a) is run at 400 K. Which statement is correct?

i) The system is doing more work at 400 K than at 273 K.
ii) The system is doing less work at 400 K than at 273 K.
iii) The surroundings are doing more work at 400 K than at 273 K.
iv) The surroundings are doing less work at 400 K than at 273 K.

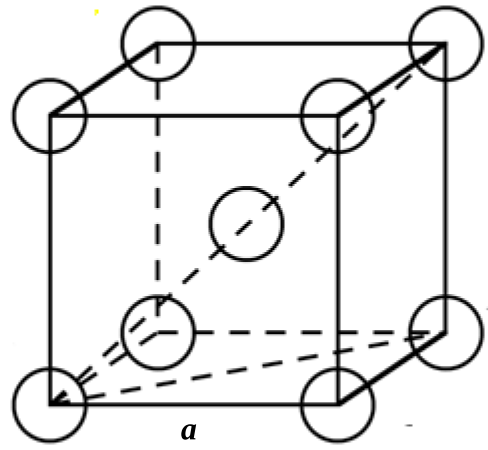
Part II.
[4 marks]
(a) A balloon contains 0.76 mol He, 0.18 mol Ne, 0.031 mol Ar and 0.026 mol Rn at 749 mm Hg. What is the partial pressure of Ne?

(b) Which of the noble gases in the above mixture should show the greatest deviation from the ideal gas law at high pressures. Circle the correct answer.

He Ne Ar Rn all deviate equally

QUESTION 2 [15 marks]

(a) Consider the body centered cubic crystal structure (shown in the small sphere representation on the right) with a unit cell edge length of ***a*** and atomic radius ***R***. Derive the expression for the lattice constant ***a*** in terms of the atomic radius ***R***. [3 marks]



(b) Calculate the atomic packing factor for the BCC crystal structure. [4 marks]

(c) Calculate the linear atomic density in the close-packed direction of the BCC crystal structure. [3 marks]

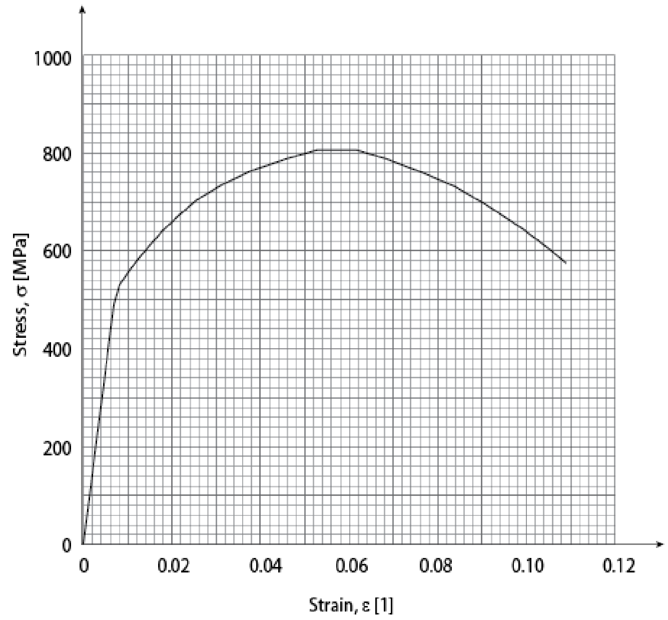
(d) Calculate the atomic radius of iron given that it has a BCC crystal structure, an atomic weight of 55.85 g/mole and mass density of 7.87 g /cm^3 . [5 marks]

Last Name: First Name: Student No.

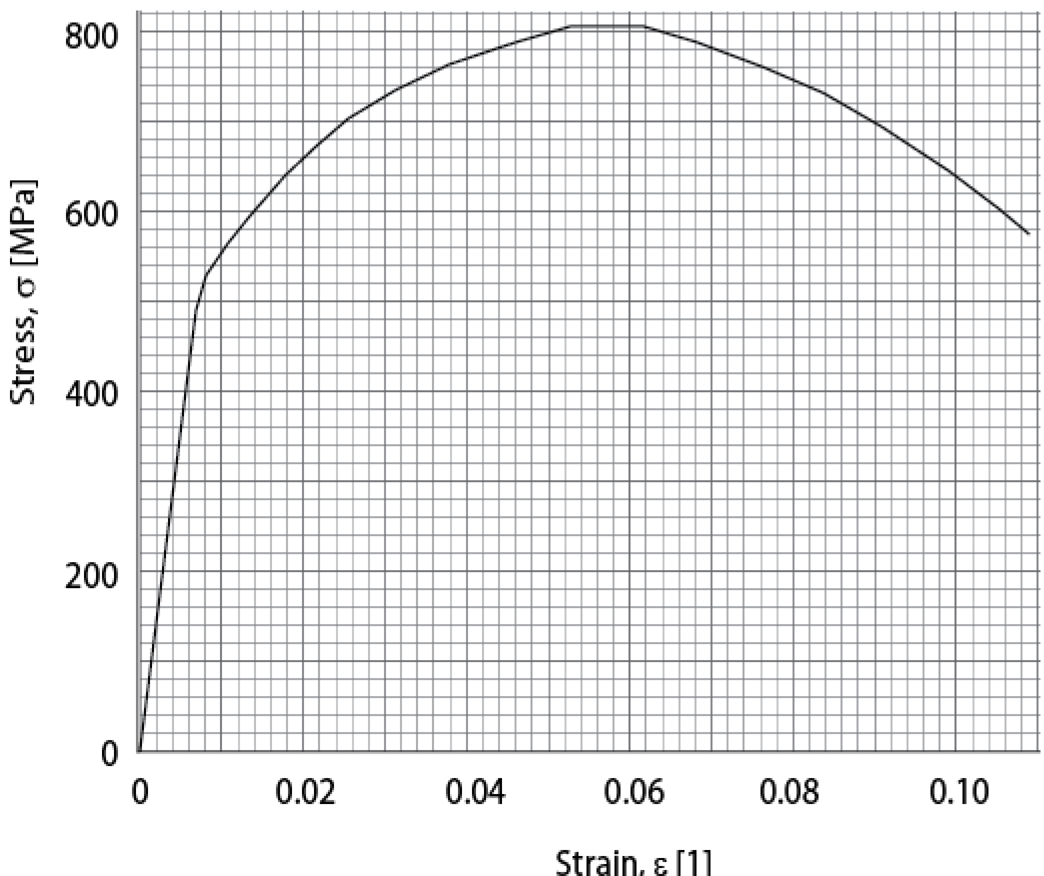
QUESTION 3 [16 marks]

(i.) Consider the engineering stress-strain curve for a particular alloy shown on the right. Clearly mark the following features/points on the graph on the right: [6 marks]

A. Tensile Strength.
B. Fracture Strength.
C. Proportional Point.
D. Shade the region that represents resiliency.
E. Highlight the strain range that represents 'strain hardening'.
F. Mark the point where 'necking' starts.



(ii.) Using the expanded engineering stress-strain curve shown below, calculate:



1) Young's modulus. [2 marks]

2) 0.5% off-set yield strength. [2 marks]

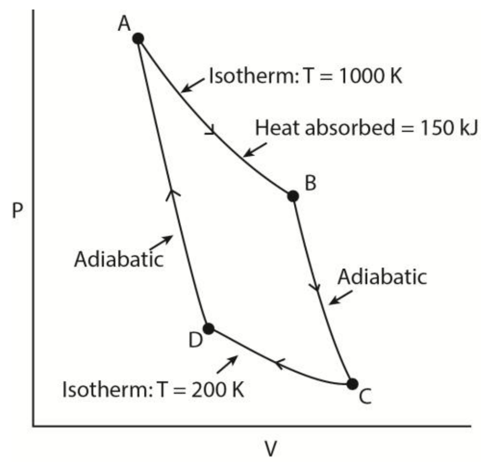
3) Strain at fracture. [2 marks]

4) Given a Poisson coefficient of 0.3, original specimen length of 100 mm, original specimen diameter of 10 mm, and applied tensile stress of 400 MPa, calculate the elongated length and the corresponding diameter of the specimen. [4 marks]

Last Name: First Name: Student No.

