UNIT 6: THERMOCHEMISTRY AND NUCLEAR CHEMISTRY

Chapter 11: Thermochemistry – Heat and Chemical Change

<u>11.1: The Flow of Energy–Heat</u>

- <u>Thermochemistry</u>: the branch of chemistry that studies the amount of heat change in a chemical change or a physical process.
- **Energy** (*E*): the ability to do **work** or produce **heat**.
- Heat (q): the transfer of energy between two objects (internal versus surroundings) due to the difference in temperature.
- <u>Work</u> (*w*): when force is applied over a displacement in the same direction ($w = F \times \Delta d$). - when a constant pressure is applied over a change in volume ($w = -P \Delta V$).
- <u>Chemical Potential Energy</u>: the energy that is "stored" within molecules.
- **<u>System</u>**: a part of the entire universe as defined by the problem.
- **<u>Surrounding</u>**: the part of the universe outside the defined system.
- <u>Universe</u>: consists of both the system and the surrounding.
- **First Law of Thermodynamics**: states that energy cannot be created or destroyed. It can only be converted from one form to another. Therefore, energy in the universe is a constant.
 - also known as the <u>Law of Conservation of Energy</u> ($\Sigma E_{initial} = \Sigma E_{final}$).

Exothermic Process ($\Delta E < 0$): - when <u>energy flows "out" of the system</u> into the surrounding. (Surrounding gets Warmer.)

Potential Energy Diagram for Exothermic Process



Endothermic Process ($\Delta E > 0$): - when <u>energy flows into the system</u> from the surrounding. (Surrounding gets Colder.)



- <u>Physical Change</u>: when the temperature of a substance is raised or lower, no new substance is formed. The only heat change is the <u>physical kinetic energy</u> of the substance as its molecules are moving or vibrating faster or slower.
 - when a substance is changing phase, no new substance is formed. The only heat change is the **<u>physical potential energy</u>** of the substance as its intermolecular bonds are being loosen or completely broken.

Heat Units: - the measuring units to measure heat or energy.

- **a.** <u>Joules</u>: the metric unit to measure heat or energy named after English physicist James Precott Joule.
- **b.** <u>Calories</u>: the old imperial unit to measure heat or energy. (1 cal = 4.19 J)

Specific Heat Capacity: - the amount of heat needed to raise one gram of substance by one degree Celsius. - the higher the specific heat capacity, the more the substance can "hold" the heat. - units are in $J/(g \bullet °C)$ or $kJ/(kg \bullet °C)$

Physical Kinetic Change		
$q = mC\Delta T$		
q = Change in Heat (J or kJ) m = mass (g or kg) C = Specific Heat Capacity [J/(g • °C) or kJ/(kg • °C)] ΔT = Change in Temperature (in °C)		

Substance	Specific Heat Capacity J/(g • °C) or kJ/(kg • °C)	Substance	Specific Heat Capacity J/(g • °C) or kJ/(kg • °C)
Ice $H_2O_{(s)}$	2.00	Aluminum Al _(s)	0.897
Water $H_2O_{(l)}$	4.19	Carbon (graphite) C _(s)	0.709
Steam $H_2O_{(g)}$	2.02	Copper Cu _(s)	0.385
Ammonia NH _{3 (g)}	2.06	Iron Fe (s)	0.449
Methanol CH ₃ OH _(l)	2.53	Silver $Ag_{(s)}$	0.235
Ethanol C ₂ H ₅ OH _(l)	2.44	Gold Au (s)	0.129

Specific Heat Capacity of Some Common Substances (at 1.00 atm and 298.15 K)

Example 1: How much energy is needed to heat 100.0 g of water from 20.0°C to 80.0°C?

Since this question involves temperature (kinetic) change only, we need to use $q = mC\Delta T$.

 $C = 4.19 \text{ J/(g } \circ ^{\circ}\text{C})$ $m = 100.0 \text{ g H}_2\text{O}$ $\Delta T = 80.0^{\circ}\text{C} - 20.0^{\circ}\text{C} = 60.0^{\circ}\text{C}$ q = ?

 $q = mC\Delta T$ $q = (100.0 \text{ g})(4.19 \text{ J/(g} \bullet \text{°C}))(60.0 \text{°C}) = 25140 \text{ J}$ $q = 2.51 \times 10^4 \text{ J} = 25.1 \text{ kJ}$

Example 2: A 20.0 g of an unknown element gave off 423 J of energy as it is cooled from 100°C to 10.0°C. Identify this unknown element by determining its specific heat capacity.

$$q = 423 \text{ J}$$

$$m = 20.0 \text{ g}$$

$$\Delta T = 100.0^{\circ}\text{C} - 10.0^{\circ}\text{C} = 90.0^{\circ}\text{C}$$

$$C = ?$$

$$q = mC\Delta T$$

$$\frac{q}{m\Delta T} = C$$

$$C = \frac{(423 \text{ J})}{(20.0 \text{ g})(90.0^{\circ}\text{ C})}$$

$$C = 0.235 \text{ J/(g • °C)}$$
From the reference table above, the unknown substance is silver.

Example 3: Calculate the final temperature of a 10.0 g piece of copper wire at 15.0°C when 3.27 kJ of heat is added.

$$q = 3.27 \text{ kJ} \qquad q = mC\Delta T \qquad \frac{q}{mC} = \Delta T C = 0.385 \text{ kJ/(kg • °C)} T_i = 15.0°C \qquad \Delta T = T_f - 15.0°C = ? \qquad \Delta T = T_f - 15.0°C \Delta T = T_f - 15.0°C = T_f - 15.0°C T_f = 849°C + 15.0°C \qquad T_f = 864°C$$

<u>Assignment</u> 11.1 pg. 299 #1 to 10

Page 126.

<u>11.3: Heat in Changes of State</u>

Enthalpy (*H*): - the amount of internal energy at a specific pressure and volume.

Energy involved in Physical Change (Temperature or Phase Change):

<u>Heating Curve</u>: - a graph of temeparture versus time as a substance is heated from a solid phase to a gaseous phase.

- when a substance is undergoing a <u>phase change</u>, its temperature remains at a constant (the plateau on the heating curve) until all molecules aquired enough energy to overcome the intermoelcular forces nexessary. This is commonly refered to as the <u>potential change</u> of a subsatnce.
- when a substance is undergoing <u>temperature change</u> within a particular phase, it is refered to as <u>kinetic change</u> (because temperature is also refered to as the average kinetic energy of a substance).



<u>Molar Heat of Fusion</u> (ΔH_{fus}): - the amount of heat needed to melt one mole of substance from solid to liquid at its melting point (in kJ/mol).

<u>Molar Heat of Vaporization</u> (ΔH_{vap}): - the amount of heat needed to evaporate one mole of substance from liquid to gas at its boiling point (in kJ/mol).

<u>Molar Heat of Solution</u> (ΔH_{soln}): - the amount of heat needed to dissolve one mole of solid substance into water under standard condition of 25°C and at 1 atm (in kJ/mol).

