

Unit 5

Thermodynamics

I Can Statements

Listed below are the learning objectives that you will be taught. At the conclusion of each lesson, check one of the four boxes to indicate your level of understanding for each individual objective.

Unit 5 • Thermodynamics

Lesson 1: Energy

Introduction

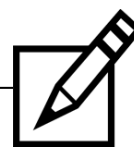
Essential Questions

Words to know

Key Concepts

Unit 5 • Thermodynamics

Lesson 1: Energy



Notes

Thermodynamics

Thermodynamics is the study of the relationships between _____ and the physical/chemical processes that causes these energy changes. For example when liquid water is heated it absorbs energy which causes water molecules to change their state from liquid to a gas. In chemistry we look closely at the relationships between _____ and _____. This is a very important concept and you must know it well.

Energy is defined as the ability to do _____ that is move a force through a distance or transfer _____. It is measured in _____.

$$\text{Energy (J)} = \text{force (N)} \times \text{distance (m)}$$

In thermodynamics it is important to understand the relationship between the system and the surroundings.

- **system** - all the chemicals that are involved (reactants and products) in a chemical reaction (the reacting mixture).
- **surroundings** - anything else in the universe which is not the reacting mixture, this includes the apparatus (e.g. test tube, thermometer), the experimenter, the medium in which the reaction goes on e.g. water, the universe.

Internal Energy

The internal energy of a system is made up of:

Kinetic energy (Thermal Energy)	Potential energy (Chemical Energy)
Kinetic energy components come from various types of motion at the molecular level:	Potential energy exists as a result of attractive or repulsive force acting on the particles within a system (Coulomb's Law).

Temperature

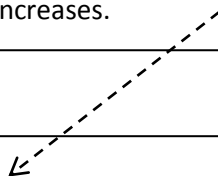
Temperature measures the average _____ of a system and is measured directly with a _____. In chemistry temperature measurements are either in degrees Celsius or in the absolute temperature scale (Kelvin).

$$K = ^\circ C + 273$$

The Kelvin scale is _____ to the _____. If the average kinetic energy doubles, the Kelvin temperature also doubles. At zero Kelvin the average kinetic energy is zero and all atoms and molecules have no _____.

Not every molecule or atom in a system has identical amounts of kinetic energy. Individual atoms and molecules that make up a system transfer kinetic energy between themselves as they interact with each other and their surroundings. The distribution of kinetic energy of a system is represented by a _____ distribution curve.

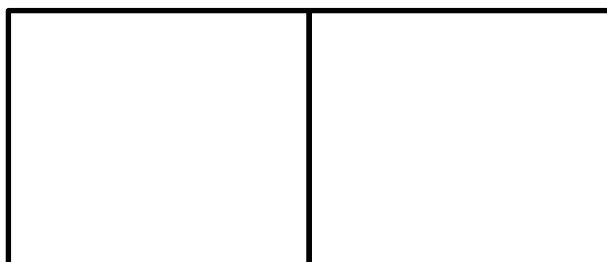
Maxwell Boltzmann distribution curve shows that the distribution of kinetic energies becomes greater (more disperse) as temperature increases.



Maxwell Boltzmann Distribution Curve for two different Temperatures

Heat Energy

Heat Energy (q) is defined as the spontaneous flow of _____ (thermal energy) from an object at a _____ temperature to one at a _____ temperature. Heat Energy (q) will continue to be _____ until the two objects have the same temperature or average kinetic energy.



If heat energy (q) is transferred from the system to the surroundings then the total internal energy of the system decreases. By convention if a system loses heat energy a _____ ($-q$) is indicated.



If heat energy (q) is absorbed by the system from the surroundings then the total internal energy of the system increases. By convention if the system absorbs heat energy a _____ ($+q$) is indicated.

