HANDOUT SET

GENERAL CHEMISTRY I

Periodic Table of the Elements

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 **H** 1.00794																	2 **He** 4.00262
2	3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.179
3	11 **Na** 22.9898	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
6	55 **Cs** 132.9054	56 **Ba** 137.34	57 **La*** 138.91	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.0254	89 **Ac**** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (264)	108 **Hs** (265)	109 **Mt** (266)	110 (270)	111 (272)	112 ******* (277)						

*Lanthanides	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
**Actinides	90 **Th** 232.038	91 **Pa** 231.0659	92 **U** 238.0289	93 **Np** 237.0482	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Mass numbers in parenthesis are the mass numbers of the most stable isotopes. As of 1997 elements 110-112 have not been named.
***Peter Armbruster and Sigurd Hofman synthesized a single atom at the Heavy-Ion Research Center in Darmstadt, Germany in 1996. The atom survived for 280 μs after which it decayed to element 110 by loss of an α-particle

Chapter 7

Thermochemistry

THERMOCHEMISTRY

CHAPTER 7

INTRODUCTION

Thermochemistry is a facet of chemistry which combines reaction writing, completion, and balancing with the heat or energy absorbed or released in the chemical reaction. In essence, you might say that the energy in a reaction is a product or reactant normally hidden from the person writing the reaction. This chapter introduces a way to determine both theoretically (Hess's Law) and experimentally (calorimetry) the energy change (enthalpy) in a chemical reaction.

GOALS

1. You must have a working knowledge of all of the terms involved in thermochemistry.
2. You should be able to calculate the amount of heat transferred in a chemical reaction when experimentally measured in a calorimeter.
3. Hess's Law allows for the calculation of ΔH of a reaction without performing an experiment. You should be able to do Hess's law calculations.

DEFINITIONS

You should have a working knowledge of at least these terms and any others used in lecture.

Energy
Heat
Enthalpy
Endothermic
Exothermic
Calorimetry
Calorimeter
Specific heat

Heat capacity
Open system
Closed system
Isolated system
Heat of reaction
Enthalpy of reaction
System
Surroundings

Standard state
Work
Joule
First law of thermodynamics

Thermochemistry I: Energy Transfer and Calorimetry

1. What amount of work (in J) is performed on the surroundings when a 1.0 L balloon at 745 mm Hg at 25°C is heated to 45°C? (1 L·atm = 101.325 J)

2. What quantity of heat (in J) is necessary to raise 3.00 L of water (*d*=1.00 g/mL) from 22.0°C to 63.0°C?

3. A 200.0 mL quantity of 0.40 M HCl was added to 200.0 mL of 0.40 M NaOH in a solution (constant pressure) calorimeter. The temperature of each solution was 25.10°C before mixing. After mixing the solution rose to a temperature of 26.60°C before beginning to cool. The heat capacity of the calorimeter was determined by separate experiment to be 55 J/°C. What is ΔH_{rxn} per mol of H_2O formed? Assume the solutions have a density of 1.00 g/mL and their specific heats are similar to water; c = 4.18 J/g·°C.

4. A 1.00 g sample of table sugar (sucrose, $C_{12}H_{22}O_{11}$) was burned in a bomb calorimeter (constant volume calorimeter) containing 1.50 kg of water. The temperature of the water in the calorimeter rose from 25.00°C to 27.32°C. What is the $\Delta H_{combustion}$ of sucrose in kJ/g and kJ/mol? The heat capacity of the calorimeter was determined by separate experiment to be 837 J/°C.

5. Camphor ($C_{10}H_{16}O$) has a $\Delta H_{combustion}$ of-5903.6 kJ/mol. A 0.7610 g sample of camphor was burned in a bomb calorimeter containing 2.00×10^3 g of water. The temperature of the water increased from 22.78°C to 25.06°C. What is the heat capacity of the calorimeter?