Physical Potential Change			
$\Delta H = n \Delta H_{\rm fus}$	$\Delta H = n \Delta H_{\rm vap}$	$\Delta H = n \Delta H_{\rm soln}$	
$\Delta H = \text{Change in Enthalpy}$ $\Delta H_{\text{fus}} = \text{Molar Heat of Fusion (} \\ \Delta H_{\text{soln}} = \text{Molar Heat of Solution}$	n = moles $\Delta H_{vap} = \text{Mole}$ (kJ/mol)	ar Heat of Vaporization (kJ/mol)	

Substance	Melting Point (°C)	Boiling Point (°C)	$\Delta H_{\rm fus}$ (kJ/mol)	ΔH _{vap} (kJ/mol)
Ice $H_2O_{(s)}$	0		6.01	
Water $H_2O_{(l)}$		100		40.65
Steam $H_2O_{(g)}$				
Ammonia NH _{3 (g)}	-77.73	-33.34	5.66	23.33
Methanol CH ₃ OH _(l)	-98	64.6	3.22	35.21
Ethanol C ₂ H ₅ OH _(l)	-114.1	78.3	4.93	38.56
Aluminum Al _(s)	660	2519	10.79	294
Carbon (graphite) C _(s)	3338	4489	117	
Copper Cu _(s)	1085	2562	12.93	300.4
Iron Fe (s)	1538	2861	13.81	340
Mercury Hg _(l)	-39	357	2.29	59.1

Physical Thermodynamic Properties of Some Common Substances (at 1.00 atm and 298.15 K)

Example 1: What is the change in enthalpy involved when 36.04 g of water boils from liquid to gas at 100°C?

Since this question involves phase change (vaporization) only, we need to use $\Delta H = n \Delta H_{vap}$.

 $\Delta H_{\text{vap}} = 40.65 \text{ kJ/mol}$ $n = \frac{36.04 \text{ g}}{18.02 \text{ g/mol}} = 2.000 \text{ mol } \text{H}_2\text{O}$ $\Delta H = ?$

 $\Delta H = n \Delta H_{\text{vap}}$ $\Delta H = (2.000 \text{ mol})(40.65 \text{ kJ/mol})$

Example 2: What is the total energy needed to heat 18.02 g of water at 80.0°C to steam at 115°C?

For this question, we have two kinetic changes (water and steam) and one phase change (vaporization).

 $\Delta H = 81.3 \text{ kJ}$

 $\Delta H = mC_w \Delta T_w + n\Delta H_{vap} + mC_s \Delta T_s$ $m = 18.02 \text{ g H}_2\text{O} = 0.01802 \text{ kg H}_2\text{O}$ (water) (vaporization) (steam) $n = -\frac{18.02}{9}$ g 18.02 g/mol $\Delta H = (0.01802 \text{ kg})(4.19 \text{ kJ}/(\text{kg} \bullet \text{°C}))(20.0 \text{°C}) +$ $n = 1.000 \text{ mol H}_2\text{O}$ (1.000 mol)(40.65 kJ/mol) + $C_{water} = 4.19 \text{ kJ/(kg \bullet ^{\circ}C)}$ $(0.01802 \text{ kg})(2.02 \text{ kJ/(kg} \bullet \text{°C}))(15 \text{°C})$ $\Delta T_{water} = 100.0^{\circ}\text{C} - 80.0^{\circ}\text{C} = 20.0^{\circ}\text{C}$ $\Delta H_{\rm vap} = 40.65 \text{ kJ/mol}$ $\Delta H = 1.510076 \text{ kJ} + 40.65 \text{ kJ} + 0.546006 \text{ kJ}$ $C_{steam} = 2.02 \text{ kJ/(kg \bullet ^{\circ}C)}$ $\Delta T_{steam} = 115^{\circ}\text{C} - 100^{\circ}\text{C} = 15^{\circ}\text{C}$ $\Delta H = 42.7 \text{ kJ}$

 $\Delta H = ?$

Writing Δ*H* Notations with Chemical Equations / Physical Process:

a. <u>Endothermic Reactions / Processes</u>

Reactant(s) + Heat \rightarrow Product(s) OR Reactant(s) \rightarrow Product(s) $\Delta H = +$ kJ

Example: Water is vaporized from its liquid state.

 $H_2O_{(l)} + 40.7 \text{ kJ} \rightarrow H_2O_{(g)}$ or $H_2O_{(l)} \rightarrow H_2O_{(g)} \qquad \Delta H = +40.7 \text{ kJ}$

b. Exothermic Reactions / Processes

Reactant(s) \rightarrow Product(s) + Heat OR Reactant(s) \rightarrow Product(s) $\Delta H = -$ ____kJ

Example: Methane undergoes combustion at constant pressure.

 $CH_{4(g)} + 2 O_{2(g)} \rightarrow CO_{2(g)} + 2 H_2O_{(g)} + 802.5 \text{ kJ} \text{ or } CH_{4(g)} + 2 O_{2(g)} \rightarrow CO_{2(g)} + 2 H_2O_{(g)} \Delta H = -803 \text{ kJ}$

Example 3: A cold pack consists of 40.0 g of NH₄NO₃ is dissolved in water. How much energy is absorbed or released into its surrounding if the ΔH_{soln} is 25.7 kJ/mol?

 $\Delta H_{\text{soln}} = +25.7 \text{ kJ/mol} (\Delta H_{\text{soln}} > 0; \text{ endothermic}) \qquad \Delta H = n \Delta H_{\text{soln}}$ (Heat is absorbed from the surrounding) $\Delta H = (0.499625281 \text{ mol})(25.7 \text{ kJ/mol})$ $n = \frac{40.0 \text{ g}}{80.06 \text{ g/mol}} = 0.499625281 \text{ mol} \text{ NH}_4 \text{NO}_3$ $\Delta H = 12.8 \text{ kJ absorbed}$ $\Delta H = 2$

Example 4: 12.9 kJ of heat is released when CaCl₂ is dissolved in water, find the mass of CaCl₂ dissolved if the molar heat of solution of CaCl₂ is -82.8 kJ/mol.

$\Delta H_{\text{soln}} = -82.8 \text{ kJ/mol} (\Delta H_{\text{soln}} < 0; \text{ exothermic})$ (Heat is released into the surrounding)	$\Delta H = n \Delta H_{\rm soln} \qquad n = \frac{\Delta H}{\Delta H_{\rm soln}}$
$\Delta H = -12.9 \text{ kJ}$ M = 110.98 g/mol CaCl ₂	$n = \frac{-12.9 \text{ kJ}}{-82.8 \text{ kJ/mol}} = 0.1557971014 \text{ mol}$
n = ? $m = ?$	m = nM = (0.1557971014 mol)(110.98 g/mol)
	m = 17.5 g

<u>Assignment</u> 11.3 pg. 311 #22 and 23; pg. 313 #24 to 29

11.2: Measuring and Expressing Heat Changes

<u>Molar Heat of Reaction</u> (ΔH_{rxn}): - the amount of heat change in a chemical reaction per mole of reactant used or product formed.