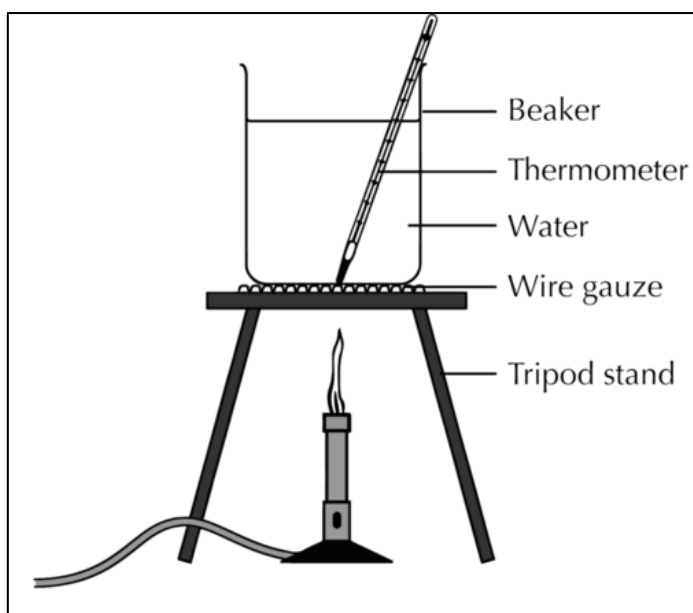
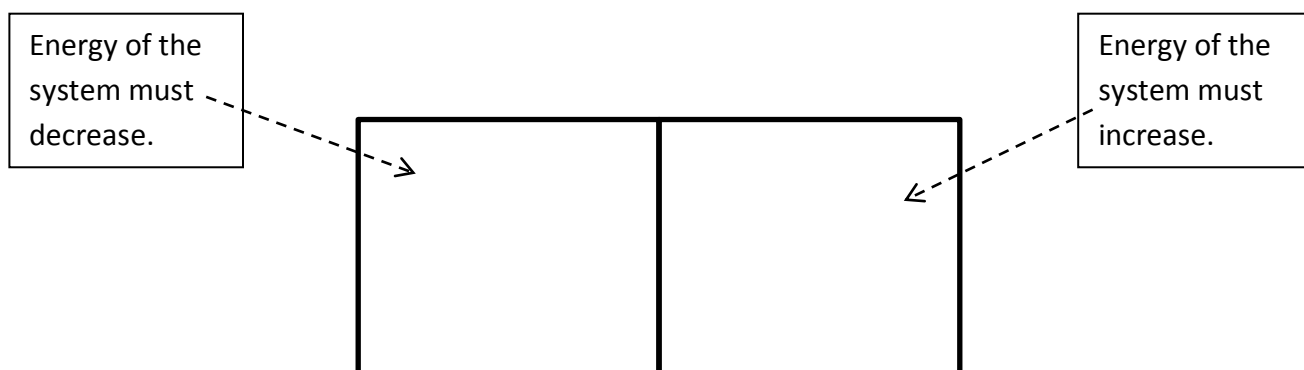


First Law of Thermodynamics

The First Law of Thermodynamics states that the total energy of the universe is _____. This simply means that energy is _____ during physical or chemical processes. This Law is also known as the Law of _____. Energy is neither created nor destroyed, but only transformed from one form to another.

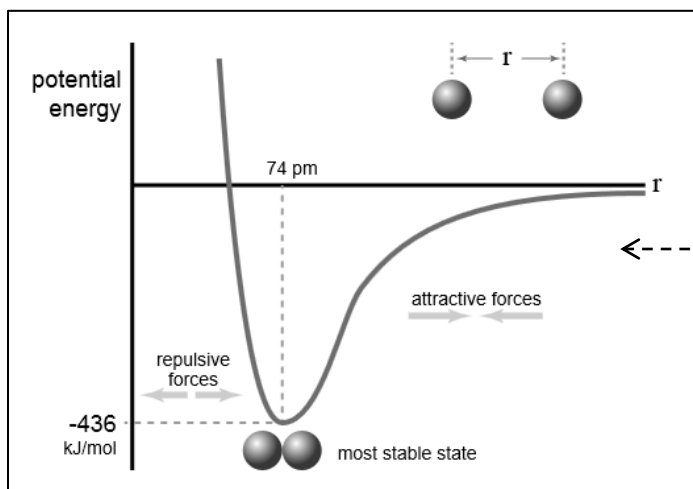
$$\Delta E_{\text{universe}} = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$$

When two systems come into contact with each other, the amount of heat energy that comes out of one system is _____ to the amount of heat energy that goes into the other system.