Determination of the Specific Heat of Copper Metal

Data

Copper		Water in Calorimeter		Calorimeter	
M_{Cu} =	____________	V_{H_2O} =	____________	C_{cal} =	____________
T_i =	____________	m_{H_2O} =	____________	T_i =	____________
T_f =	____________	c_{H_2O} =	____________	T_f =	____________
ΔT_{Cu} =	____________	T_i =	____________	ΔT_{cal} =	____________
		T_f =	____________		
		ΔT_{H_2O} =	____________		

$$q_{Cu} + q_{H_2O} + q_{cal} = 0$$

Thermochemistry II: Calorimetry, Enthalpy, and Hess' Law

1. When 100.0 mL of 1.00 M HCl is mixed with 100.0 mL of 1.00 M NaOH, both initially at 21.1°C, are mixed in a two-cup calorimeter the temperature of the mixture rises to 27.9°C. Determine the ΔH of neutralization for the reaction

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

   By a prior experiment, the heat capacity of the calorimeter was determined to be 125 J/°C. Assume the density of the final solution is 1.0 g/mL and the specific heat of the mixture is 4.18 J/g°C.

2. Consider the reaction

$$C_{12}H_{22}O_{11(s)} + 12\ O_{2(g)} \rightarrow 12\ CO_{2(g)} + 11\ H_2O_{(g)}$$

   which has a ΔH of -5.65 x 10^3 kJ/mol ($C_{12}H_{22}O_{11}$). How much heat (energy) can be produced during the complete combustion of 100.0 g of sucrose?

3. If all of the energy in question 2 were used to heat 1.0 L of water at 22.0°C, what would the final temperature of the water be? (Assume 100% energy transfer to the water.)

4. Using standard enthalpies of reaction, calculate the $\Delta H°$ for the following reactions:

$$\mathbf{C_2H_{2(g)} + 2\ H_{2(g)} \rightarrow C_2H_{6(g)}}$$

$$\mathbf{2\ CH_{4(g)} + \tfrac{1}{2}\ O_{2(g)} \rightarrow C_2H_{6(g)} + H_2O_{(l)}}$$

TABLE OF SOME STANDARD ENTHALPIES OF FORMATION AND REACTION

$C_{(s)} + 2\,H_{2(g)} \rightarrow CH_{4(g)}$	ΔH°_{f} = -74.9 kJ/mol
$2\,C_{(s)} + 3\,H_{2(g)} \rightarrow C_2H_{6(g)}$	ΔH°_{f} = -84.7 kJ/mol
$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$	ΔH°_{f} = -393.5 kJ/mol
$CH_{4(g)} + 2\,O_2 \rightarrow CO_{2(g)} + 2\,H_2O_{(l)}$	$\Delta H^{\circ}_{combustion}$ = -890.4 kJ/mol(CH_4)
$C_2H_{2(g)} + \frac{5}{2}\,O_{2(g)} \rightarrow 2\,CO_{2(g)} + H_2O_{(l)}$	$\Delta H^{\circ}_{combustion}$ = -1299.4 kJ/mol(C_2H_2)
$H_{2(g)} + \frac{1}{2}\,O_{2(g)} \rightarrow H_2O_{(g)}$	ΔH°_{f} = -241.8 kJ/mol
$H_{2(g)} + \frac{1}{2}\,O_{2(g)} \rightarrow H_2O_{(l)}$	ΔH°_{f} = -285.8 kJ/mol
$Na_{(s)} \rightarrow Na_{(g)}$	$\Delta H^{\circ}_{sublimation}$ = 108 kJ/mol
$Na_{(g)} \rightarrow Na^{+}_{(g)} + e^{-}$	$\Delta H^{\circ}_{ionization}$ = 459.9 kJ/mol
$2\,Na_{(s)} + \frac{1}{2}\,O_{2(g)} \rightarrow Na_2O_{(s)}$	ΔH°_{f} = -99.8 kJ/mol
$Na_{(s)} + \frac{1}{2}\,O_{2(g)} + \frac{1}{2}\,H_{2(g)} \rightarrow NaOH_{(s)}$	ΔH°_{f} = -98.9 kJ/mol