- the molar heat of a combustion reaction is referred to as the <u>Molar</u> <u>Heat of Combustion</u> (ΔH_{comb})



Example 1: Calculate the amount of energy generated when 500 g of octane is burned in a gasoline engine of a vehicle. ($\Delta H_{comb} = -5470.1 \text{ kJ/mol}$)

 $\Delta H_{\text{comb}} = -5470.1 \text{ kJ/mol} (\Delta H_{\text{comb}} < 0; \text{ exothermic})$ (Heat is released into the surrounding) $n = \frac{500 \text{ g}}{114.26 \text{ g/mol}} = 4.375984597 \text{ mol} \text{ C}_8\text{H}_{18}$ $\Delta H = ?$ $\Delta H = 2.40 \times 10^4 \text{ kJ} = 24.0 \text{ MJ} \text{ released}$

Example 2: $CH_2=CH_2_{(g)} + H_2O_{(l)} \rightarrow C_2H_5OH_{(l)} + 44.2 \text{ kJ}$. What is the mass of ethanol produced when 322 kJ is released from the reaction?

$$\Delta H_{\text{rxn}} = -44.2 \text{ kJ/mol } (\Delta H_{\text{rxn}} < 0; \text{ exothermic})$$
(Heat is released into the surrounding)

$$\Delta H = -322 \text{ kJ}$$

$$M = 46.08 \text{ g/mol } \text{C}_2\text{H}_5\text{OH}$$

$$n = ? \qquad m = ?$$

$$M = n \Delta H_{\text{rxn}} \qquad n = \frac{\Delta H}{\Delta H_{\text{rxn}}}$$

$$n = \frac{-322 \text{ kJ}}{-44.2 \text{ kJ/mol}} = 7.285067873 \text{ mol}$$

$$m = nM = (7.285067873 \text{ mol})(46.08 \text{ g/mol})$$

$$m = 336 \text{ g of } \text{C}_2\text{H}_5\text{OH}$$

- <u>Calorimetry</u>: uses the conservation of energy (Heat Gained = Heat Lost) to measure calories (old unit of heat: 1 cal = 4.18 J).
 - physical calorimetry involves the mixing of two systems (one hotter than the other) to reach some final temperature.
 - chemical calorimetry involves the reaction of one system in the reaction chamber and the measurement of the change in temperature of the water in the calorimeter.
 - <u>the key to do these problems is to identify which system is gaining heat and which one</u> <u>is losing heat.</u>

A Simple Calorimeter









(Check out Calorimetry Animation at http://web.umr.edu/~gbert/animation.html)

Copyrighted by Gabriel Tang B.Ed., B.Sc.

Page 131.

Example 3: Hot water at 90.0°C is poured into 100 g of cold water at 10.0°C. The final temperature of the mixture is 70.0°C. Determine the mass of the hot water?

$m_{\rm cold water} = 100 {\rm g}$	Heat Lost = Heat Gained
$C = 4.19 \text{ J/(g} \bullet ^{\circ}\text{C})$	(hot water, kinetic) (cold water, kinetic)
$\Delta T_{\text{hot water}} = 90.0^{\circ}\text{C} - 70.0^{\circ}\text{C} = 20.0^{\circ}\text{C}$	$m_{\rm hw} C \Delta T_{\rm hw} = m_{\rm cw} C \Delta T_{\rm cw}$
$\Delta T_{\text{cold water}} = 70.0^{\circ}\text{C} - 10.0^{\circ}\text{C} = 60.0^{\circ}\text{C}$	$m_{\rm t} = \frac{m_{\rm cw}\Delta T_{\rm cw}}{2}$
	$\Delta T_{ m hw}$
$m_{\rm hotwater} = ?$	$(100 \text{ g})(60.0^{\circ} \text{ C})$
	$m_{\rm hw} = \frac{(20.0^{\circ} \rm C)}{(20.0^{\circ} \rm C)}$
	$m_{\rm hw} = 300 {\rm g}$

Example 4: A 1500 g of iron metal at 330°C is dropped into a beaker of 1000 g of water at 25.0°C. What will be the final temperature?

$T_f = ?$	Heat Lost = Heat Gained
·	(iron, kinetic) (water, kinetic)
$m_{\rm Fe} = 1500 {\rm g}$	$m_{\rm Fe}C_{\rm Fe}\Delta T_{\rm Fe} = m_{\rm w}C_{\rm w}\Delta T_{\rm w}$
$C_{\rm Fe} = 0.449 \mathrm{J/(g \bullet ^{\circ}C)}$	$(1500 \text{ g})(0.449 \text{ J/(g} \bullet ^{\circ}\text{C}))(330^{\circ}\text{C} - T_f) = (1000 \text{ g})(4.19 \text{ J/(g} \bullet ^{\circ}\text{C}))(T_f - 25.0^{\circ}\text{C})$
$\Delta T_{\rm Fe} = 330^{\circ}{\rm C} - T_f$	$222255 - 673.5T_f = 4190T_f - 104750$
	$-673.5T_f - 4190T_f = -104750 - 222255$
$m_{\text{water}} = 1000 \text{ g}$	$-4863.5T_f = -327005$
$C_{\text{water}} = 4.19 \text{ J/(g} \bullet ^{\circ}\text{C})$	-327005
$\Delta T_{\text{water}} = T_f - 25.0^{\circ}\text{C}$	$I_f = -4863.5$
	$T_f = 67.2^{\circ}\mathrm{C}$

Example 5: When 10.02 g of liquid heptane is burned in the reaction vessel of a calorimeter, 1.50 L of water around the vessel increased its temperature from 20.0°C to 85.0°C. Ignore the metallic material of the calorimeter,

- a. determine the experimental molar heat of combustion heptane.
- b. calculate the % error in the calorimetry experiment for the combustion of heptane ($\Delta H_{comb} = -4.82 \text{ MJ/mol}$ for heptane burned).
- c. explain why the experimental ΔH is different than its theoretical counterpart.

a. We use the conservation of heat to calculate experimental $\Delta H_{\rm rxn}$.

$$n = \frac{10.02 \text{ g}}{100.23 \text{ g/mol}}$$

$$n = 0.0999700688 \text{ mol } C_7H_{16}$$

$$m_{water} = 1.50 \text{ kg} (1 \text{ kg} = 1 \text{ L of water})$$

$$\Delta T = 85.0^{\circ}\text{C} - 20.0^{\circ}\text{C} = 65.0^{\circ}\text{C}$$

$$C_{water} = 4.19 \text{ kJ / (kg • °C)}$$

$$\Delta H_{rxn} = ?$$

$$n \Delta H_{rxn} = m_w C_w \Delta T$$

$$\Delta H_{rxn} = \frac{m_w C_w \Delta T}{n} = \frac{(1.50 \text{ kg})(4.19 \text{ kJ/(kg • °C)})(65.0^{\circ}\text{ C})}{(0.0999700688 \text{ mol})}$$

$$\Delta H_{rxn} = 4086.473129 \text{ kJ/mol (released)}$$

$$\Delta H_{rxn} = -4.09 \text{ MJ/mol of } C_7H_{16} \text{ burned}$$

Page 132.

Honour Chemistry

Unit 6: Thermochemistry and Nuclear Chemistry

- **b.** % error = $\frac{|\text{Theoretical} \text{Experimental}|}{|\text{Theroretical}|} \times 100\%$ % error = $\frac{|(-4.82 \text{ MJ}) - (-4.09 \text{ MJ})|}{(-4.82 \text{ kJ})} \times 100\%$ % error = 15.1%
- c. Some of the possible reasons why experimental ΔH_{comb} (-4.08 MJ) is different than the theoretical ΔH_{comb} (-4.82 MJ)
- Some of the heat released by the reaction is absorbed by the metal calorimeter itself. Thus, the temperature gained by the water is not an exact reflection of the energy lost by the combustion.
- > The calorimeter is not a closed system. <u>Heat might escape into the surrounding</u>.
- Even if the system is closed, the <u>buildup of gases from the reaction</u> would increase pressure and volume. Hence, <u>some of the energy produced from the reaction is used to do work by the</u> <u>system</u>. Thereby, lowering the heat available to warm the water.