Enthalpy

Potential energy is stored in chemical bonds because of the electrostatic (Coulombic) attractions or repulsions between charge particles. The _____ the electrostatic attractions between charge particles the lower the potential energy and the more stable the system is.



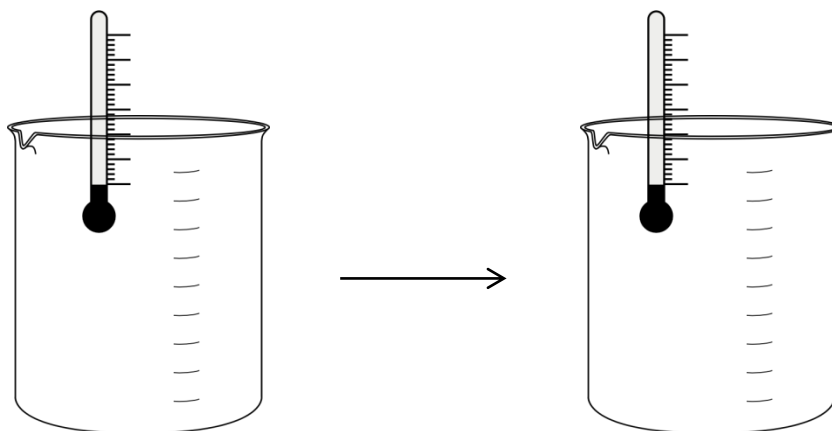
Since the bond-making process is an electrostatic one, it is governed by Coulomb's law. Distance between attractive charge particles plays a big part in the amount of potential energy between them. The optimal distance between charged particles that will result in the lowest potential energy state is called the bond length.

When the system is under _____ atmospheric pressure, the total potential energy in the bonds and intermolecular forces of the substances in the system is known as its **enthalpy, H**. The total _____ of the system cannot be measured, but what can be measured is the heat absorbed or released during a physical or chemical process (reaction), termed the change in enthalpy (ΔH). This means that for a reaction studied at constant pressure, the flow of heat is a measure of the _____ for the system. For this reason, the terms **heat of reaction** and **change in enthalpy** are used interchangeably for reactions studied at constant pressure.

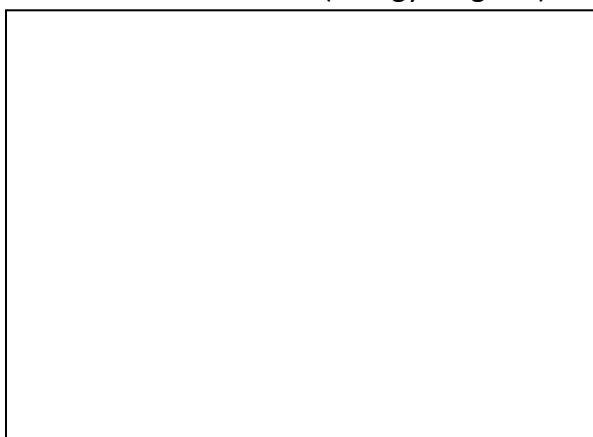
Exothermic and Endothermic Reactions

During a chemical reaction _____ is required to break the chemical bonds in the reactants, and energy is _____ when new bonds are formed in the products. As a result of bond breaking and bond forming there is a change in potential energy content or enthalpy of the system. The enthalpy change (ΔH) depends if the bonds in the products are stronger than the bonds in the reactants.

