

HANDOUT SET

GENERAL CHEMISTRY I

Periodic Table of the Elements

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|-----------------------------|-----------------------------|-------------------------------|---------------------------|-----------------------------|----------------------------|----------------------------|---------------------------|-----------------------------|---------------------------|-----------------------------|----------------------------|-----------------------------|----------------------------|-----------------------------|---------------------------|----------------------------|---------------------------|
| | IA | | | | | | | | | | | | 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) | | | | | | |

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|--------------|---------------------------|-----------------------------|---------------------------|--------------------------|---------------------------|---------------------------|---------------------------|----------------------------|---------------------------|----------------------------|---------------------------|-----------------------------|---------------------------|----------------------------|
| *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 μ s 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 H₂O 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 $25.00^{\circ}C$ to $27.32^{\circ}C$. What is the $\Delta H_{\text{combustion}}$ of sucrose in kJ/g and kJ/mol? The heat capacity of the calorimeter was determined by separate experiment to be $837 J/^{\circ}C$.
5. Camphor ($C_{10}H_{16}O$) has a $\Delta H_{\text{combustion}}$ of -5903.6 kJ/mol . A 0.7610 g sample of camphor was burned in a bomb calorimeter containing $2.00 \times 10^3 \text{ g}$ of water. The temperature of the water increased from $22.78^{\circ}C$ to $25.06^{\circ}C$. What is the heat capacity of the calorimeter?

Determination of the Specific Heat of Copper Metal

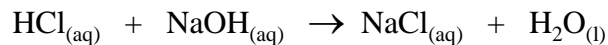
Data

| Copper | Water in Calorimeter | Calorimeter |
|--------------------------------|---|---------------------------------|
| $M_{\text{Cu}} =$ _____ | $V_{\text{H}_2\text{O}} =$ _____ | $C_{\text{cal}} =$ _____ |
| $T_i =$ _____ | $m_{\text{H}_2\text{O}} =$ _____ | $T_i =$ _____ |
| $T_f =$ _____ | $c_{\text{H}_2\text{O}} =$ _____ | $T_f =$ _____ |
| $\Delta T_{\text{Cu}} =$ _____ | $T_i =$ _____ | $\Delta T_{\text{cal}} =$ _____ |
| | $T_f =$ _____ | |
| | $\Delta T_{\text{H}_2\text{O}} =$ _____ | |

$$q_{\text{Cu}} + q_{\text{H}_2\text{O}} + q_{\text{cal}} = 0$$

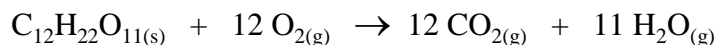
Thermochemistry II: Calorimetry, Enthalpy, and Hess' Law

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



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



which has a ΔH of -5.65×10^3 kJ/mol ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$). 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 ΔH° for the following reactions:

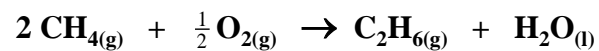
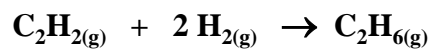


TABLE OF SOME STANDARD ENTHALPIES OF FORMATION AND REACTION

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