<u>Assignment</u> 11.2 pg. 302 #11 and 12; pg. 304 #13 and 14; pg. 306 #15 to 19

<u>11.4: Calculating Heat Changes</u>

- <u>Hess's Law</u>: the <u>addition of ΔH </u> of a series of reactions to find the change in enthalpy of an overall net reaction.
 - when adding reactions, <u>compared the reactants and products of the overall net reaction</u> with the intermediate reactions given. Decide on the intermediate reactions that need to be reversed or multiply by a coefficient or both, such that when added, the intermediate products will cancel out perfectly yielding the overall net reaction.
 - if a particular reaction needs to be <u>reversed (flipped)</u>, the <u>sign of the ΔH </u> for that reaction will also <u>need to be reversed</u>.
 - if a **coefficient** is used to <u>multiply</u> a particular reaction, the ΔH for that reaction will also <u>have to multiply</u> by that same coefficient.

(Check out Hess's Law Animation at http://intro.chem.okstate.edu/1314F00/Lecture/Chapter6/Hesslaw2.html)

Example 1: Calculate ΔH for the reaction N_{2 (g)} + 2 O_{2 (g)} \rightarrow 2 NO_{2 (g)}, when the following reactions are given.

$N_{2(g)} + O_{2(g)} \rightarrow 2 \text{ NO}_{(g)}$	$\Delta H = 180 \text{ k.}$
$2 \operatorname{NO}_{2(g)} \rightarrow 2 \operatorname{NO}_{(g)} + \operatorname{O}_{2(g)}$	$\Delta H = 112 \text{ k.}$

Note that 2 NO₂ in the net reaction is on the product side, whereas 2 NO₂ in the second reaction is on the reactant side. Hence, we need to reverse the second reaction and its sign of the ΔH .

	$N_{2(g)} + O_{2(g)} \rightarrow 2 - NO_{(g)}$	$\Delta H = 180 \text{ kJ}$
(Flipped)	$\frac{2 \operatorname{NO}_{(g)}}{2 \operatorname{NO}_{2(g)}} \rightarrow 2 \operatorname{NO}_{2(g)}$	$\Delta H = -112 \text{ kJ}$
	$N_{2(g)} + 2 O_{2(g)} \rightarrow 2 NO_{2(g)}$	$\Delta H = +68 \text{ kJ}$

Copyrighted by Gabriel Tang B.Ed., B.Sc.

Page 133.

Unit 6: Thermochemistry and Nuclear Chemistry

Example 2: Determine the ΔH for the reaction $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$, when the following reactions are given.

$$S_{(s)} + \frac{3}{2}O_{2(g)} \rightarrow SO_{3(g)}$$
 $\Delta H = -395.2 \text{ kJ}$
2 SO_{2(g)} + O_{2(g)} \rightarrow 2 SO_{3(g)} $\Delta H = -198.2 \text{ kJ}$

- a. SO₂ in the net reaction is on the product side, whereas 2 SO₂ in the second reaction is on the reactant side. Hence, we need to reverse the second reaction and its sign of the ΔH .
- b. There is only 1 SO₂ in the net reaction, whereas there are 2 SO₂ in the second reaction. Therefore the second reaction and its ΔH need to be multiply by the coefficient of $\frac{1}{2}$.

(Flipped and × ¹/₂)

$$S_{(s)} + \frac{3}{2}O_{2(g)} \rightarrow SO_{3(g)} \qquad \Delta H = -395.2 \text{ kJ}$$

$$\frac{1}{2}(2 \text{ SO}_{3(g)} \rightarrow 2 \text{ SO}_{2(g)} + O_{2(g)}) \qquad \Delta H = \frac{1}{2}(+198.2 \text{ kJ})$$

$$S_{(s)} + \frac{3}{2}O_{2(g)} \rightarrow SO_{3(g)} \qquad \Delta H = -395.2 \text{ kJ}$$

$$\frac{SO_{3(g)} \rightarrow SO_{2(g)} + \frac{1}{2}O_{2(g)} \qquad \Delta H = -99.1 \text{ kJ}}{S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}} \qquad \Delta H = -296.1 \text{ kJ}$$

Example 3: Find the ΔH for the overall reaction of 2 N_{2 (g)} + 5 O_{2 (g)} \rightarrow 2 N₂O_{5 (g)}, when the following reactions are given.

$$\begin{array}{ccc} H_{2\,(g)} + \frac{1}{2} & O_{2\,(g)} \rightarrow H_2 O_{(l)} & \Delta H = -285.8 \text{ kJ} \\ N_2 O_{5\,(g)} + H_2 O_{(l)} \rightarrow 2 \text{ HNO}_{3\,(l)} & \Delta H = -76.6 \text{ kJ} \\ \frac{1}{2} & N_{2\,(g)} + \frac{3}{2} & O_{2\,(g)} + \frac{1}{2} & H_{2\,(g)} \rightarrow \text{HNO}_{3\,(l)} & \Delta H = -174.1 \text{ kJ} \end{array}$$

- a. $2 N_2O_5$ in the net reaction is on the product side, whereas N_2O_5 in the second reaction is on the reactant side. Hence, we need to reverse the second reaction and its sign of the ΔH .
- b. There are 2 N₂O₅ in the net reaction, whereas there is only 1 N₂O₅ in the second reaction. Therefore the second reaction and its ΔH need to be multiply by the coefficient of 2.
- c. There are 2 N₂ in the next reaction on the reactant side. Since $\frac{1}{2}$ N₂ is on the reactant side of the third reaction, we need to multiply the third reaction and its ΔH by the coefficient of 4.
- d. In order for H₂O to cancel from the first and second reactions, we have to multiple the first reaction by 2 and flipped. This is because H₂O in the second reaction has also flipped and has been multiplied by 2.

$$\begin{array}{ll} (\text{Flipped and } \times 2) & 2 \left(\text{H}_2 \text{O}_{(l)} \rightarrow \text{H}_{2\,(g)} + \frac{1}{2} \text{O}_{2\,(g)} \right) & \Delta H = 2(+285.8 \text{ kJ}) \\ (\text{Flipped and } \times 2) & 2 \left(2 \text{ HNO}_{3\,(l)} \rightarrow \text{N}_2 \text{O}_{5\,(g)} + \text{H}_2 \text{O}_{(l)} \right) & \Delta H = 2(+76.6 \text{ kJ}) \\ (\times 4) & 4 \left(\frac{1}{2} \text{N}_{2\,(g)} + \frac{3}{2} \text{O}_{2\,(g)} + \frac{1}{2} \text{H}_{2\,(g)} \rightarrow \text{HNO}_{3\,(l)} \right) & \Delta H = 4(-174.1 \text{ kJ}) \\ & \frac{2 \text{H}_2 \text{O}_{4(l)} \rightarrow 2 \text{H}_{2\,(g)} + \text{O}_{2\,(g)}}{4 \text{HNO}_{3\,(l)} \rightarrow 2 \text{N}_2 \text{O}_{5\,(g)}} + \frac{2 \text{H}_2 \text{O}_{4(l)}}{2 \text{N}_{2\,(g)} + 6 \text{O}_{2\,(g)} + \frac{2 \text{H}_{2\,(g)}}{2 \text{H}_{2\,(g)} \rightarrow 4 \text{HNO}_{3\,(l)}} & \Delta H = +571.6 \text{ kJ} \\ & 2 \text{N}_{2\,(g)} + 6 \text{O}_{2\,(g)} + \frac{2 \text{H}_{2\,(g)}}{2 \text{H}_{2\,(g)} \rightarrow 4 \text{HNO}_{3\,(l)}} & \Delta H = -696.4 \text{ kJ} \\ & 2 \text{N}_{2\,(g)} + 5 \text{O}_{2\,(g)} \rightarrow 2 \text{N}_2 \text{O}_{5\,(g)} & \Delta H = +28.4 \text{ kJ} \end{array}$$

<u>Molar Heat of Formation</u> (ΔH_f) : - the amount of heat required / given off to make 1 mole of compound from its elemental components.