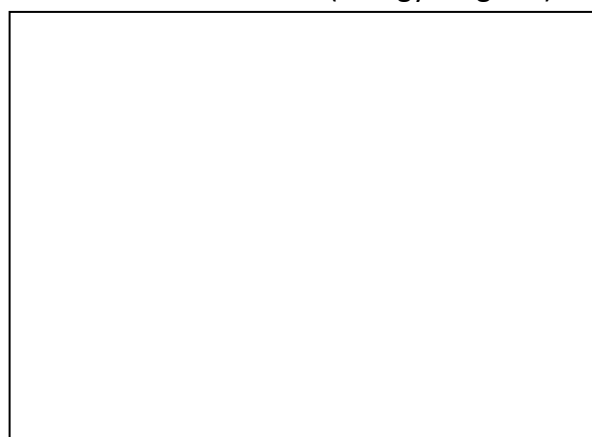
- **Exothermic** – A reaction is exothermic if the energy needed to break bonds is _____ than the energy released when new bonds are formed. This means _____ energy is released than needed. This excess energy goes to the surroundings as heat energy. This happens because the bonds within the reactant particles are _____ (at a higher potential energy level) than the bonds within the products. Exothermic reactions result in products being more _____ than the reactants and there will be an increase in temperature of the surroundings
- **Endothermic** – A reaction is endothermic if the energy needed to break bonds is _____ than the energy released when new bonds are formed. This means that heat energy is _____ by the system from the surroundings. This happens because the bonds within the reactant particles are _____ (at a lower potential energy level) than the bonds within the products. Endothermic reactions result in products being less stable than the reactants and there will be a decrease in temperature of the surroundings.



Endothermic Reaction (Energy Diagram)

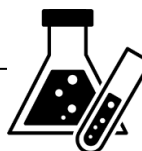


Exothermic Reaction (Energy Diagram)



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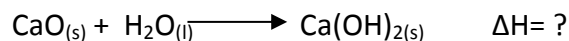
Chemistry Demo



Chemistry Demo

The Chef Demo Questions

The reaction between calcium oxide and water is as follows:



1. Record all of your observations here.
2. Is this chemical reaction endothermic or exothermic? Explain why?
3. What is the chemical explanation for the increase in temperature associated with this reaction in terms of the chemical reaction and the change in internal energy of the reactants and products?
4. Draw an energy level diagram for this reaction

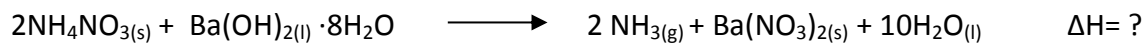
5. Are the reactants or products more stable? Explain your reasoning.

6. Use the following table to calculate the heat of reaction.

Chemical	Heat of Formation (KJ/mole)	Standard Entropy (J/K·mole)	Molar Mass
CaO _(s)	-635.1	40	56.08
Ca(OH) _{2(s)}	-986.1	83	74.10
Ca(OH) _{2(aq)}	-1002.8		74.10
H ₂ O _(l)	-285.8	70	18.02

7. The reaction took place at room temperature. Would this reaction be spontaneous at much higher temperatures? Explain your reasoning.

Frozen Demo Questions



1. Record all of your observations here.

2. Is this chemical reaction endothermic or exothermic? Explain why?
3. What is the chemical explanation for the increase in temperature associated with this reaction in terms of the chemical reaction and the change in internal energy of the reactants and products?
4. Draw an energy level diagram for this reaction
5. Are the reactants or products more stable? Explain your reasoning.
6. The reaction took place at room temperature. Would this reaction be spontaneous at much higher temperatures? Explain your reasoning.

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Lesson 1: Calorimetry

Introduction

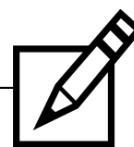
Essential Questions

Words to know

Key Concepts

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Lesson 2: Calorimetry



Notes

Specific Heat Capacity (c_p)

Specific Heat – Specific heat capacity is most easily thought of as the heat (energy) required _____ the temperature of _____ of a substance by _____ degree Celsius. Metals have relatively low specific heats, indicating that relatively less energy is required to raise their temperatures. By comparison, water has a relatively high specific heat, so will require much more energy to achieve a similar temperature change.

$$\text{Specific Heat Capacity } (C_p) = \frac{\text{Quantity of heat supplied}}{(\text{Mass of object})(\text{Temperature change})}$$

