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

25 April 2016

APS 104S

INTRODUCTION TO MATERIALS AND CHEMISTRY

Exam Type B

Examiners: G. Azimi, C. Chin, P. Yaneff, J. Nogami

NAME: ______________________________
Last First

STUDENT NO: ______________________________

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

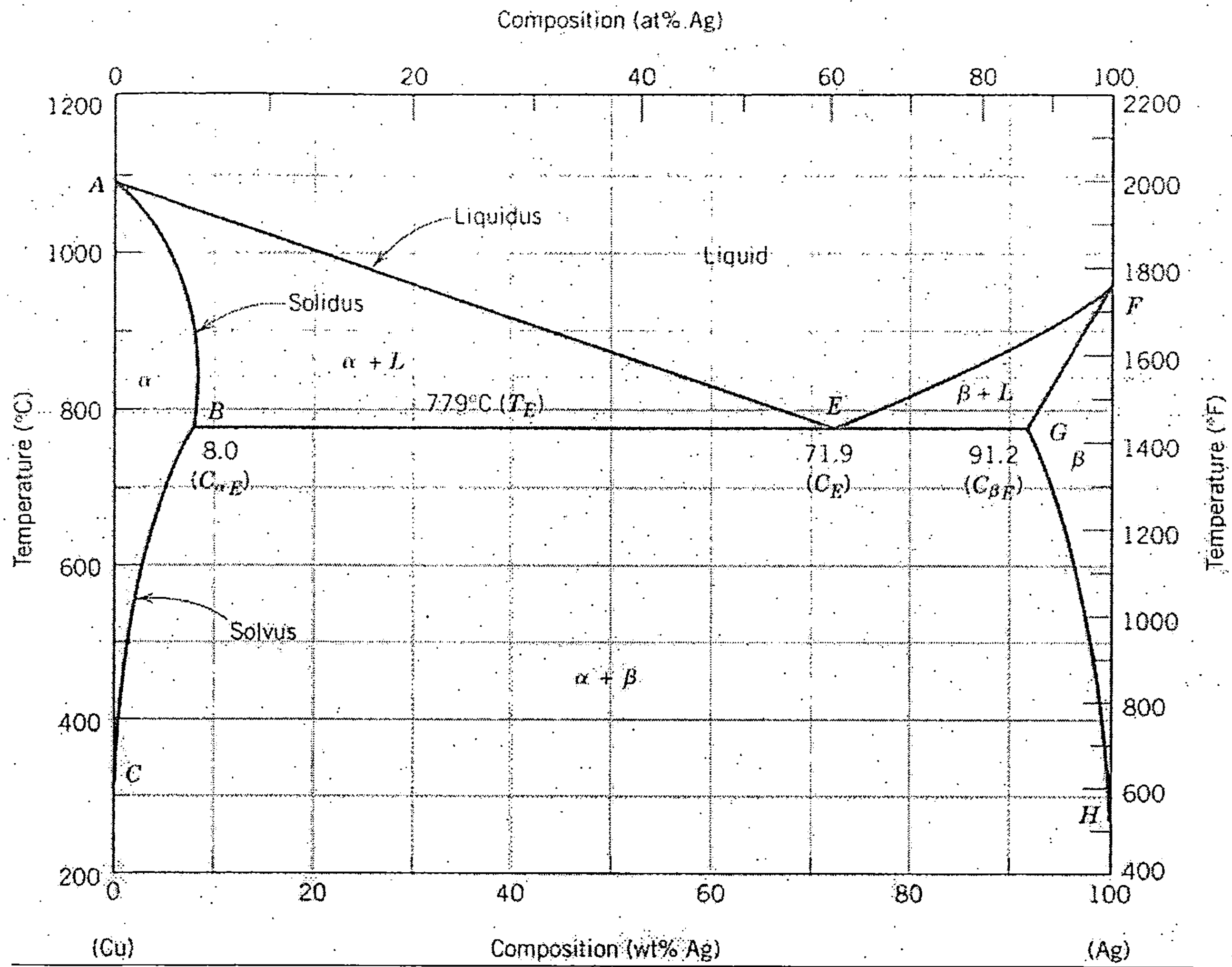
INSTRUCTIONS:

- This is a Type B examination. Only non-programmable calculators are allowed.
- Answer all 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. **All answers should include the relevant units.**
- 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.*
- Put your name and student number on every page, in case your exam paper gets unstapled.