- the Molar Heat of Formation of ALL ELEMENTS is 0 kJ.
- the state of the compound affects the magnitude of H_f . (H₂O_(g) has $H_f = -241.8$ kJ/mol; H₂O_(l) has $H_f = -285.8$ kJ/mol)
- Standard Molar Heat of Formation (*H*°_{*f*}) is the heat of formation under standard conditions (1 atm and 25°C).

(See Table 11.6 on pg. 316 in the Addison-Wesley 5th ed. Chemistry textbook for a list of *H*^o_f)

Enthalpy of Formation (Chemical) $\Delta H = n \Delta H_f$ ΔH = Change in Enthalpyn = moles ΔH_f = Molar Heat of Formation (kJ/mol)

Example 4: Find the molar heat of formation of table salt given that 2 Na $_{(s)}$ + Cl_{2 (g)} \rightarrow 2 NaCl $_{(s)}$ + 822 kJ.

$\Delta H = -822 \text{ kJ}$	$\Delta H = n \Delta H_f$	
$n = 2 \mod of \operatorname{NaCl}$	$\Delta H_c = \frac{\Delta H}{\Delta H} = \frac{-822 \text{ kJ}}{-822 \text{ kJ}}$	$\Lambda H_c = -411 \text{ kJ/mol}$
$\Delta H_f = ?$	$n \qquad 2 \bmod n$	

Example 5: What is the amount of heat absorbed / released when 100 g of $CO_{2(g)}$ is produced from its elements (CO₂ has $\Delta H_f = -393.5$ kJ/mol)?

 $n = \frac{100 \text{ g}}{44.01 \text{ g/mol}}$ n = 2.272210861 mol NaCl $\Delta H = n\Delta H_f$ $\Delta H = (2.272210861 \text{ mol})(-393.5 \text{ kJ/mol})$ $\Delta H = -894 \text{ kJ}$ (894 kJ is released) $\Delta H = ?$

Example 6: Iron (III) oxide, rust, is produced from its elements, iron and oxygen. What is the mass of rust produced when 1.20 MJ is released when iron is reacted with oxygen ($\Delta H_f = -824.2 \text{ kJ/mol}$ for Fe₂O₃)?

 $\Delta H = 1.20 \text{ MJ} = -1.20 \times 10^{3} \text{ kJ}$ $\Delta H_{f} = -824.2 \text{ kJ/mol}$ $M = 159.7 \text{ g/mol Fe}_{2}\text{O}_{3}$ $n = ? \quad m = ?$ m = nM = (1.455957292 mol)(159.7 g/mol) m = 233 g

Unit 6: Thermochemistry and Nuclear Chemistry

Example 7: Calculate the molar heat of formation of silver (I) oxide when 91.2 g of Ag₂O is produced from its elements and 12.2 kJ of heat is released from the process.

91.2 g	$\Delta H = n \Delta H_f$
$n = \frac{1}{231.74 \mathrm{g/mol}}$	$\Delta H_c = \frac{\Delta H}{\Delta H} = \frac{-12.2 \text{ kJ}}{-12.2 \text{ kJ}}$
$n = 0.3935444895 \text{ mol Ag}_2\text{O}$	<i>n</i> 0.3935444895 mol
$\Delta H = -12.2 \text{ kJ}$	
$\Delta H_f = ?$	$\Delta H_f = -31.0 \text{ kJ/mol}$

<u>Molar Enthalpy of Reaction</u>: - the amount of heat involved when 1 mol of a particular product is produced or 1 mol of a particular reactant is consumed.

- it is equal to <u>the difference between of all enthalpies of products and</u> <u>all enthalpies of reactants</u>.
- if the reaction is a **combustion**, it is called the **molar heat of combustion**.

(Note: In hydrocarbon combustion, assume all products are gaseous unless otherwise stated.)

Theoretical Enthalpy of Reaction

 $\Delta H_{\rm rxn} = \Sigma H_{\rm products} - \Sigma H_{\rm reactants}$

 $\Delta H_{\text{rxn}} = \text{Change in Enthalpy of Reaction}$ $\Sigma H_{\text{products}} = \text{Sum of Heat of Products (from all } n\Delta H_f \text{ of products})$ $\Sigma H_{\text{reactants}} = \text{Sum of Heat of Reactants (from all } n\Delta H_f \text{ of reactants})$

Example 8: Propane is a clean burning fossil fuel that is widely used in outdoor barbecue.

- a. Calculate the ΔH of combustion of propane.
- b. Draw its potential energy diagram.
- c. How much energy will be absorbed or released when 15.0 g or propane is burned?
- **a.** We have to first write out a balance equation for the combustion of propane.

 $\begin{array}{rcl} & & C_{3}H_{8\,(g)} &+& 5\ O_{2\,(g)} &\to& 3\ CO_{2\,(g)} &+& 4\ H_{2}O_{\,(g)} \\ & & \Delta H_{f}\colon & -103.8\ \text{kJ/mol} & 0\ \text{kJ/mol} & -393.5\ \text{kJ/mol} & -241.8\ \text{kJ/mol} \\ & & \Delta H_{rxn} = \sum H_{\text{products}} - \sum H_{\text{reactants}} \\ & \Delta H_{rxn} = [3\ \text{mol}\ (-393.5\ \text{kJ/mol}) + 4\ \text{mol}\ (-241.8\ \text{kJ/mol})] - [1\ \text{mol}\ (-103.8\ \text{kJ/mol}) + 5\ \text{mol}\ (0\ \text{kJ/mol})] \\ & \Delta H_{rxn} = [-2147.7\ \text{kJ}] - [-103.8\ \text{kJ}] \\ & & \Delta H_{rxn} = -2044\ \text{kJ/mol}\ \text{of}\ C_{3}H_{8}\ \text{burned} \end{array}$



Example 9: Determine the amount of heat released when 34.9 g of butane gas is burned $(\Delta H_f = -125.7 \text{ kJ/mol for butane}).$

We have to first write out a balance equation for the combustion of butane.

 $2 C_4 H_{10(g)} + 13 O_{2(g)} \rightarrow 8 CO_{2(g)} + 10 H_2 O_{(g)}$ (We have to divide all coefficients by 2 because we are calculating ΔH_{rxn} per mol of butane burned.)

 $C_{4}H_{10 (g)} + \frac{13}{2} O_{2 (g)} \rightarrow 4 CO_{2 (g)} + 5 H_{2}O_{(g)}$ $\Delta H_{f}: -125.7 \text{ kJ/mol} \quad 0 \text{ kJ/mol} -393.5 \text{ kJ/mol} -241.8 \text{ kJ/mol}$ $\Delta H_{rxn} = \Sigma H_{products} - \Sigma H_{reactants}$ $\Delta H_{rxn} = [4 \text{ mol} (-393.5 \text{ kJ/mol}) + 5 \text{ mol} (-241.8 \text{ kJ/mol})] - [1 \text{ mol} (-125.7 \text{ kJ/mol}) + \frac{13}{2} \text{ mol} (0 \text{ kJ/mol})]$ $\Delta H_{rxn} = [-2783 \text{ kJ}] - [-125.7 \text{ kJ}]$ $\Delta H_{rxn} = -2657 \text{ kJ/mol of } C_{4}H_{10} \text{ burned}$ $n = \frac{34.9 \text{ g}}{58.14 \text{ g/mol}} = 0.60027519878 \text{ mol } C_{3}H_{8} \quad \Delta H = n\Delta H_{rxn}$ $\Delta H = n\Delta H_{rxn}$ $\Delta H = -1.59 \text{ MJ} (1.59 \text{ MJ is released})$

Example 10: $HCOOH_{(g)}$ were completely burned to $CO_{2(g)}$ and $H_2O_{(l)}$ in a calorimeter. The following are the observation of the experiment.

Mass of HCOOH _(g) burned	9.22 g
Initial Temperature of Calorimeter and Water	21.5°C
Final Temperature of Calorimeter and Water	37.3°C
Specific Heat of Calorimeter and Water	3.20 kJ/°C

a. Determine the experimental molar heat of formation of $HCOOH_{(l)}$.

b. If the theoretical ΔH_f for HCOOH (g) is -363 kJ/mol, calculate the % error of this experiment.

a. We use the conservation of heat to calculate experimental ΔH_{rxn} .

 $n = \frac{9.22 \text{ g}}{46.03 \text{ g/mol}}$ n = 0.2003041495 mol HCOOH $m_{water}C_{water} = 3.20 \text{ kJ/°C}$ $\Delta T = 37.3^{\circ}\text{C} - 21.5^{\circ}\text{C} = 15.8^{\circ}\text{C}$ $\Delta H_{rxn} = \frac{m_{w}C_{w}\Delta T}{n} = \frac{(3.20 \text{ kJ/°C})(15.8^{\circ}\text{ C})}{(0.2003041495 \text{ mol})}$ $\Delta H_{rxn} = 252.4161388 \text{ kJ/mol (released)}$ Experimental $\Delta H_{rxn} = -252 \text{ kJ/mol of HCOOH burned}$

Next, we use Hess's Law to find the ΔH_f of HCOOH.

HCOOH_(l) + ¹/₂ O_{2(g)} → CO_{2(g)} + H₂O_(l) ΔH_f: **? kJ/mol** 0 kJ/mol −393.5 kJ/mol −285.8 kJ/mol

 $\Delta H_{rxn} = \Sigma H_{products} - \Sigma H_{reactants}$ $-252 \text{ kJ} = [1 \text{ mol} (-393.5 \text{ kJ/mol}) + 1 \text{ mol} (-285.8 \text{ kJ/mol})] - [1 \text{ mol} (\Delta H_f) + \frac{1}{2} \text{ mol} (0 \text{ kJ/mol})]$ $-252 \text{ kJ} = [-679.3 \text{ kJ}] - [\Delta H_f]$ $\Delta H_f = -679.3 \text{ kJ} + 252 \text{ kJ} = -427.3 \text{ kJ}$ **Experimental HCOOH** $\Delta H_f = -427 \text{ kJ/mol}$ **b.** % error = $\left| \frac{\text{Theoretical} - \text{Experimental}}{\text{Theoretical}} \right| \times 100\% = \left| \frac{(-363 \text{ kJ}) - (-427 \text{ kJ})}{(-363 \text{ kJ})} \right| \times 100\%$



<u>11.5: Energy Productions and Environments</u>

<u>Greenhouse Effect</u>: - the emission of greenhouses gases that traps more of the sun's radiant (heat) energy in the atmosphere than it occurs naturally.



Greenhouses Gases: - man-made and naturally occur gases that contribute to the Greenhouse Effect.

- 1. Carbon dioxide (CO₂) is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned.
- 2. Methane (CH₄) is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock.
- **3.** Nitrous oxide (N₂O) is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.
- 4. Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur Hexafluoride (SF₆) are very powerful greenhouse gases that are not naturally occurring that are generated in a variety of industrial processes.

Each greenhouse gas differs in its ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. Often, estimates of greenhouse gas emissions are presented in units of millions of metric tons of carbon equivalents (MMTCE), which weights each gas by its GWP value, or Global Warming Potential. (Information from US. EPA)

Unit 6: Thermochemistry and Nuclear Chemistry

- Automobiles and Major Transportations account for 34% of CO₂ emissions globally (Power Plants contributes 33%; Major Industries and Home Heating contribute the remaining 33%).
- Presently 89% of Energy Productions involve the burning of Fossil Fuels (Coal, Petroleum, Natural Gas and Biomass).
- Heat and Electricity generated from combustion of fossil fuel is at most 30% efficient.

(Data from University of Michigan: http://www.umich.edu/~gs265/society/greenhouse.htm)

The Environmental Effect of Using Fossil Fuel: (Greenhouse Effect)

- 1. <u>Global Warming</u>: the warming of global temperature due to an increased of greenhouse gases in the atmosphere.
- 2. <u>Rise of Water Level</u>: low-lying islands and coastal area are endangered as polar icecaps melt due to the rise of temperature as a result of the greenhouse effect.
- 3. <u>Unpredicted and Erratic Climate</u>: greenhouse effect is related to droughts and dry whether in many parts of the world.
- 4. <u>Deforestation</u>: another cause of an increased in CO₂ level in the atmosphere. As forests disappeared, there is a lack of plants to absorb carbon dioxide using photosynthesis.
 - also causes mud and landslides, demineralization of the soil, lost animal habitats and extinction, destruction of entire ecosystems. Plants that may have important medicinal values can also be destroyed.

Alternate Energy Sources without the Emission of Greenhouse Gas

- 1. <u>Solar Energy</u>: the most efficient energy source where energy from the sun is converted directly to electricity through the use of photovoltaic cells (solar panels) or heat using high efficient insulated glass and an effective water heating system.
 - technology exists but fairly expensive; requires many solar panels to generate adequate amount of electricity.
- 2. <u>Wind Power</u>: the use of wind turbines to generate electricity.
 - very efficient and extremely economical, but location specific and not very reliable when there is no wind.
 - can disrupt migratory routes of birds (they get caught in the turbine), aesthetic problems for the landscapes.
- 3. <u>Geothermal Power</u>: the use of underground steam to generate electricity.
 - very efficient somewhat reliable, but location specific.
 - geothermal power is widely use in Iceland where it is sitting on the Atlantic ridge and there are lots of hot springs.

- 4. <u>Tidal Power</u>: the use of tidal current to generate electricity.
 - very efficient somewhat reliable, but location specific.
 - tidal power involves establishing electric turbines at a narrow mouth of a channel where normal tides can cause bigger current and quick rise in water levels. It is being used in the Bay of Fundy at Nova Scotia, Canada and Kvalsund at the Arctic tip of Norway.
 - tidal power can sometimes disrupt migratory routes of marine species.
- 5. <u>Hydroelectricity</u>: the use of dam and reservoir to turn electric turbines as water falls from a higher level to the spillway (potential energy converted to kinetic energy to electricity).
 - very efficient and no emission of greenhouse gas.
 - location specific and very expensive to built. The reservoir flooding can destroy ecological habitats and force migrations of people from towns and villages (Aswan Dam in Egypt and the Three Gorges Dam in China displaced thousands of people and submerged ancient cities). The presence of the dam can disrupt aquatic migratory routes as well.
 - dams have a limited life span (the collection of silt and mud at the bottom of the dam has to be clear periodically to maintain the structural integrity of the dam). Dams can burst during earthquakes or poor maintenance. Flash flooding of towns along spillway is always a danger.
- 6. <u>Hydrogen Fuel</u>: burning hydrogen to form water and generate heat and electricity.
 - very efficient and zero pollution.
 - hydrogen is very explosive and technologies are still needed for supplying and storing hydrogen safely in automobiles and homes.

<u>Assignment</u> Chapter 11 Review: pg. 322–324 #36 to 48, 50 to 63, 69 to 75

Chapter 28: Nuclear Chemistry

28.1: Nuclear Radiation

- <u>**Radioisotopes**</u>: unstable atoms that have different mass number but the same atomic number or number of protons.
 - when decaying to more stable atoms, they tend to emit large amount of energy.



<u>Radioactivity</u>: - the process by which radioisotopes give off energy or particles. - first discovered by Marie Curie with uranium ore and later studied by Antoine Becquerel.

- **<u>Radiation</u>**: the penetrating rays and particles emitted by a radioisotopes that can also have ionizing power.
- <u>**Radioactive Decay</u>**: a process where a radioisotope decomposes into a different nucleus to achieve more stability.</u>

Types of Radioactive Decay

1. <u>Alpha Particle</u> (α particle): - basically a helium nucleus ($_{2}^{4}$ He), commonly found during radioactive decay from heavier nuclide.

Example: ${}^{218}_{84}$ Po $\rightarrow {}^{214}_{82}$ Pb + ${}^{4}_{2}$ He

- 2. <u>Beta Particle</u> (β particle): basically an electron $({\begin{smallmatrix} 0\\-1 \end{smallmatrix})^0 e)$ that is emitted with the net result of increasing the atomic number.
 - electrons have a mass number of 0 and an atomic number assignment of -1, due to its charge.

Example: ${}^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}e$

3. <u>Gamma Ray</u> (γ ray): - also known as a high-energy photon $\begin{pmatrix} 0 \\ 0 \end{pmatrix}$ that is usually a by-product of an

alpha-particle decay.

- photon has no mass and no atomic number.

Example: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + 2 {}^{0}_{0}\gamma$

Effects from Radiation

- 1. Penetrating Ability: the lighter the particles, the more penetrating they can be. In terms of penetrating ability: γ ray is the strongest, follows by β particles and α particle is the least penetrating.
- 2. Ionization Ability: as high-energy particles pass through tissue, it can cause ionization that is damaging to the organism. α particles can ionize the most along its path whereas γ ray does not. Therefore, α particle producers like plutonium and radon can cause severe radiation damage if ingested or inhaled.



28.2: Nuclear Transformation

<u>Half-Life</u> $(t_{1/2})$: - the amount of time it takes to half the amount of radioactive nuclides.

Example 1: Technetium-99, the first synthetic element in the Table, is used as a radiotracer for many organs such as heart, liver and lungs. It has a half-life of 6.0 hours. Draw a graph showing how 100 mg of ⁹⁹/₄₃ Tc decays over time. What is the radioactive amount of ⁹⁹/₄₃ Tc after 2.00 days?



<u>**Radiocarbon Dating**</u>: - sometimes called <u>carbon-14 dating</u>. ${}^{14}_{6}$ C can be found naturally in organic

material and the atmosphere. It decays as soon as the organism dies.

$${}^{14}_{6}\mathrm{C} \rightarrow {}^{0}_{-1}\mathbf{e} + {}^{14}_{7}\mathrm{N}$$

- uses the known ratio of ${}_{6}^{14}C/{}_{6}^{12}C$ of similar organic sample of the day with the ratio in the artefact and the half-life of ${}_{6}^{14}C$ being 5730 years to determine the age of the artefact.
- accurate within 50,000 years in the past. Beyond that time, the amount of carbon-14 is too little to make an accurate analysis.
- <u>Uranium-238 Dating</u>: due to its lengthy half-life $(4.5 \times 10^9 \text{ years})$, it is used to date rocks and other ancient inorganic material. $^{238}_{92}\text{U}/^{206}_{82}\text{Pb}$ ratio is used as $^{238}_{92}\text{U}$ eventually decays to stable $^{206}_{82}\text{Pb}$.
- **Example 1**: A archaeologist unearthed a femur that contained one-sixteenth the amount of carbon-14 compared to a similar size femur of a person today. Knowing that carbon-14 has a half-life of 5730 years, what is the approximate age of this femur?

$$\frac{1}{16}$$
 of the original amount is 4 half-lives. $\left[\left(\frac{1}{2} \right)^4 = \frac{1}{16} \right]$ Hence, it has been
4 × 5730 years = 22,920 years

Isotopic Dating Using Logarithm

Logarithm can be used to solve for an exponent. This is helpful when we need to find the time elapsed or the half-life in isotopic dating. In general, we can solve for an exponent by doing the conversion to the right.

$$b^x = a$$
 $x = \frac{\log a}{\log b}$

Example 2: Solve for *x*



Example 3: Cobalt-60 is commonly used in chemotherapy and it has a half-life of 5 years. If a patient has received 6.00 mg of cobalt-60 during her treatment, how many years will it take until 0.25 mg of the original isotope remains?



Example 4: A radioactive isotope decayed to 35.4% of its original value in 4.26 millisecond. What is its half-life?

N = 35.4 % $N_0 = 100 \%$ t = 4.26 ms	$N = N_{\rm o} \left(\frac{1}{2}\right)^{\left(\frac{t}{t_{1/2}}\right)} $	$0.354 = (0.5)^{(4.26/t_{1/2})}$ $\frac{\log 0.354}{\log 0.5} = \frac{4.26}{t_{1/2}}$	4.26*109(0.5)/10 9(0.354) 2.843452454
$t_{V_2} = ?$	$\frac{35.4}{100} = (0.5)^{(4.26/t)}_{1/2}$	$t_{\frac{1}{2}} = \frac{4.26 \times \log 0.5}{\log 0.354}$ $t_{\frac{1}{2}} = 2.84 \text{ ms}$	

Transmutation: - the reaction where one element is converted to another element by changing the number of protons.

Transuranium Elements: - elements that have been synthesized by nuclear transformation after the last natural element, uranium.

 $^{244}_{94}$ Pu + $^{48}_{20}$ Ca $\rightarrow ^{289}_{114}$ Uuq + 3 $^{1}_{0}$ n (Discovered in 1998 and $t_{1/2}$ = 30 seconds) Example:

Particle Accelerator: - a device that alternates electric field to speed up a particle to add into a target nuclide.

Cyclotron: - a type of particle accelerator that utilizes a changing electric field along with a magnetic a. field to increase the speed of an ion around a disc before hitting a target nuclide.



Schematic of Accelerated charged particle a Cyclotron to collide with target nuclide COMET: A medical superconducting cyclotron. It is used to generate thallium-201 (coronary arteries) and gallium-67 (soft-tissue tumors). It can also produce radiopharmaceutical needed for PET and SPECT scans

Unit 6: Thermochemistry and Nuclear Chemistry

b. <u>Linear Accelerator</u>: - a particle accelerator that speeds up a particle by using an alternating electric field at different segment of a linear tube to add an ion into a target nuclide.



Example 2: Balance the following nuclear equations.

a. $^{222}_{86}$ Rn produces an α particle.

- c. ${}^{49}_{21}$ Sc produces a β particle and a neutron. ${}^{49}_{21}$ Sc $\rightarrow {}^{48}_{22}$ Ti + ${}^{0}_{-1}$ e + ${}^{1}_{0}$ n A: 49 = (48) + (0) + (1) $Z: 21 = (22 \rightarrow \text{Ti}) + (-1) + (0)$
- d. ${}^{1}_{1}H$ reacts with ${}^{15}_{7}N$ to produce an α particle with γ ray.

$$\begin{array}{c} {}^{1}\mathrm{H} + {}^{15}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma \quad A: 1+15=(12)+(4)+(0) \\ Z: 1+7=(6\rightarrow\mathrm{C})+(2)+(0) \\ Z: 1+7=(6\rightarrow\mathrm{C})+(2)+(0) \\ Z: 1+7=(6\rightarrow\mathrm{C})+(2)+(0) \\ F. \quad {}^{239}_{94}\mathrm{Pu} + \underline{} \rightarrow {}^{242}_{96}\mathrm{Cm} + {}^{1}_{0}\mathrm{n} \\ A: 20=20+(0) \\ Z: 9=10+(-1) \\ Z: 9=10+(-1) \\ {}^{0}_{-1}e \\ {}^{20}_{9}\mathrm{F} \rightarrow {}^{20}_{10}\mathrm{Ne} + {}^{0}_{-1}e \\ {}^{239}_{94}\mathrm{Pu} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{242}_{96}\mathrm{Cm} + {}^{1}_{0}\mathrm{n} \\ {}^{239}_{94}\mathrm{Pu} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{242}_{96}\mathrm{Cm} + {}^{1}_{0}\mathrm{n} \end{array}$$

Assignment 28.2 pg. 851 #6, 8 and 10 and Worksheet: Isotopic Dating and Half Life

Page 146.

Copyrighted by Gabriel Tang B.Ed., B.Sc.

b. ${}^{14}_{6}$ C produces a β particle.

 ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e \quad A: 14 = (14) + (0)$ Z: 6 = (7 \rightarrow N) + (-1)

Worksheet: Isotopic Dating and Half-Life

- 1. Strontium-90 has a half-life of 28 years. How long will it take for all of the strontium-90 presently on earth to be reduced to 1/32 of its present amount?
- 2. The half life of plutonium-239 is 24,110 years. Of an original mass of 100 g, how much remains after 96,440 years?
- 3. The half life of thorium-227 is 18.72 days. How many days are required for only 1/8 of the original amount to be left?
- 4. The half-life of cesium-137 is 30 years. Of an initial 100 g sample, how much cesium-137 will remain after 300 years?
- 5. A 24.0 g sample of Ra-226 is supplied to a lab. It is predicted 9540 years later, only 0.375 g of Ra-226 will remain. What is the half-life of Ra-226?
- 6. Mercury -197 is used for kidney scans and has a half-life of 3 days. If the amount of mercury-197 needed for a study is 4.00 gram and the time allowed for shipment is 14 days, how much mercury-197 will need to be ordered?
- 7. If one million atoms of element-106 were prepared and after 12.33 seconds, only 75 atoms remains, what is the half-life of element-106?
- 8. Iodine -131 is to treat hyperthyroidism and it has a half-life of 8 days. If the amount of iodine-131 used was 50.0 mg on a patient, how much time must elapse before his iodine-131 level reaches 3.00 mg?
- 9. Uranium-235 is used in geological dating and it has a half-life of 4.5 billion years. If a piece of rock contains 2.00 mg of uranium-235 out of an estimated 3.20 mg as initial mass. How old is this rock?
- 10. A new element is found and it decayed to 15.3% of its original amount in 2.4 nanosecond. What is its half-life?
- 11. You are at a dinner party and your host brings out a bottle of brandy for which he paid a great deal of money because he was told that it was bottled in the time of Napoleon (1769-1821). Since you are a research chemist, you are asked if there is any way in which the age of the brandy can be determined. You assert that tritium (³H) dating is the way to do it. Ordinary water contains a very small amount of tritium that is formed in the earth's atmosphere by reactions involving cosmic rays. Tritium disintegrates by beta-emission at a rate equal to that at which it is formed. Water exposed to the atmosphere will contain a constant tritium content. Because brandy contains water, it should be possible to estimate its age. Since tritium in the bottle will not be replaced after it decays, the older the brandy, the lower its tritium content should be. You agree to test a sample of your host's brandy. You find that the sample has a tritium content of 3.25% of that of present-day water. How long ago was the brandy bottled if the half-life of tritium is 12.3 years?

Answers

1. 140 years	2. 6.25 g	3. 56.16 days	4. 0.09766 g	5. 1590 years
6. 102 g	7. 0.8998 seconds	8. 32.5 days	9. 3.2 billion years	10. 0.89 ns
11. 60.8 years				

28.3: Fission and Fusion of Atomic Nuclei

Nuclear Fission: - the breaking up of a heavier nucleus into two nuclei with small mass number.

Example: ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}^{1}_{0}\text{n}$ $\Delta H = 1.692 \times 10^{10} \text{ kJ}$

(See Animation at http://reactor.engr.wisc.edu/fission.htm)

- <u>Chain Reaction</u>: when the nuclear fission is self-sustaining.
- **a.** Subcritical: when there is on average, less than one neutron produced per $^{235}_{92}$ U consumed. The fission will eventually stop.
- **b.** Critical: when there is on average, exactly one neutron produced per $^{235}_{92}$ U consumed. The fission can then be self-sustaining at the same level.
- c. Supercritical: when there is one average, more than one neutron produced per $^{235}_{92}$ U consumed. The fission can increase its rate rapidly and a violent explosion can result.



<u>Nuclear Reactors</u>: - fission reactors where enriched $^{235}_{92}$ U is placed in the reactor core (nuclear core),

- **control rods (usually made of carbon to absorb extra neutrons)** can be lifted or lowered to control the rate of the fission process. As the water of the surrounding is heated, it transferred the heat to a steam generator to generate electricity via a steam turbine. The water is then cooled and recycled.
- the by-products of $^{235}_{92}$ U fission have a very long half-lives and can remain radioactive for a long time. Great efforts are needed to dispose of the wastes properly. The danger of a nuclear meltdown is also a constant danger as in the cases of Three Mile Island, Pennsylvania in 1979 and Chernobyl, Ukraine in 1986.





Bruce Power Nuclear Plant at Tiverton (Lake Huron), Canada

Nuclear Fusion: - the combining of two light nuclei into a heavier and more stable nucleus.

Example: ${}_{1}^{2}H + {}_{1}^{3}H \rightarrow {}_{2}^{4}He + {}_{0}^{1}n$

 $\Delta H = 1.698 \times 10^9 \text{ kJ}$

(See Animation at http://reactor.engr.wisc.edu/fission.htm)

- the availability of hydrogen isotopes, deuterium $\binom{2}{1}$ H) and tritium $\binom{3}{1}$ H), in sea water and the harmless product, $\frac{4}{2}$ He, makes nuclear fusion an environmental friendly alternative to generate power.
- however, fusion reactions such as the one above usually require initial temperature above 4×10^7 K to overcome the strong electrostatic repulsion between the two protons (the release of significant binding energy can only achieve when the distance between the two protons is approximately 10^{-15} m). High-powered laser and heating by electric currents are being studied as methods to attain this high temperature to initial a control fusion reaction.



European Tokamak Fusion Test Reactor Vacuum Vessel employs the design of a toroid with a super strength magnetic field to contain plasma without having it touch the wall of the reactor. A similar experimental fusion reactor can also be found at Princeton, USA.



Fusion reaction is the driving force of our sun's energy.

Relative Amounts of Energy Involved

Nuclear >> Chemical Reactions >> Physical Potential (Phase Changes) >> Kinetic (Temperature Change)

<u>Assignment</u> 28.3 pg. 856 #11 to 15

<u>Assignment</u>

Chapter 28 Review: pg. 864–865 #22 to 29, 34 to 36, 39, 41, 45 to 47 Unit 6 Review: pg. 325 #1 to 16; pg. 867 #1 to 6, 10 to 13

Copyrighted by Gabriel Tang B.Ed., B.Sc.

<u>Page 149.</u>