The amount of heat transferred from can be calculated using this equation

$$q = (m)(c)(\Delta T)$$

where q = heat transferred

m = mass of substance

c = specific heat capacity

$\Delta T = T_{\text{final}} - T_{\text{initial}}$ = change in temperature

Table of Specific Heat of various substances

Substance	Specific Heat (J/g ·°K)
Water	4.18
Aluminum	.902
Copper	.385
Iron	.444
Brass	.380
Tin	.210
Glass	.840

Calorimetry

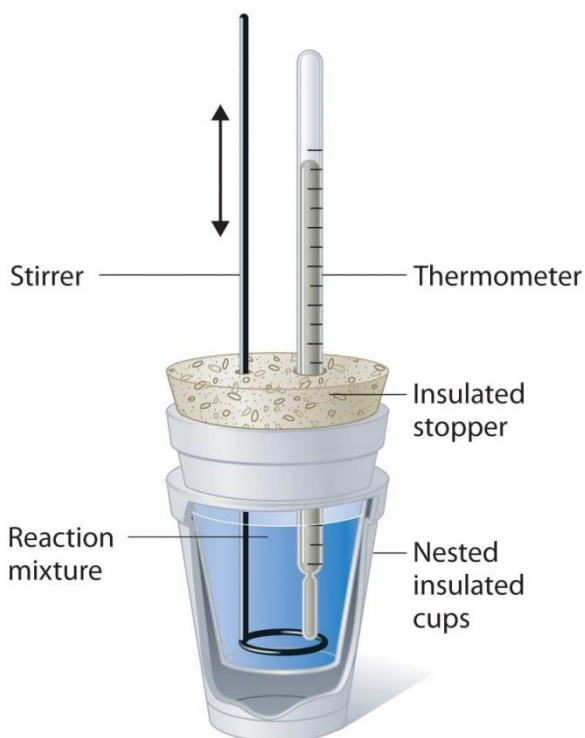
Calorimetry is an experimental _____ used to measure the change in _____ of a chemical reaction or phase change.

- General principles: Put a chemical reaction or phase change in contact with a _____ bath. We can measure the _____ in temperature of the heat bath. Knowing the heat capacity of the heat bath, you can calculate the energy change in the heat bath by applying :

$$q = (m)(c)(\Delta T)$$

The energy change in the water bath will be the _____ magnitude in energy as the chemical reaction or phase change, just with the _____. If the water bath gains energy, its temperature goes _____, meaning the energy of the chemical reaction or phase change went down (it lost energy) and vice versa.

- Coffee cup calorimeter – Styrofoam _____ are commonly used as insulators in the high school chemistry lab, to measure temperature changes without a loss of energy to the surroundings.



- When solving calorimetry problems there are **three steps** that you should calculate.

1. Determine the amount of heat gained by the water bath using the following equation:

$$q = (m)(c)(\Delta T)$$

2. Determine the heat of reaction by changing the sign of the calculated amount of heat gained by the water. This can be done because of the first law of thermodynamics.

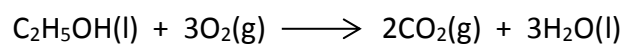
$$+q_{\text{water}} = -q_{\text{rxn}}$$

3. Calculate the enthalpy change of the reaction (ΔH_{rxn}) in kJ/mol.

Solving Calorimetry Problem

1. Heat of Combustion(ΔH_c)

A student used a simple calorimeter to determine the enthalpy change for the combustion of ethanol.



When 0.690 g (0.015 mol) of ethanol was burned it produced a temperature rise of 13.2 K in 250 g of water Calculate ΔH for the reaction.

2. Heat of Solution (ΔH_{sol})

50.0 cm³ of 1.00 mol dm⁻³ (M) hydrochloric acid solution was added to 50.0 cm³ of 1.00 mol dm⁻³ (M) sodium hydroxide solution in a Styrofoam cup. The initial temperature of both solutions was 16.7 °C. After stirring and accounting for heat loss the highest temperature reached was 23.5 °C. Calculate the enthalpy change for this reaction.