Name: ______________________________ Student No: ________________________

Problem 1. Binary Phase Diagrams

A phase diagram of copper and silver is shown below. For Part 1a-1d, we examine the slow cooling of a **20 wt% Cu-80 wt% Ag mixture** from the liquid phase to 600 °C.



1a. What is the highest temperature at which the mixture is completely solidified. Specify the temperature in °C. [2 pts]

°C

1b. What is the maximum wt% Cu that can exist in the β solid solution. [2 pts]

wt % Cu

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1c. Determine the i) phase(s), ii) their respective weight fractions, and iii) their composition(s) of the phases at a temperature of 800 °C for the 20 wt% Cu-80 wt% Ag mixture.

[2 pts] Phase(s):

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

[2 pts] Weight Fraction(s):

1d.

i) Sketch the microstructure at T = 780°C. Label all of the phases present. [2 pts]

ii) Sketch the microstructure at T = 778°C. Label all of the phases present. [2pts]

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1e) At T = 778°C, calculate the total weight fractions of the two solid solutions. [2 pts]

1f) At T = 778°C, calculate the weight fractions of the solid solution versus the eutectic phase. [2 pts]

1g) At T = 778°C, what percentage of the α solid solution is in the eutectic phase? [2 pts]

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Problem 2: Electrical Properties

Assume an FCC metal has a lattice constant of 0.405 nm and its resistivity is $2.9 \times 10^{-8}\ \Omega\cdot\text{m}$, and the electron mobility is $1.2 \times 10^{-3}\ \text{m}^2/(\text{Vs})$.

2a) How many conduction electrons are contributed per atom? [5 pts]

2b) The mass density of the metal is $2.7\ \text{g/cm}^3$. Identify the element. [5 pts]

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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

2c) Calculate the conductivity of intrinsic Si [2 pts]

2d) If we want to increase the conductivity of Si to 1000 times the above value by doping with As, what would be the required concentration of As? [3 pts]

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Problem 3: Thermodynamics

3a) A mixture of 1 mol of Ar and 1 mol of Kr is enclosed in **an adiabatic piston** and cylinder assembly. The mixture is an ideal gas. The initial temperature is 400 K and pressure is 5 atm. The piston has a diameter of 35 cm. [8 pts]

Process A. The gas expands against vacuum until the temperature reaches 200 K. Determine the

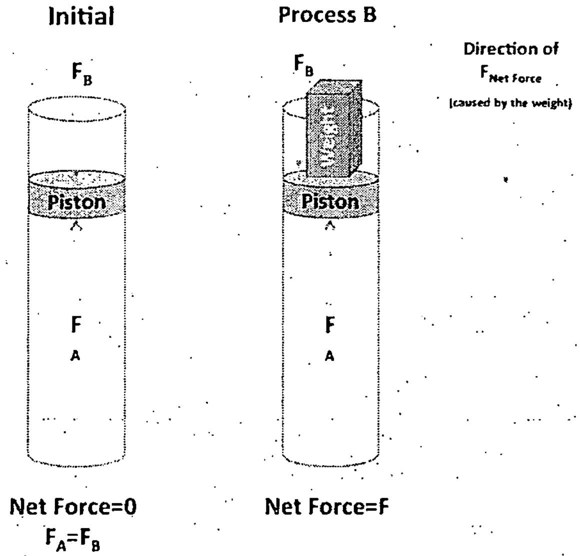
(i) work done,
(ii) entropy change of the system,
(iii) entropy change of the surrounding,
(iv) is the process spontaneous?

w:
ΔS_{sys}:
ΔS_{surr}:
Is the process spontaneous?