QUESTION 4 [15 marks]

The diagram below represents a reversible Carnot cycle for an ideal gas:



(a) [2 marks] What is the thermodynamic efficiency of the engine?

(b) [2 marks] How much heat is rejected at the lower temperature, 200 K, during the isothermal compression?

(c) [2 marks] What is the entropy increase during the isothermal expansion at 1000 K?

(d) [2 marks] What is the entropy decrease during the isothermal compression at 200 K?

(e) [2 marks] What is the overall entropy change for the entire cycle?

(f) [2 marks] What is the change in Gibbs free energy during the process A→ B?

(g) [3 marks] The above diagram shows a Carnot cycle in the form of a pressure-volume diagram. Sketch the corresponding entropy-temperature diagram, labeling the individual steps A→ B (isothermal), B→ C (adiabatic), C→ D (isothermal), and D → A (adiabatic).

QUESTION 5 [15 marks]

If the reaction $NO_2(g) \rightleftharpoons NO(g) + \frac{1}{2} O_2(g)$ comes to equilibrium at a total pressure of 1 bar, analysis of the gas shows that at 700 K, $\frac{P_{NO}}{P_{NO_2}} = 0.872 \ and \ \frac{P_{O_2}}{P_{NO}} = 0.500$, and at 800 K, $\frac{P_{NO}}{P_{NO_2}} = 2.50 \ and \ \frac{P_{O_2}}{P_{NO}} = 0.500$, if only $NO_2(g)$ was initially present in the gas phase.

(a) [6 marks] Calculate K_P at 700 and 800 K.

(b) [3 marks] Calculate $\Delta H^{\circ}_{reaction}$ assuming that it is independent of temperature.

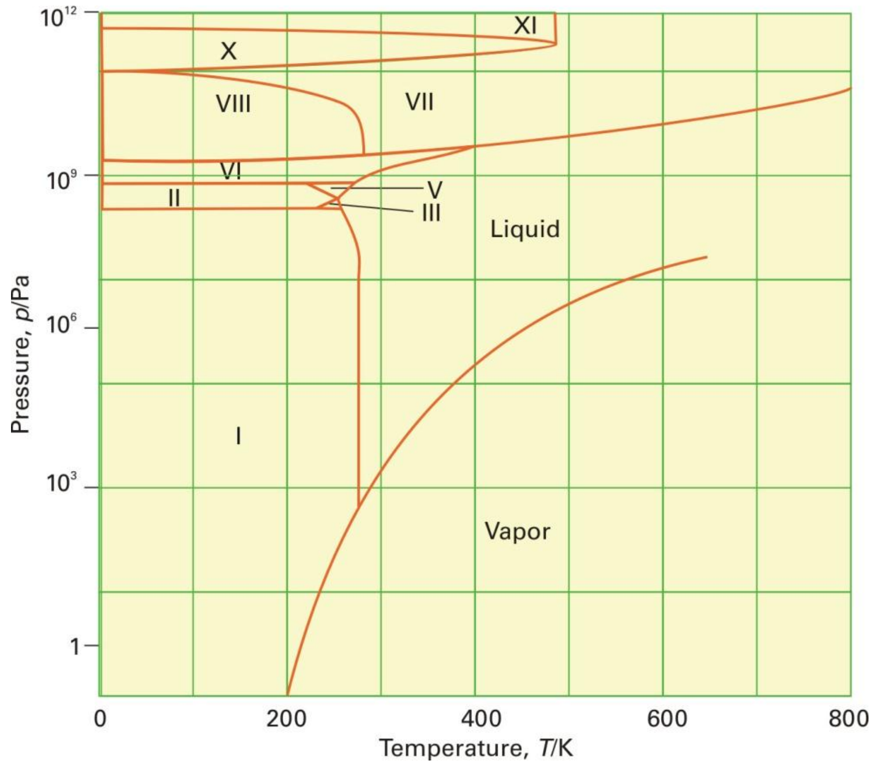
(c) [3 marks] Calculate $\Delta G^{\circ}_{reaction}$ for this reaction at 298.15 K.