3. A 30 g sample water at 280 K is mixed with 50.0g of water at 330 K. Calculate the final temperature of the mixture assuming no heat is loss to the surroundings. Remember that the heat gained by the cooler water is equal to the heat lost by the warmer water.

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Lesson 3: Bond Enthalpies



Notes

Bond Enthalpies

The process in breaking chemical bonds is _____. Energy is required to break chemical bonds. The bond enthalpy is the energy needed to break one mole of bonds in _____ molecules under standard conditions. It is important to learn the definition of bond enthalpy. A common error is to fail to indicate that all species have to be in the gaseous state.

Average bond Enthalpies (kJ/mole)

Single Bonds

C—H	413	N—H	391	O—H	463	F—F	155
C—C	348	N—N	163	O—O	146		
C—N	293	N—O	201	O—F	190	Cl—F	253
C—O	358	N—F	272	O—Cl	203	Cl—Cl	242
C—F	485	N—Cl	200	O—I	234		
C—Cl	328	N—Br	243			Br—F	237
C—Br	276			S—H	339	Br—Cl	218
C—I	240	H—H	436	S—F	327	Br—Br	193
C—S	259	H—F	567	S—Cl	253		
		H—Cl	431	S—Br	218	I—Cl	208
Si—H	323	H—Br	366	S—S	266	I—Br	175
Si—Si	226	H—I	299			I—I	151
Si—C	301						
Si—O	368						
Si—Cl	464						

Multiple Bonds

C=C	614	N=N	418	O ₂	495
C≡C	839	N≡N	941		
C=N	615	N=O	607	S=O	523
C≡N	891			S=S	418
C=O	799				
C≡O	1072				

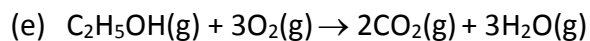
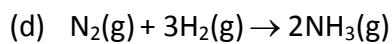
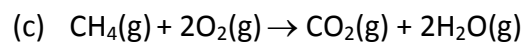
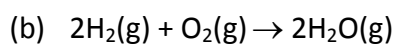
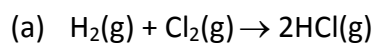
The process of making bonds is _____. Energy is released when a bond is formed. The _____ amount of energy _____ to break a bond is also released when a bond is formed. Bond making involves bringing atoms together which are attracted by an electrostatic force of _____. This process decreases the enthalpy of the reaction.

Bond enthalpies can be used to calculate the enthalpy change ($\Delta H^\circ_{\text{rxn}}$) for a reaction by using the following equation:

$$\Delta H^\circ_{\text{rxn}} = \sum \Delta H^\circ_{\text{Bonds Broken}} - \sum \Delta H^\circ_{\text{Bonds Formed}}$$

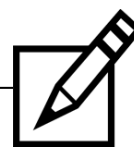
Solving Bond Enthalpy Problem

1. Calculate the enthalpy change for these reactions using bond enthalpies.



Unit 5 • Thermodynamics

Lesson 4: Hess's Law



Notes

Standard Conditions for Enthalpy Changes (ΔH°)

The enthalpy change (ΔH) for a reaction depends on the _____ under which the reaction occurs. In many reactions these conditions take place under _____. Standard conditions for enthalpy changes (ΔH°) are listed below:

The standard conditions for enthalpy changes are:

- A Temperature of _____
- A Pressure of _____
- Concentrations of _____ for all solutions
- All the substances in their _____ states.

Standard Enthalpy of Formation

The standard enthalpy of formation of a substance is the enthalpy change that occurs when one mole of the substance is formed from its elements in their standard states under standard conditions.



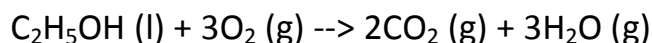
The standard enthalpy change of formation for an element $\Delta H^\circ_{\text{form}} = 0$. There is no chemical change and so no enthalpy change when an element is formed from itself.