Name: ______________________________ Student No: ______________________________

3b) **Process B.** (start from the same initial conditions as described in 3a))

(i) Initially, the piston remains stationary and the net force is zero. In this situation, determine the force, $\mathbf{F_A}$, exerted on the piston by the gas inside the chamber. [2 pts]

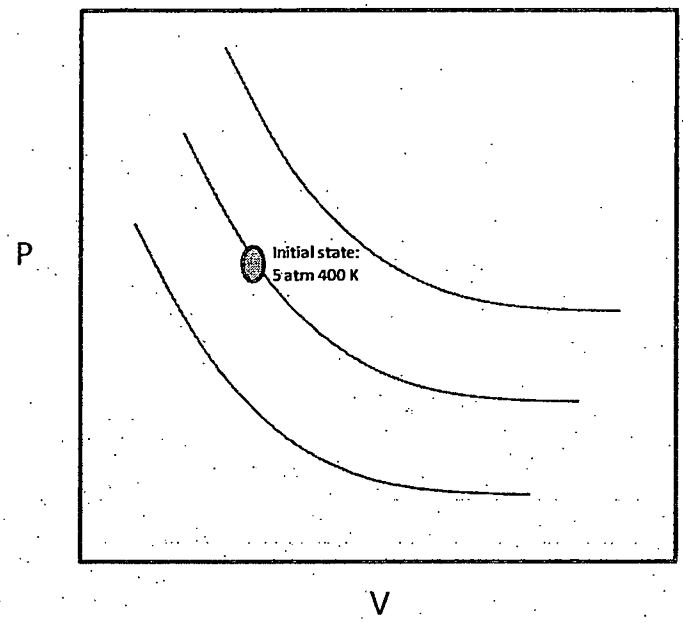


(ii) In this process (Process B), a net force of F is exerted on the piston, causing the piston to move and as a result, the gas is compressed. The net force is caused by the addition of 500 kg of mass placed on top of the piston (Note that F=ma, a=9.8 ms^{-2}). Determine the total external force P_{ext}, and the work done during the compression. [4 pts]

P_{ext}:
w:

Name: ______________________________ Student No: ______________________________

3c) In the PV-diagram below, sketch the two processes (Process A and B) and indicate on the diagram the work done associated with these processes. [3 pts]



Name: ______________________________ Student No: ________________________

3d) The chamber filled with air (79% N_2 and 21 % O_2) is being cooled from 273 K to a temperature at which all the O_2 condenses into the liquid phase and N_2 remains in the gas phase. The pressure is maintained at 1 atm throughout the process. Determine the temperature of O_2 condensation. [3 pts]

	Vaporizatio n	Freezing		
Phase change for O_2				
ΔH (J/mol)	6848	-2×10^3		
ΔS (J/(mol-K))	75	15		
Liquid O_2 heat capacity (kJ/(mol-K))			0.028	
Liquid N_2 heat capacity (kJ/(mol-K))				0.03

T=

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Problem 4: Misc Questions

4a) (2 pts) Real Gases. Comparing the SO_2 and O_2 (Circle the correct answer)

I. Smaller molecules like O_2 tend to interact with each other much more than the larger molecules (SO_2), therefore the actual pressure is expected to be smaller than that predicted from the ideal gas law.

II. The larger Van der Waals constant ***a*** in for SO_2 than O_2 indicates a stronger deviation; this constant is used to correct for the stronger attractive forces between the SO_2 molecules than those between O_2 molecules.

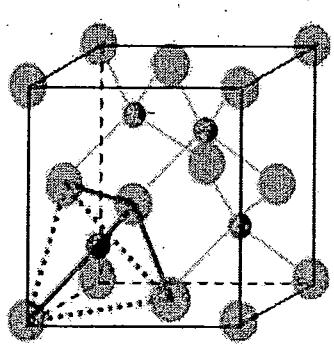
III. The Van der Waals constant ***b*** reflects the correction used to account for the difference in molecular weights and the effects of gravity on the gases.

Table 5.2

Van der Waals constants for several common gases

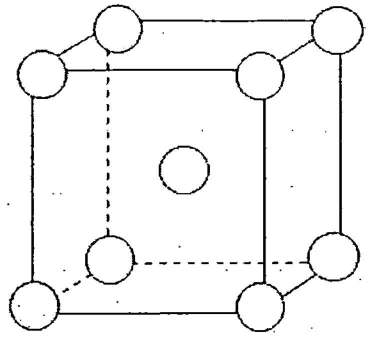
Gas	a (atm L^2 mol^{-2})	b (L mol^{-1})
Ammonia, NH_3	4.170	0.03707
Argon, Ar	1.345	0.03219
Carbon dioxide, CO_2	3.592	0.04267
Helium, He	0.034	0.0237
Hydrogen, H_2	0.2444	0.02661
Hydrogen fluoride, HF	9.433	0.0739
Methane, CH_4	2.253	0.04278
Nitrogen, N_2	1.390	0.03913
Oxygen, O_2	1.360	0.03183
Sulfur dioxide, SO_2	6.714	0.05636
Water, H_2O	5.464	0.03049

4b) (2 pts) The crystal structure is: ______________________________

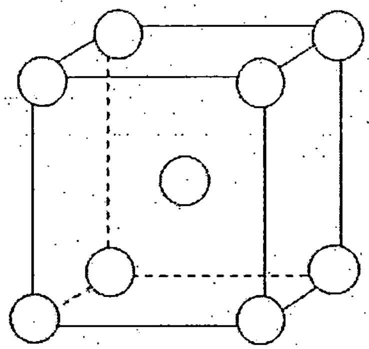


Name: ______________________ Student No: ______________________

4c) (2 pts) Indicate on the diagram the most likely slip plane for BCC.



4d) (2 pts) Indicate on the diagram below a slip direction lying in the slip plane drawn in 4c.



4e) (2 pts). Determine the heat of reaction for $2H_2+O_2 \rightarrow 2H_2O$

TABLE 7.1 Average Bond Dissociation Energies, *D* (kJ/mol)

H–H	436[a]	C–H	410	N–H	390	O–H	460	F–F	159[a]
H–C	410	C–C	350	N–C	300	O–C	350	Cl–Cl	243[a]
H–F	570[a]	C–F	450	N–F	270	O–F	180	Br–Br	193[a]
H–Cl	432[a]	C–Cl	330	N–Cl	200	O–Cl	200	I–I	151[a]
H–Br	366[a]	C–Br	270	N–Br	240	O–Br	210	S–F	310
H–I	298[a]	C–I	240	N–I	—	O–I	220	S–Cl	250
H–N	390	C–N	300	N–N	240	O–N	200	S–Br	210
H–O	460	C–O	350	N–O	200	O–O	180	S–S	225
H–S	340	C–S	260	N–S	—	O–S	—		
Multiple covalent bonds[b]									
C=C	611	C≡C	835	C=O	732	O=O	498[a]	N≡N	945[a]

[a] Exact value

[b] We'll discuss multiple covalent bonds in Section 7.5.

Table 7-1 Chemistry, 5/e

Name: ______________________________ Student No: ______________________________

True / False (2 pts each)

T	F	
☐	☐	For the same chemical species, the heat capacity of gas is always higher than liquid, because gas molecules occupy a larger volume and the energy required to heat the gas are much higher than liquid.
☐	☐	Heat of combustion has a positive value.
☐	☐	Molar entropy of fusion is always positive.
☐	☐	In order to reach the same final pressure, the work done in adiabatic compression is always larger than isothermal compression
☐	☐	The atomic packing factor (APF) for Pt (a fcc crystal) is higher than Fe (a bcc crystal).

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Problem 5: Electrochemistry

A voltaic electrochemical cell consists of a lead electrode in contact with 1 L of 0.2 M $Pb(NO_3)_2$ and a tin electrode in contact with 1 L of a 0.1 M $Sn(NO_3)_2$ solution at 25°C. Given the following data:

$Pb^{2+} + 2e^- \rightarrow Pb(s)$ ($E° = -0.13$ V)
$Sn^{2+} + 2e^- \rightarrow Sn(s)$ ($E° = -0.14$ V)

5a) Write down the cell reaction and Calculate E° and E for the cell at 25°C. [3 pts]

5b) Write the cell notation (cell diagram) for the voltaic cell that incorporates the above reaction. [2 pts]

5c) A current is drawn from the cell until 2 g of lead has been deposited at the lead electrode. Calculate the value of cell potential E for the cell at this stage. (Pb=207 g/mol) [4 pts]

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5d) Determine E for the cell once the cell has reached equilibrium, and determine the equilibrium concentration of ions. [4 pts]

5e) When E of the cell reaches 0.005, what is the concentration of lead ion? [2 pts]

5f) Is it possible to run the cell from initial condition at a current of 2 A for 2.5 h? (Note: Calculate the final composition and final cell potential) [5 pts]

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Problem 6: Chemical Equilibrium

When 1.33 mol of CO_2 and 1.33 mol of H_2 are mixed in a 0.750 L container and heated to 395°C, they react according to the following reaction:

$$CO_{2(g)} + H_{2(g)} \leftrightarrow CO_{(g)} + H_2O_{(g)}$$

6a) If $K = 0.802$, what are the equilibrium concentrations of each component of the equilibrium mixture? [5 pts]

6b) What happens to the value of K if H_2O is removed during the course of the reaction? (circle the correct answer) [2 pts]

Increases Decreases No change

Name: ______________________________ Student No: ______________________________

6c) If K at 298.15 K is 8.05×10^{-5}, calculate $\Delta H°$ for the reaction (assuming that it is independent of temperature). [Note: use K from part a]. [4 marks]

6d) Calculate $\Delta G°$ for the reaction at 395 °C. [2 marks]

6e) Calculate $\Delta S°$ for the reaction if it is also independent of temperature. [2 marks]

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6f) Calculate K for the following reactions at 395°C: [2 marks]

$1/2CO_{2(g)} + 1/2H_{2(g)} \leftrightarrow 1/2\ CO_{(g)} + 1/2H_2O_{(g)}$

$CO_{(g)} + H_2O_{(g)} \leftrightarrow CO_{2(g)} + H_{2(g)}$

6g) Predict in which direction the reaction will shift as a function of the following stresses [4 marks]:

1) Pressure of the system is doubled	Right	Left	No change
2) Temperature is increased to 500°C	Right	Left	No change
3) Part of CO is removed from the system	Right	Left	No change
4) Some catalyst is added to the system	Right	Left	No change

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Problem 7: Mechanical Properties

(a) Put the correct number of the term matching the correct definition below [7 pts].

1. Elastic deformation
2. Anelastic behaviour
3. Yield point
4. Ductility
5. Tensile strength
6. Strain hardening
7. Hall Petch equation

[ ] A solid's ability to deform under tensile stress.
[ ] A measurement of the maximum force with which one can pull something such as a wire or a structural beam without it breaking.
[ ] Any deformation in which the stress and strain are proportional.
[ ] The influence of cold work on stress strain behaviour.
[ ] The stress at which a material begins to deform plastically.
[ ] The effect of grain size on mechanical strength.
[ ] The property of a solid in which deformation depends on the time rate of change of stress as well as on the stress itself.

(b) Given the data below, which of the following alloys would you predict to have the higher modulus of resilience? Circle the correct answer and justify your answer with calculations by filling in the chart below [7 pts].

Aluminum Alloy Titanium Alloy

Alloy	Elastic Modulus, GPa	Poisson's Ratio	Yield Strength, MPa	Modulus of Resilience, J/m^3
Aluminum	69	0.33	250	
Titanium	107	0.34	800	

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(c) A cylindrical metal specimen having an original diameter of 6.4 mm and gauge length of 25.40 mm is pulled in tension until fracture occurs. The diameter at the point of fracture is 3.30 mm, and the fractured gauge length is 36.07 mm. Calculate the ductility in terms of percent reduction in area and percent elongation [6 pts].

Ductility (percent reduction in area)
Ductility (percent elongation)

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

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

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

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

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

STP: 273.15K, 1 atm ***SATP***: 298.15K, 1 bar 1L atm = 101.325 J 1 Pa = 1 J/$\mathrm{m^3}$

Mechanical properties

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

$\nu = -\frac{\epsilon_L}{\epsilon} = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$ $\sigma = FL/\Pi R^3$

Electrical properties

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

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

Electrochemistry

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

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):

$P_1V_1^\gamma = P_2V_2^\gamma$

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

$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{-R/\bar{C}_v}$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/\bar{C}_p}$

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 $\Delta S_{trans} = \frac{\Delta H_{trans}}{T_{trans}}$

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

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

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

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

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)

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

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

where

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

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

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

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	9 VIIIB	10	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				

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)