(d) [3 marks] How would the equilibrium position change, if the following actions were performed on this reaction system? Circle the correct response.

i) increase in temperature:	*move to right*	*move to left*	*doesn't shift*
ii) decrease the reaction flask volume:	*move to right*	*move to left*	*doesn't shift*
iii) addition of inert gas:	*move to right*	*move to left*	*doesn't shift*

QUESTION 6 [20 marks]

6-1. Consider the following phase diagram of water:



(a) Circle on the phase diagram the triple point and explain below what you would observe if the system was at the triple point. **[2 marks]**

(b) Circle on the phase diagram the critical point. State below the significance of the critical point. **[2 marks]**

(c) Explain below what happens as you move along a constant pressure line at 10^6 Pa starting from 0 K and moving to 600K. **[2 marks]**

6-2. Consider the following phase diagram:

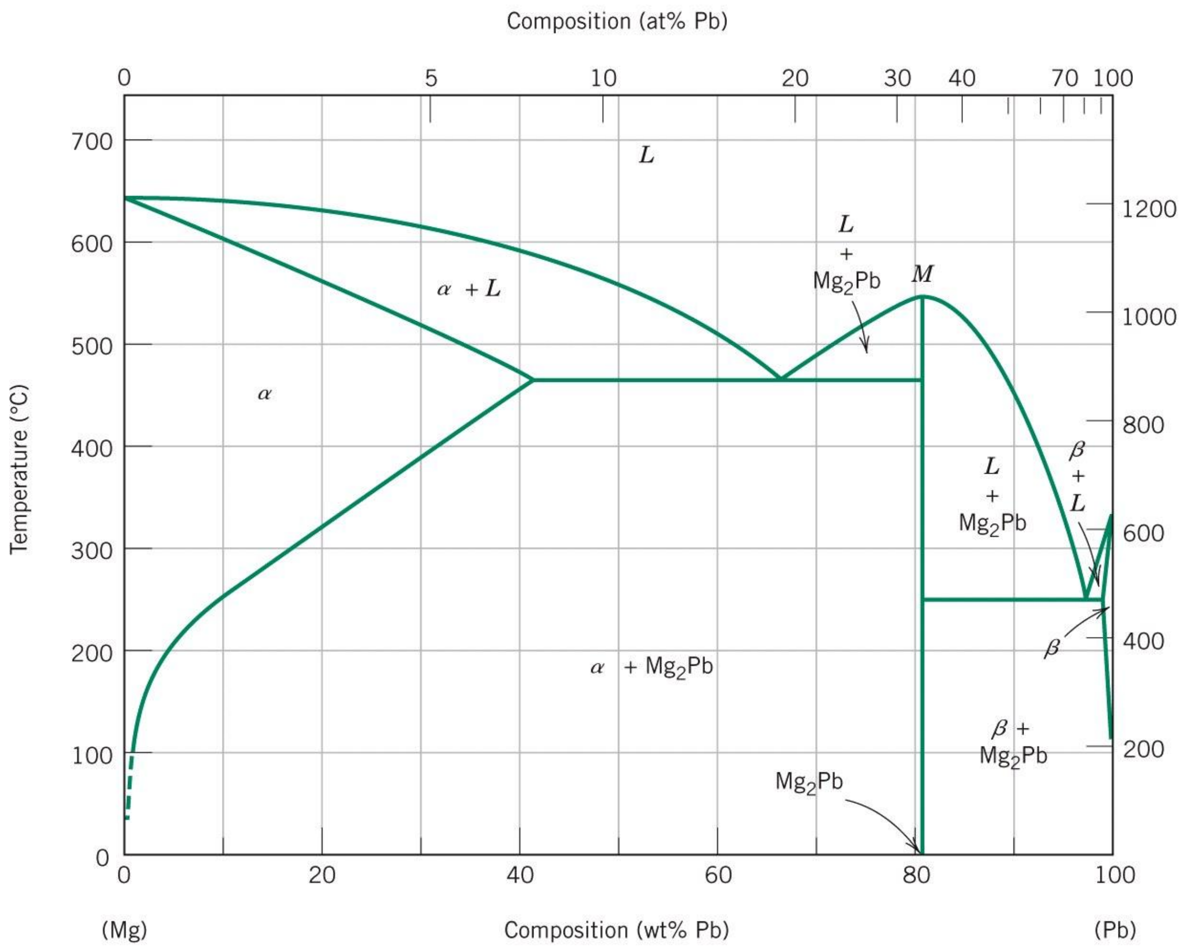


Figure 10.20

(a) For a mixture of 37 kg of Pb and 6.5 kg of Mg state the phase(s) that are present at 800 °C. **[2 marks]**

(b) Does Pb-Mg form a eutectic mixture? If yes: circle a eutectic point on the phase diagram and identify a eutectic isotherm. If no: explain why with reference to the phase diagram. **[2 marks]**

(c) Does Pb-Mg form a stoichiometric compound? If yes: identify it and state its melting point? If no: explain why with reference to the phase diagram. **[2 marks]**

Parts d-g pertain to the following:

A 50wt% Pb-50wt% Mg mixture is **slowly** cooled from 700 °C to 300 °C.

(d) At what temperature does the first solid phase form? **[1 mark]**

Answer:

(e) What is the composition of the first small amount of solid phase formed? **[3 marks]**

Answer:

(f) A what temperature does the liquid completely solidify? **[1 mark]**

Answer:

(g) What is the composition of the last remaining liquid phase just before complete solidification? **[3 marks]**

Answer:

QUESTION 7 [15 marks]

A voltaic electrochemical cell consists of a silver electrode in contact with 346 mL of 0.100 M $AgNO_3$ solution and a magnesium electrode in contact with 288 mL of a 0.100 M $Mg(NO_3)_2$ solution.

Given: $Ag^+ + e^- \rightarrow Ag$ $\quad E° = 0.800$ V

$Mg^{2+} + 2\,e^- \rightarrow Mg$ $\quad E° = -2.372$ V

(a) [2 marks] Write the overall reaction and the shorthand notation for this voltaic cell.

(b) [3 marks] Calculate the value of E for the cell at 25°C.

(c) [6 marks] A current is drawn from the cell until 1.20 g of silver have been deposited at the silver electrode. Calculate the value of E for the cell at this stage of operation.

(d) [1 mark] Determine E_{cell} once the cell has reached equilibrium.

(e) [3 marks] True or False? Circle the correct response.

(i) In the electrolyte of an electrochemical cell, current is carried by anions moving toward the anode and cations moving in the opposite direction. T or F

(ii) Electrons are produced at the cathode of a voltaic cell. T or F

(iii) In a fuel cell, an external source of electrical power is used to drive a non-spontaneous reaction in which a fuel is produced. T or F

QUESTION 8 (10 marks)

(a) Draw the energy band diagrams for an insulator, semiconductor, and metal – making sure to clearly highlight the differences. **[3 marks]**

Insulator Semiconductor Metal

(b) Calculate the number of free electrons per cubic meter of silver, assuming there are 1.5 free electrons per atom of silver. The electrical conductivity, density and atomic weight of silver are 6.8 x 10^7 $(\Omega.m)^{-1}$, 10.49 g cm^{-3} and 107.87 g mol^{-1} respectively. **[3 marks]**

Answer:

(c) Using the results from part (b) compute the electron mobility for silver. **[3 marks]**

Answer:

(d) Compute the resistance of a copper wire 3mm in diameter and 2 m in length given the conductivity of copper is 6.0×10^7 $(\Omega.m)^{-1}$. **[1 mark]**

Answer:

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

R = 8.3145 J·K^{-1} mol^{-1} = 0.0820574587 L·atm· K^{-1} mol^{-1} = 0.083145 L·bar·K^{-1}·mol^{-1}
1 atm = 101.325 kPa = 1.01325 bar= 14.696 psi = 760 Torr = 760 mmHg
N_A = 6.022 x 10^{23} mol^{-1} k = 8.62 x 10^{-5} eV/K 1 eV = 1.60 x 10^{-19} J
T(K) = T(°C) + 273.15 K F = 9.6485309 × 10^{4} C mole^{-1} e = 1.60217733 × 10^{-19} C
STP: 273.15K, 1 bar ***SATP***: 298.15K, 1 bar 1L atm = 101.325 J

$$V = \frac{4\pi\ r^3}{3} \qquad \rho = \frac{nA}{V_C N_A} \qquad \%IC = \{1 - \exp[-0.25(X_A - X_B)^2]\} \times 100 \qquad E = \int F\,dr \qquad \frac{d}{dx}(x^n) = nx^{n-1}$$

$$APF = \frac{TotalSphereVolume}{TotalUnitCellVolume} \qquad LD = \frac{NumberOfAtomsCentredOnDirectionVector}{LengthOfDirectionVector}$$

$$PD = \frac{NumberOfAtomsCentredOnAPlane}{AreaOfPlane} \qquad DP = \frac{\overline{M_n}}{m} \qquad \overline{M_n} = \sum x_i M_i \qquad \overline{M_w} = \sum w_i M_i$$

$$N_V = N\exp(-\frac{Q_v}{kT}) \qquad N_S = N\exp(-\frac{Q_S}{2kT}) \qquad N_{fr} = N\exp(-\frac{Q_{fr}}{2kT})$$

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

$$\sigma_y = \sigma_o + k_y d^{-1/2} \qquad \nu = -\frac{\epsilon_L}{\epsilon} = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z} \qquad \tau_R = \sigma\cos\phi\cos\lambda \qquad \sigma_y = \frac{\tau_{crss}}{(\cos\phi\cos\lambda)_{max}}$$

$$\theta = \cos^{-1}\left(\frac{u_1 u_2 + v_1 v_2 + w_1 w_2}{\sqrt{(u_1^2 + v_1^2 + w_1^2)(u_2^2 + v_2^2 + w_2^2)}}\right) \qquad \sigma = n|e|\mu_e$$

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

Idea gas equation of state: $PV = nRT$
Van der Waals equation of state:

$$P = \frac{nRT}{(V - nb)} - \frac{an^2}{V^2}$$

First law, closed systems
ΔU = q + wdU = dq +dw
dw= −P_{ext}dV
dU = n$C_{v,m}$dT

$H \equiv U + PV$
dH = n$C_{p,m}$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
ΔG= ΔH-TΔS

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):

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$
$$T_1 V_1^{(\gamma-1)} = T_2 V_2^{(\gamma-1)} \qquad T_1 P_1^{[(1-\gamma)/\gamma]} = T_2 P_2^{[(1-\gamma)/\gamma]} \qquad \left(\frac{\bar{C}_P}{\bar{C}_V}\right) = \gamma$$

υ_i: stoichiometric coefficient
Assuming no phase change, constant C_p
$\Delta H^\circ_{rxn} = \Sigma \upsilon_i * \Delta H^\circ_{f,i} + \Delta C_p * (T - 25°C)$
$\Delta C_p = \Sigma \upsilon_i * C_{p,i}$

Efficiency = |w|/q_{in}

ε(ideal) = 1 – T_C/T_H

For solids or liquids:

$$\Delta S = nR\ln\frac{V_f}{V_i} \quad \text{(isothermal)}$$

$$\Delta S = nC_v\ln\frac{T_f}{T_i} \quad \text{(change in T at const V)}$$

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

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

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

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

ΔG° = -RTlnK $\qquad \ln\left(\dfrac{K_p(T_1)}{K_p(T_2)}\right) = -\dfrac{\Delta H^o_{reaction}}{R}\left(\dfrac{1}{T_1} - \dfrac{1}{T_2}\right)$ (assuming $\Delta H^o_{reaction}$ independent of T)

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

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

where $Q = \left[\dfrac{a_C^c a_D^d}{a_A^a a_B^b}\right]$ where a= activity (~ concentration)

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

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

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

Last Name: First Name: Student No.

(You may tear this sheet off.)

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 | 10.811 — RELATIVE ATOMIC MASS (1)
SYMBOL — B
BORON — ELEMENT NAME

PERIOD	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

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

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)