Write the standard enthalpy of formation reaction for ethanol ($\text{C}_2\text{H}_5\text{OH}$) in the box below. The enthalpy of formation value for ethanol is $\Delta H^\circ_f = -278 \text{ kJ/mol}$

Standard enthalpy change of formation values can be used to calculate the standard enthalpy change of any reaction. This can be done by using the following equation:

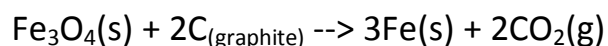
$$\Delta H^{\circ}_{\text{rxn}} = \Sigma \Delta H^{\circ}_{\text{f}}(\text{products}) - \Sigma \Delta H^{\circ}_{\text{f}}(\text{reactants})$$

For example we can determine the standard enthalpy change for the combustion of ethanol by using the following standard enthalpy of formation values:



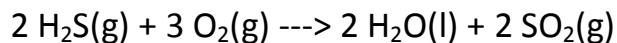
	$\Delta H^{\circ}_{\text{f}}/\text{kJ/mol}$
$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-278
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{g})$	-286

We can also determine the standard enthalpy change ($\Delta H^{\circ}_{\text{rxn}}$) for the following reaction:



	$\Delta H^{\circ}_{\text{f}}/\text{kJ/mol}$
$\text{Fe}_3\text{O}_4(\text{s})$	-1118
$\text{CO}_2(\text{g})$	-394

Let's do one more practice problem. Determine the standard enthalpy change ($\Delta H^{\circ}_{\text{rxn}}$) for the following reaction:



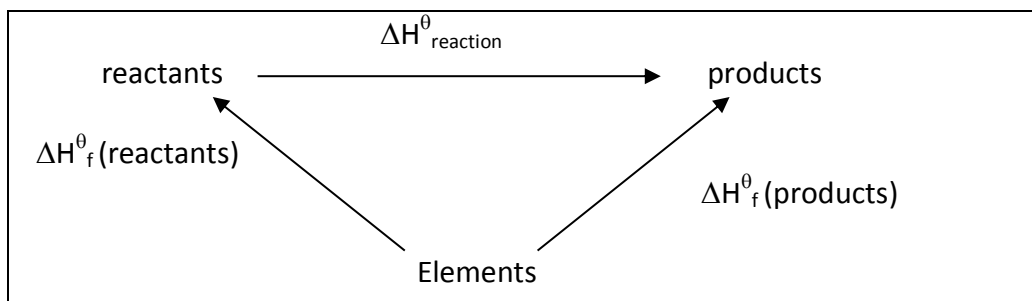
	$\Delta H^{\circ}_{\text{f}}/\text{kJ/mol}$
$\text{H}_2\text{S}(\text{g})$	-20
$\text{SO}_2(\text{g})$	-296
$\text{H}_2\text{O}(\text{g})$	-286

Hess's Law

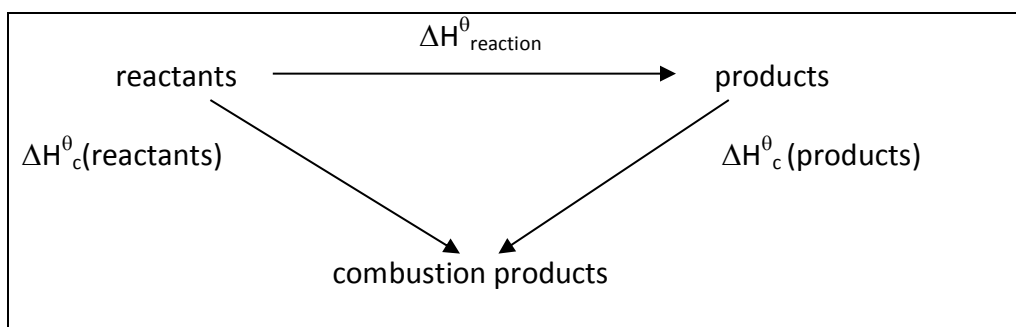
Hess's Law states that the enthalpy change for any chemical change is independent of the route, provided the starting conditions and final conditions, and reactants and products, are the same.

Enthalpy Cycles

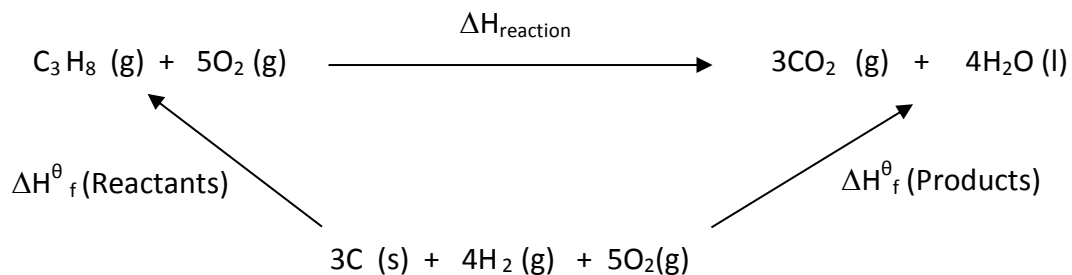
Example 1: using enthalpies of formation, ΔH_f^θ



Example 2: using enthalpies of combustion, ΔH_c^θ



Here is a real example of an Enthalpy Cycle:

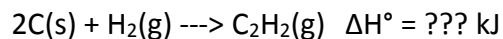


$$\Delta H_{\text{reaction}}^\theta = \Delta H_f^\theta(\text{Products}) - \Delta H_f^\theta(\text{Reactants}) = -2324.1 \text{ kJ} - (-105 \text{ kJ}) = -2219.1 \text{ kJ}$$

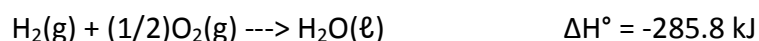
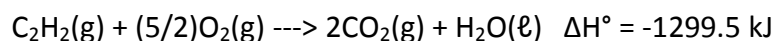
Drawing of cycles becomes very difficult when more than 2 equations are involved. Vertical addition of equations is the best method although you could still be asked to draw enthalpy/energy cycle diagrams.

Vertical addition using Hess's Law is not overly difficult but does require some practice. Let do a few practice problems together.

Example #1: Calculate the enthalpy for this reaction:

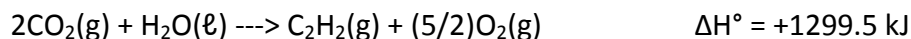


Given the following thermochemical equations:



1) Determine what we must do to the three given equations to get our target equation:

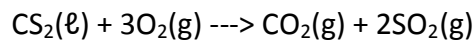
2) Rewrite all three equations with changes applied:



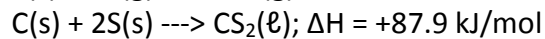
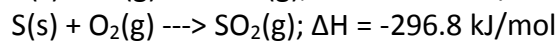
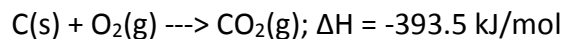
3) Examine what cancels:

4) Add up ΔH values for our answer:

Example #2: Calculate the enthalpy of the following chemical reaction:

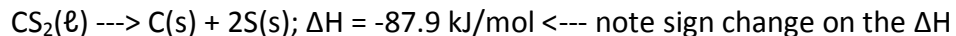
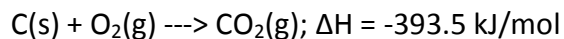


Given:



1) Determine what we must do to the three given equations to get our target equation:

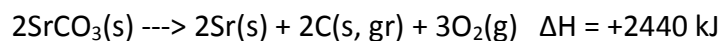
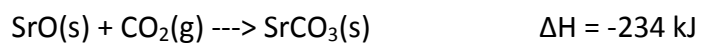
2) Rewrite all three equations with changes applied:



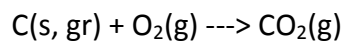
3) Examine what cancels:

4) Add up ΔH values for our answer:

Example #3: Given the following data:



Find the ΔH of the following reaction:



1) Determine what we must do to the three given equations to get our target equation:

2) Rewrite all three equations with changes applied:



3) Examine what cancels:

4) Add up ΔH values for our answer:

