

CHAPTER 5
THERMOCHEMISTRY

5

TABLES

~Bond Energy

~Bond Length

Bond Energies (kJ/mol)

Bond	Bond Energy	Bond	Bond Energy	Bond	Bond Energy
H-H	436	C-S	260	F-Cl	255
H-C	415	C-Cl	330	F-Br	235
H-N	390	C-Br	275	Si-Si	230
H-O	464	C-I	240	Si-P	215
H-F	569	N-N	160	Si-S	225
H-Si	395	N = N	418	Si-Cl	359
H-P	320	N \equiv N	946	Si-Br	290

Table 7.2

Bond Energies (kJ/mol)

Bond	Bond Energy	Bond	Bond Energy	Bond	Bond Energy
H-S	340	N-O	200	Si-I	215
H-Cl	432	N-F	270	P-P	215
H-Br	370	N-P	210	P-S	230
H-I	295	N-Cl	200	P-Cl	330
C-C	345	N-Br	245	P-Br	270
C = C	611	O-O	140	P-I	215
C \equiv C	837	O = O	498	S-S	215
C-N	290	O-F	160	S-Cl	250
C = N	615	O-Si	370	S-Br	215
C \equiv N	891	O-P	350	Cl-Cl	243
C-O	350	O-Cl	205	Cl-Br	220
C = O	741	O-I	200	Cl-I	210
C \equiv O	1080	F-F	160	Br-Br	190
C-F	439	F-Si	540	Br-I	180
C-Si	360	F-P	489	I-I	150
C-P	265	F-S	285		

Table 7.2

Average Bond Lengths and Bond Energies for Some Common Bonds

Bond	Bond Length (Å)	Bond Energy (kJ/mol)
C-C	1.54	345
C = C	1.34	611
C \equiv C	1.20	837
C-N	1.43	290
C = N	1.38	615
C \equiv N	1.16	891
C-O	1.43	350
C = O	1.23	741
C \equiv O	1.13	1080

Table 7.3

CHAPTER 5 THERMOCHEMISTRY

Energy Basics [5.1]

- Thermochemistry -- aka Chemical Thermodynamics -- heat & energy flow
- Chemistry is the study of matter: it's properties, interactions, reactions, and ENERGY CHANGES.
- ΔE occurs with almost every chemical, physical, or nuclear change

Energy

KE: from VRT — temperature

PE: from IMF [5.3] — attraction/repulsion

$$E = q + w$$

energy = heat + work

TWO TYPES

- Kinetic — motion
- Potential — position

1st LAW (Conservations of Energy) — in a chemical reaction or physical change, energy can be neither created nor destroyed.

Thermal Energy, Temperature, and Heat

THERMAL ENERGY MANIFESTS as three types of molecular/atomic motion:

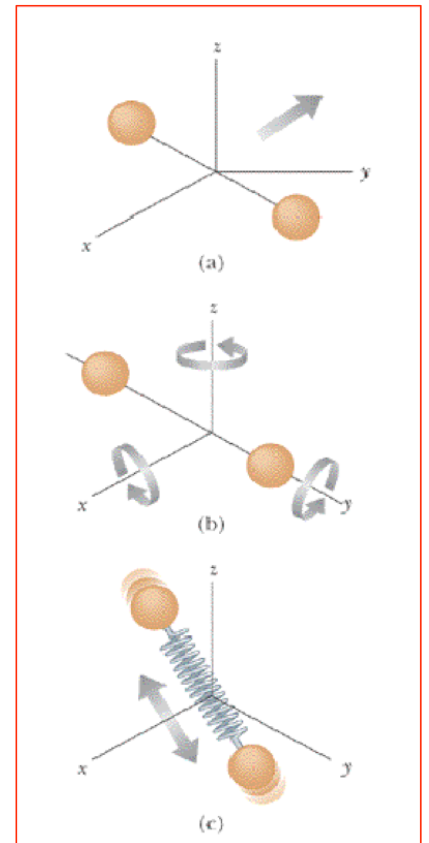
- ① Vibrational
- ② Rotational
- ③ Translational

RELATIONSHIP: TEMPERATURE AND MOTION

- ➔ $T \propto$ amount of motions ➔ more motion = higher temp
- ➔ $T \propto$ KE(AVERAGE)

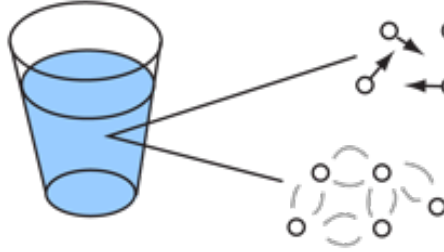
RELATIONSHIP: MATTER AND MOTION

- Gas – motion such that molecules cannot interact
- Liquid – motion such that molecules can interact somewhat
- solid – motion such that molecules interact significantly



Does a glass of water sitting on a table have any energy?

No apparent energy of the glass of water on a macroscopic scale.



KE (VRT)

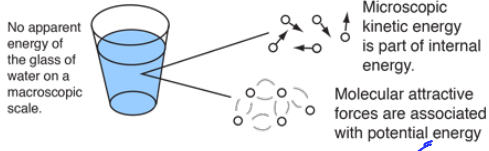
Microscopic kinetic energy is part of internal energy.

Molecular attractive forces are associated with potential energy

PE (bonding)

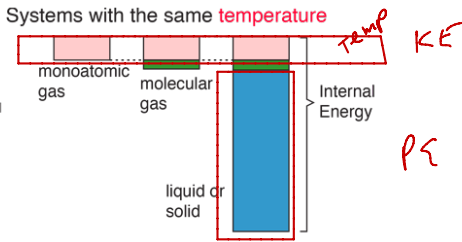
<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

Does a glass of water sitting on a table have any energy?

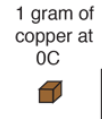


UKT

PE



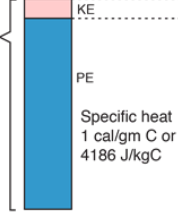
What is the same and what is different?



The internal energy is not the same.

The same temperature implies that the average molecular kinetic energy is the same*

Why is the specific heat of water more than 10 times that of copper?!



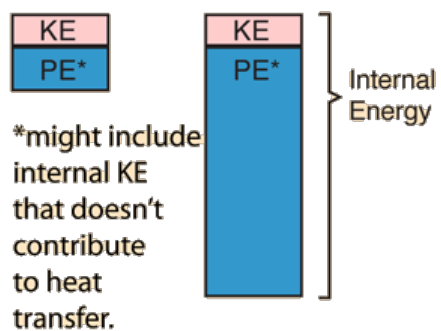
Specific heat 0.092 cal/gm C or 386 J/kgC

Specific heats are not the same.

* More precisely, the translational kinetic energies are the same. The rotational and vibrational kinetic energies are neglected in this simplified illustration.

SPECIAL EXAM

Temperature is not directly proportional to internal energy since temperature measures only the kinetic energy part of the internal energy, so two objects with the same temperature do not in general have the same internal energy



<http://chemsite.lsrhs.net/chemKinetics/PotentialEnergy.html>

Chemical Potential Energy

A chemical bond can be thought of as an attractive force between atoms.

Because of this, atoms and molecules can have chemical potential energy.

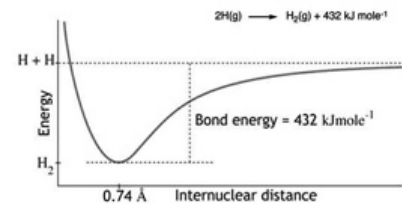
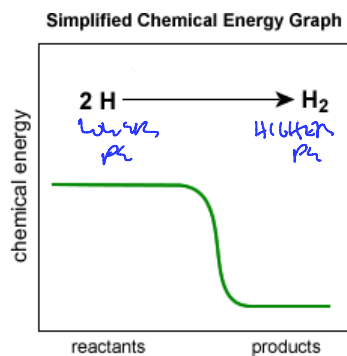
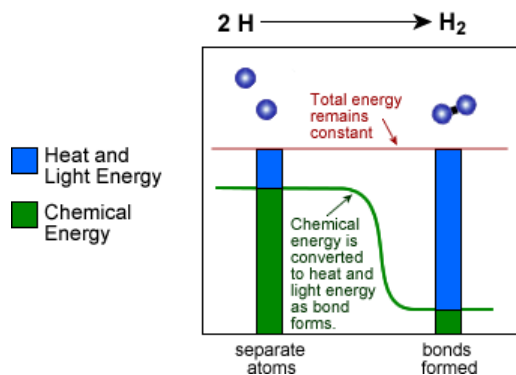
Anytime two atoms form a strong covalent or ionic bond or two molecules form a weak van der Waals bond, chemical energy is converted into other forms of energy, usually in the form of heat and light.

→ The amount of energy in a bond is somewhat counterintuitive - the stronger or more stable the bond, the less chemical energy there is between the bonded atoms.

Strong bonds have low chemical energy and weak bonds have high chemical energy.

Lot's of heat and/or light energy is released when very strong bonds form, because much of the chemical energy is converted to heat and/or light energy. The reverse is true for breaking chemical bonds. It takes more energy to break a strong bond than a weak bond. The breaking of a bond requires the absorption of heat and/or light energy which is converted into chemical energy when the bond is broken.

See an example below of how a chemical reaction converts chemical energy into heat and light energy:

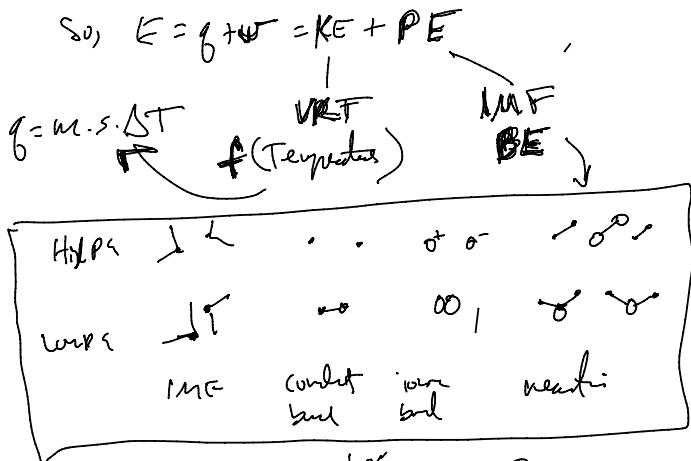


<http://chemsite.isrhs.net/chemKinetics/PotentialEnergy.html>

An increase in the enthalpy $H = U + PV$ might be associated with an increase in internal energy which could be measured by calorimetry, or with work done by the system, or a combination of the two.

The internal energy U might be thought of as the energy required to create a system in the absence of changes in temperature or volume.

But if the process changes the volume, as in a chemical reaction which produces a gaseous product, then work must be done to produce the change in volume. For a constant pressure process the work you must do to produce a volume change ΔV is $P\Delta V$. Then the term PV can be interpreted as the work you must do to "create room" for the system if you presume it started at zero volume.



$Q = \Delta U + P\Delta V$

$\Delta H = \Delta U + P\Delta V$ (As a result)

$Q = \Delta H_p$

with or s, i

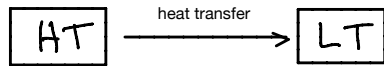
instead PΔV work

to / Am to / by

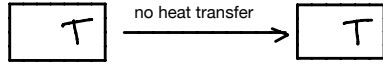
↑ ASIDE ↑

Heat

- HEAT (q), or heat flow, is the transfer of thermal energy between two bodies at different temperatures.

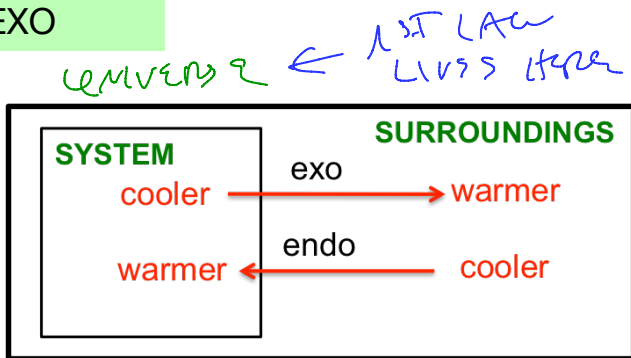


- THERMAL EQUILIBRIUM -- both substances are at the same temperature, and their molecules have the same average kinetic energy.



@ equil: $KE(\text{object 1}) = KE(\text{object 2})$

ENDO vs. EXO



$$\text{SYS} + \text{SURR} = \text{UNIVERSE}$$

Units of Measure

- A calorie is the amount of energy required to raise one gram of water by 1 degree C (1 kelvin).
- The Calorie (with a capital C), is commonly used in quantifying food energy content,
 - ↳ is a kilocalorie.
 - ↳ is also known as a “large calorie”, or “food calorie,”
 - ↳ for example, an apple contains about 90 Cal (which is 90 Kcal, or 90,000 cal)
- The SI unit of heat, work, and energy is the joule.
 - ↳ A joule (J) is the amount of energy used when a force of 1 newton moves an object 1 meter.
 - ↳ One joule is equivalent to $1 \text{ kg m}^2 / \text{s}^2$, which is also called 1 newton-meter.
- 1 calorie is equal to 4.184 joules.
- Two useful conversion factors:

$$\left(\frac{4.184 \text{ J}}{\text{cal}} \right)$$

$$\left(\frac{1000 \text{ cal}}{\text{C}} \right)$$

Heat Capacity vs. Specific Heat

HEAT CAPACITY

- [def] the amt of heat absorbed or released when undergoing a temperature change
- Extensive property (dependent on AMOUNT of material present)

$$C = \frac{q}{\Delta T} \left(\frac{J}{^{\circ}C} \right) \quad \text{Heat Capacity (C)}$$

SPECIFIC HEAT CAPACITY ("SPECIFIC HEAT")

- [def] the amt of heat needed to raise 1 g of material 1°C (or K)
- Intensive property (depends on the KIND material present)

$$c = \frac{q}{m\Delta T} \left(\frac{J}{g^{\circ}C} \right)$$

Specific heat capacity (c)



MISC VALUES

- 4.148 – water
- 2.093 – ice
- 1.864 – steam
- 1.007 – air
- 0.897 – Al
- 0.449 – Fe
- 0.385 – Cu
- 0.130 – Pb
- 0.129 – Au

Heat calculations

$$q = m s \Delta T \quad (J)$$

how much \downarrow \downarrow *how far*
how hard \downarrow

$$Q = m s (T_f - T_i)$$

(EX) Calculate Heat for Given Temperature Change

How much heat, in J, is needed to raise 205 g of water from 21.2 °C to 94.4 °C?

[ex 1-20; w10]

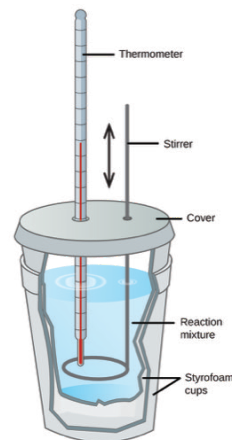
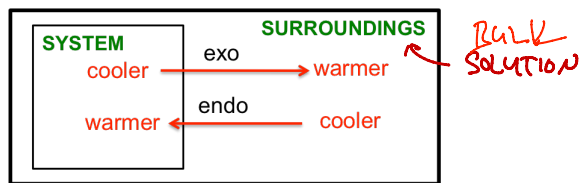
$$\begin{aligned}
 ? J &= \frac{205 \text{ g}}{1} \cdot \frac{4.18 \text{ J}}{1 \text{ g} \cdot ^\circ\text{C}} \cdot \frac{73.2^\circ\text{C}}{1} = 6.02 \times 10^4 \text{ J} \\
 &\quad \cdot \frac{1 \text{ kJ}}{1000 \text{ J}} = 6.02 \text{ kJ}
 \end{aligned}$$

three \swarrow (pointing to 73.2)
 $q = m$ s ΔT

Calorimetry [5.2]

CALORIMETRY — “calor” = heat; metry = “measure”

Calorimeter -- device to measure Q chg



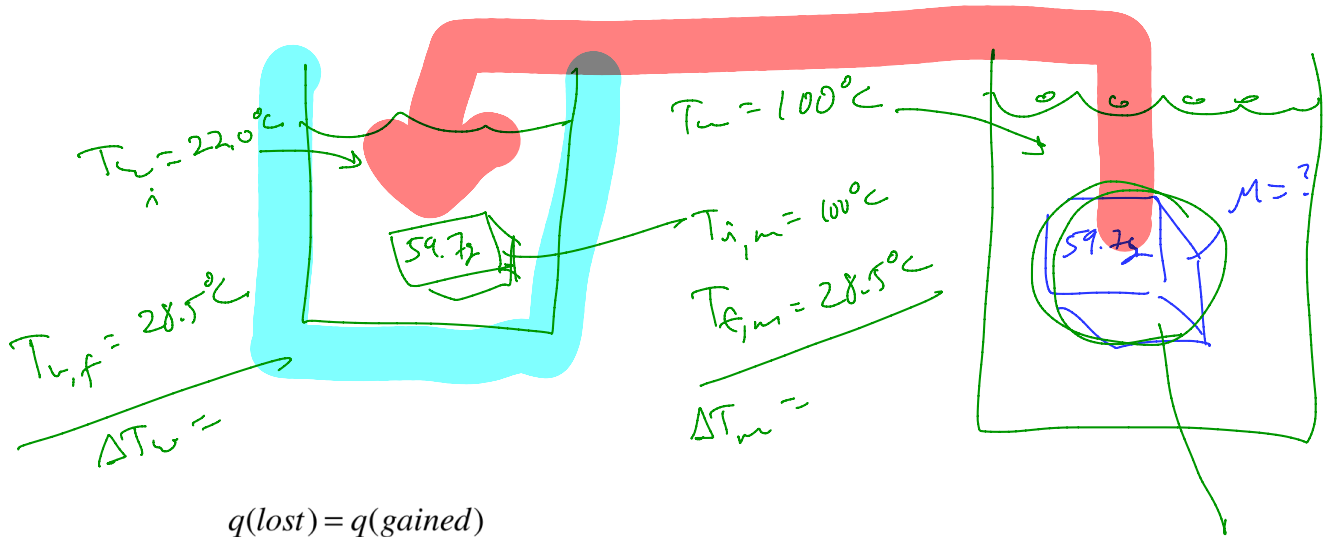
Fundamental Calorimetry Equations

(A) $q(\text{in}) = q(\text{out})$
 $q(\text{lost}) = q(\text{gained})$
 $\Sigma q_{(\text{items that LOSE heat})} = \Sigma q_{(\text{items that GAIN heat})}$

(B) **AT EQUILIBRIUM**
 $q(\text{hot item}) + q(\text{cold item}) = 0$
 $q(\text{hot item}) = -q(\text{cold item})$

(EX) ID Metal via Calorimetry [ex 5.4]

A 59.7 g piece of metal that had been submerged in boiling water was quickly transferred into 60.0 mL of water initially at 22.0 °C. The final temperature is 28.5 °C. Use these data to determine the specific heat of the metal. Use this result to ID the metal?



$$q(\text{lost}) = q(\text{gained})$$

$$q(\text{lost by metal}) = -q(\text{gained by water})$$

$$m_M s_M \Delta T_M = m_W s_W \Delta T_W$$

$$s_M = \frac{m_W s_W \Delta T_W}{m_M \Delta T_M} = \frac{60.0 \text{ g } 4.184 \text{ J/g}^\circ\text{C} (28.5^\circ\text{C} - 22.0^\circ\text{C})}{59.7 \text{ g } (28.5^\circ\text{C} - 100.0^\circ\text{C})}$$

$$s_M = 0.35 \text{ J/g}^\circ\text{C}$$

→ this value is very probably copper

$$q = m \cdot s \cdot \Delta T$$

Thu, Oct 10

(EX) Calc heat produced by RXN [ex 5.5b]

When 100. mL of 0.200 M NaCl(aq) and 100. mL of 0.200 M AgNO₃(aq), both at 21.9 °C, are mixed in a coffee cup calorimeter, the temperature increases to 23.5 °C as solid AgCl forms. How much heat is produced by this precipitation reaction? What assumptions did you make to determine your value?

Ⓐ $\frac{100. \text{ mL} \times 0.200 \text{ mol/L}}{\text{L}}$

Ⓑ $\frac{100. \text{ mL} \times 0.200 \text{ mol/L}}{\text{L}}$



$S_{\text{soln}} = S_{\text{w}} = \frac{4.184 \text{ J}}{\text{g} \cdot \text{C}}$
 $m_{\text{soln}} = 200$
 $q = m \cdot S \cdot \Delta T$ (circled in red)

$q_{\text{lost}} = -q_{\text{GAIN}}$

$q_{\text{rxn}} = -q_{\text{soln}}$

$q_{\text{rxn}} = -q_{\text{lost}}$

$q_{\text{rxn}} = q_{\text{soln}}$ (circled in red)

$q_{\text{rxn}} = m \cdot S \cdot \Delta T$

MULTI EQ

- VAPOR
- CUP MASS
- CUP CAL

- 100 mL
- ① (M) + vol
 - ② ~~ST~~ ST



(EX) Calc heat produced by RXN [ex 5.5b]

¿When 100. mL of 0.200 M NaCl(aq) and 100. mL of 0.200 M AgNO₃(aq), both at 21.9 °C, are mixed in a coffee cup calorimeter, the temperature increases to 23.5 °C as solid AgCl forms. How much heat is produced by this precipitation reaction? What assumptions did you make to determine your value?

$$q(\text{lost}) = q(\text{gained})$$

$$q(\text{lost by chemical rxn}) = -[q(\text{gained by solution}) + q(\text{gained by calorimeter})]$$

-> assume no heat absorbed by calorimeter

$$q(\text{rxn}) = q(\text{solution})$$

-> assume solution has same specific heat as water

-> assume solution has same density as water

$$q(\text{rxn}) = ms\Delta T = \frac{(100\text{g} + 100\text{g}) 4.184\text{J} (23.5 - 21.9^\circ\text{C})}{\text{g}^\circ\text{C}}$$

$$q(\text{rxn}) = 1338\text{J} \Rightarrow 1340\text{J}$$

Bomb Calorimetry

↳ SEALED... used to det'n Heats of Reaction

↳ can produce large pressure, hence the term "bomb"

(EX) Calc heat of combustion [ex 5.7b]

¿When 0.963 g of benzene, C_6H_6 , is burned in a bomb calorimeter, the temperature of the calorimeter increases by $8.39^\circ C$. The bomb has a heat capacity of $784 J/^\circ C$ and is submerged in 925 mL of water. How much heat was produced by the combustion of the glucose sample?

ΔT

$$C = \left(\frac{784 J}{1^\circ C} \right)$$

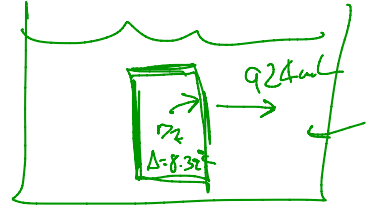
benzene

$d =$
 \downarrow
 $925g$

$q = m \cdot s \cdot \Delta T$

$q_{lost} = q_{gained}$

$q_{rxn} = q_{soln} = q_{cal} + q_{water}$
 $= C \Delta T + m \cdot s \cdot \Delta T$



$q_{(lost)} = q_{(gained)}$

$q_{(lost \text{ by chemical rxn})} = -[q_{(gained \text{ by solution})} + q_{(gained \text{ by calorimeter})}]$

-> assume solution has same specific heat as water

-> assume solution has same density as water

$$q_{(rxn)} = ms \Delta T = \left[\frac{925 g \cdot 4.184 J}{g^\circ C} \cdot 8.39^\circ C \right] + \left[\frac{784 J}{^\circ C} \cdot 8.39^\circ C \right]$$

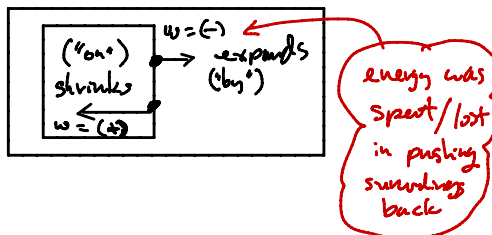
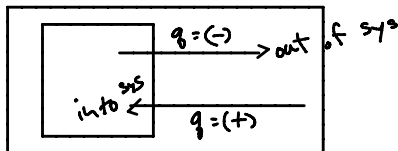
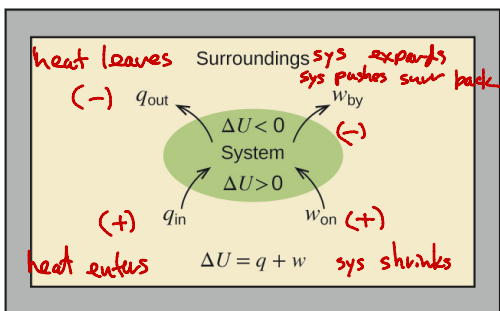
$q_{(rxn)} = 39,048 J \Rightarrow 39.0 kJ$

Enthalpy [5.3]

CHEMICAL THERMODYNAMICS – deals with HEAT–WORK–OTHER ΔE in relation to chemical and physical phenomena

1st Law of Thermodynamics – Internal Energy

$\hookrightarrow \Sigma (\text{matter} + \text{energy}) = k$ ← universe
 $\hookrightarrow \text{Heat/Energy Lost} = \text{Heat/Energy Gained}$ ← SYS v. SURR
 $\hookrightarrow \Delta U = q + w$



- positive q is heat flow in; negative q is heat flow out
- positive w if work is done on the system; and negative w if work is done by the system.

Enthalpy (Heat under constant pressure conditions)

$$H = U + PV \quad \leftarrow \text{arbitrary Def.}$$

can't measure H directly, \downarrow but can measure difference

$$\Delta H = \Delta U + P\Delta V + V\Delta P$$

@ constant pressure \downarrow $\Delta P \rightarrow 0$ or $P = k$

$$\Delta H = \Delta U + P\Delta V$$

$$P\Delta V = -w$$

ΔV and w are opposite signs, by def.
if $\Delta U_{\text{sys}} = (+)$, then sys expands,
then sys does work on surr, then $w = (-)$

$$\Delta H = \Delta u + P\Delta V \quad \leftarrow \text{expansion work}$$
$$= (q_p + w) + (-w)$$

need-to-know
punchline

$$\Delta H = q_p$$

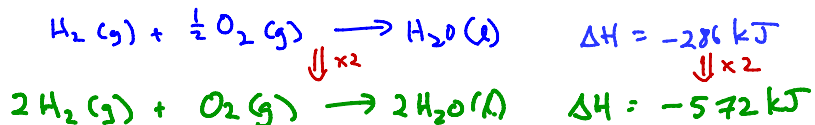
Enthalpy = Heat @ $P = k$

Enthalpy as Reactant (or Product): Three useful conventions to remember

①

Equation multiplier

- ΔH is associated with a particular chemical eq., with specified coefficients.
- ΔH is **EXTENSIVE** property, = $f(\text{amt})$, and changing coefficient means changing ΔH value proportionately.



②

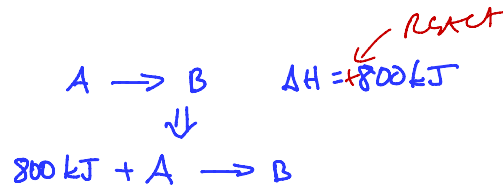
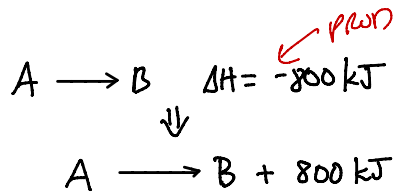
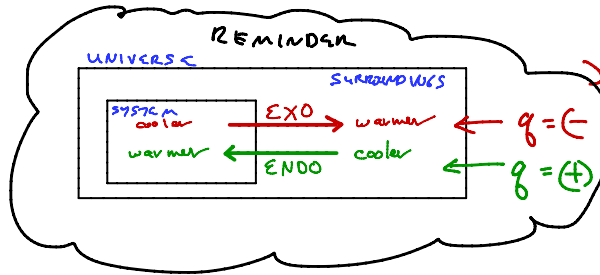
Phase often matters

Equations are also specific for phase (s, l, g, aq).

③
Sign of ΔH as it relates to EXO/ENDO reactions

Sign of ΔH ...

- If $\Delta H = (-)$, then EXO:
write as **PRODUCT**
- If $\Delta H = (+)$, then ENDO:
write as **REACTANT**



- Two types of problems
 - ↳ ΔH for rxn given, calc ΔH for given quantity of material
 - ↳ ΔH for quantity of material given, calc ΔH for rxn

Two Types of ΔH Stoichiometry Problems

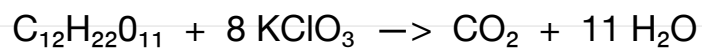
- (1) Amount of heat (ΔH) given for a specific quantity of reactant or product
- (2) Amount of heat (ΔH) given for a specific reaction equation

Solutions

- (1) Amount of heat (ΔH) given for a specific quantity of reactant or product
 - Ratio an amount of reactant or product to the amount of heat generated/consumed
 - Use that ration as a CF, and use Dimensional Analysis to solve
- (2) Amount of heat (ΔH) given for a specific reaction equation
 - Use traditional stoichiometry to calculate the heat generated/consumed by a specific amount of reactant or product
 - The “box” belongs below the in-line heat value (i.e., in the mole hole”

(EX) ΔH for quantity of material given, calc $\Delta H(\text{rxn})$ [ex 5.9]

A gummy bear contains 2.67 g sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$. When it reacts with 7.19 g potassium chlorate, KClO_3 , 43.7 kJ of heat are produced. Determine the enthalpy change for the reaction, if sucrose is in excess...



(1) Amount of heat (ΔH) given for a specific quantity of reactant or product

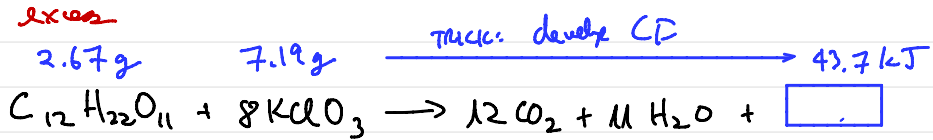
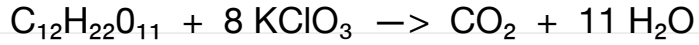
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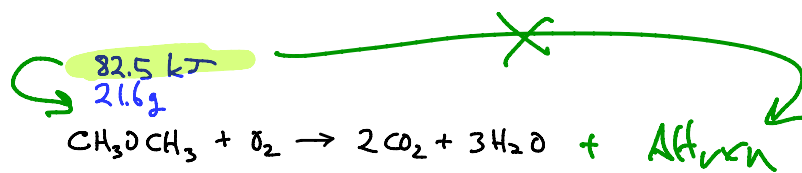
$$\boxed{\text{kJ}} = \frac{43.7 \text{ kJ}}{7.19 \text{ g KC}} \times \frac{122.52 \text{ KC}}{1 \text{ mol KC}} \times \frac{8 \text{ mol KC}}{1} = 5,956 = \boxed{5960 \text{ kJ}}$$

mol rxn

↑ CF ↑ MM ↑ givien

(EX) ΔH for quantity of material given, calc $\Delta H(\text{rxn})$

When 2.61 g of dimethyl ether is burned at constant pressure, 82.5 kJ of heat is given off. What is $\Delta H(\text{rxn})$?



$$\frac{\square \text{ kJ}}{\text{mol rxn}} = \frac{82.5 \text{ kJ}}{\quad}$$

$$\frac{\square \text{ kJ}}{\text{mol rxn}} = \frac{82.5 \text{ kJ}}{2.61 \text{ g, ME}} \times \frac{46.02 \text{ ME}}{1 \text{ mol ME}} \times \frac{1 \text{ mol ME}}{1 \text{ mol rxn}} = \boxed{1450 \text{ kJ/mol rxn}} \quad \begin{matrix} 1454.02 \\ \text{calc} \end{matrix}$$

Standard State: The Reference Point for Thermodynamic Calculations

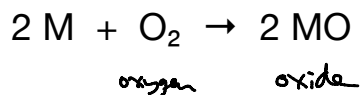
- standard state = reference point $\approx 0^\circ\text{C} = \text{fp}(\text{water})$
 - ↳ (gas) $P = 1 \text{ bar} = 0.987 \text{ atm}$
 - ↳ (aq) $M = 1 \text{ M}$
 - ↳ (s, l) pure
- "o" indicates std state:
 - ↳ ΔH_{298}° = occurs under std state @ 298K
 - ↳ ΔH = " NON-std-state conditions
- "mole reaction" (P 251/259)
 - ↳ divided ΔH_{rxn} by ants (moles) of reactant s:
 - ↳ yield INTENSIVE property from 2 EXTENSIVE prop
 ΔH and # moles
 - ... analogous to DENSITY (INTENSIVE)
from Mass (EXT) and Volume (EXT)

STP

ΔH°

Std Enthalpy of Combustion, ΔH_c°

↳ If ΔH_c° given, then often becomes a problem of the type:
' ΔH for rxn given, calc ΔH for given quantity of material'



$$\Delta H_c^\circ = -\#$$

(Exo)

Examples

Item	ΔH_c° (kJ/mol)
carbon, C	-393.5
Mg	-601.6
CH ₄	-890.8
HCECH	-1,301.1
i-C ₈	-5461
EtOH	-1366.8

→ 3rd hottest natural chem. flame
(3600 K / 3330°C / 6020°F)

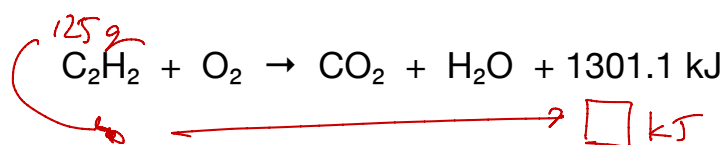
→ flame Temp (900°C / 1650°F)

← TEST BOOK EX.

Aside: Flame Temperatures:
Natural gas 2,070°C
Kero 2,093

(EX) ΔH for quantity of material given, calc ΔH for rxn [ex 5.10b]

¿How much heat is produced by the combustion of 125 g of acetylene, given $\Delta H_{\text{c}}^{\circ} = -1301.1 \text{ kJ/mol}$ @ 25°C ?



$\Delta H_{\text{rxn}}^{\circ}$
not ΔH for same
amt of material

$$\frac{\text{kJ}}{1} = \frac{125 \text{ g C}_2\text{H}_2}{26.0 \text{ g C}_2\text{H}_2} \times \frac{1 \text{ mol C}_2\text{H}_2}{1 \text{ mol rxn}} \times \frac{1301.1 \text{ kJ}}{1 \text{ mol C}_2\text{H}_2} =$$

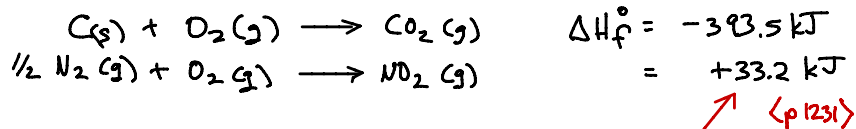
True Oct 15

$$\text{kJ} = \frac{125 \text{ g}}{26.0 \text{ g}} \times \frac{1 \text{ mol}}{1 \text{ mol rxn}} \times \frac{1301.1 \text{ kJ}}{1 \text{ mol rxn}} = 6255 = \boxed{6.25 \times 10^3 \text{ kJ}}$$

Standard Enthalpy of Formation

↳ Essentially, the amount of heat it takes to produce 1 mole of compound from "scratch" (elements), assuming the

↳ Std Enthalpy of formation of each element is zero (unless otherwise noted).



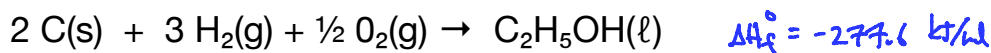
(APPENDIX G)

<p 1231>

(EX) Write ΔH_f Reaction [ex 5.12a]

Write the heat of reaction for $\text{C}_2\text{H}_5\text{OH}$, ethanol?

Using APPENDIX G data:

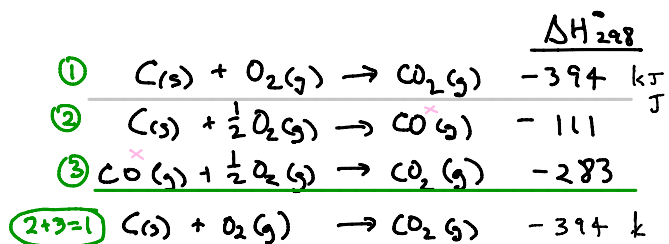
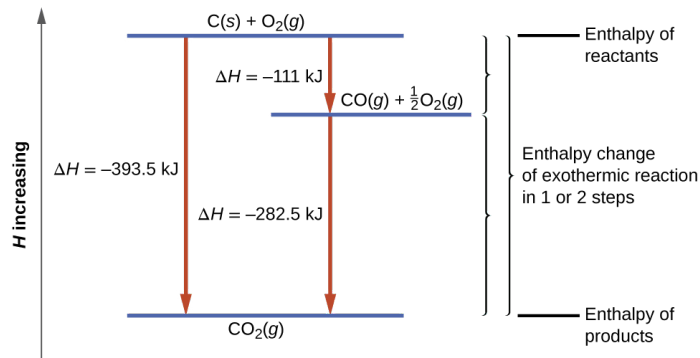


↑ 1 mol ↑

Hess's Law

Rack-n-stack two or more equations so the sum equals a Target (desired) equation.

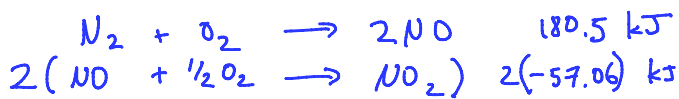
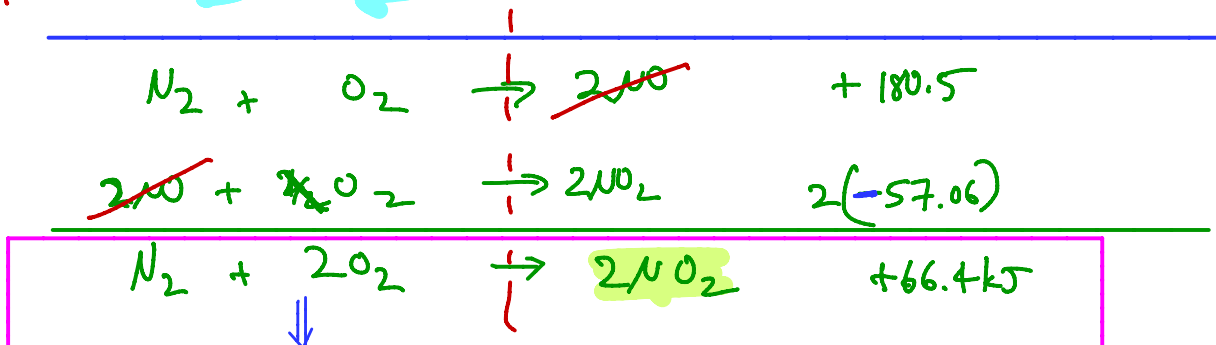
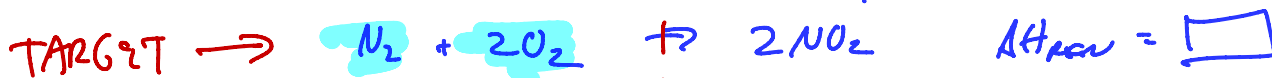
$$\Delta H_{\text{rxn}}^{\circ} = \Delta H_{\text{rxn a}}^{\circ} + \Delta H_{\text{rxn b}}^{\circ} + \Delta H_{\text{rxn c}}^{\circ} = \sum \Delta H_{\text{rxn, i}}^{\circ}$$



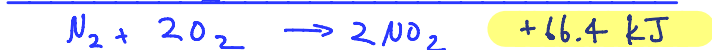
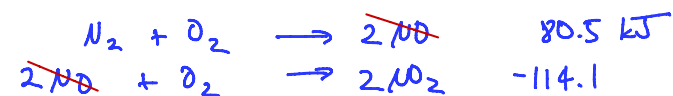
(EX) HESS (2-tier+rev+multiplier) [ex 5.13b]

Calc $\Delta H(\text{rxn})$ for the equation: $\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$
given,

- (a) $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g}) \quad \xrightarrow{+180.5 \text{ kJ/mol rxn}}$
(b) $\text{NO}(\text{g}) \rightarrow \text{NO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \quad \xrightarrow{+57.06 \text{ kJ/mol rxn}}$



\Downarrow



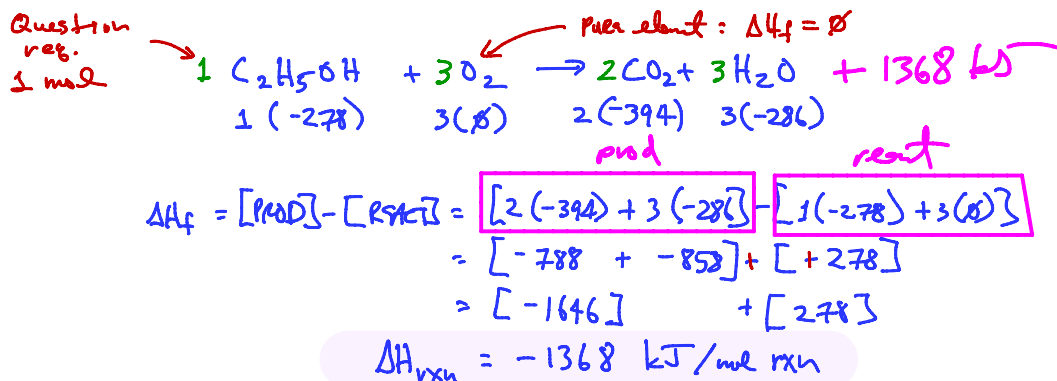
Hess' Law and ΔH_f° Combined



$$\Delta H_f^\circ(\text{rxn}) = \sum n \Delta H_f^\circ(\text{PROD}) - \sum n \Delta H_f^\circ(\text{REACT})$$

(EX) Hess: Calc ΔH° from Reactant & Prod ΔH_f° values [5.15b]

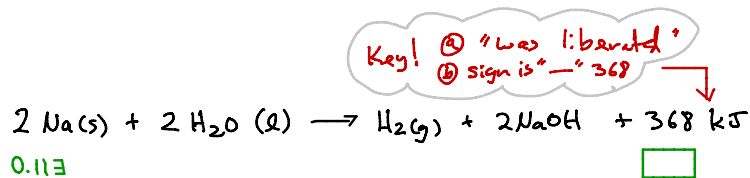
¿ Calc $\Delta H(\text{comb})$ for 1 mole of ethanol, $\text{C}_2\text{H}_5\text{OH}(\ell)$, given $\Delta H^\circ(\text{form})$ value for $\text{C}_2\text{H}_5\text{OH}(\ell)$ (-278 kJ/mol), H_2O (-286), and CO_2 (-394)?



Exam Review Practice Problems

(EX) Calculate $\Delta H(\text{liberated})$ based on $\Delta H(\text{std rxn})$

¿How much heat is liberated when 0.113 mole of sodium reacts with excess water, according to the equation what has a $\Delta H(\text{rxn})$ value of -368 kJ/mol rxn ?



$$\square \text{ kJ} = \frac{0.113 \text{ mol Na}}{2 \text{ mol Na}} \left| \frac{368 \text{ kJ}}{2 \text{ mol Na}} \right. = 28.8 \text{ kJ} = \boxed{-28.8 \text{ kJ}}$$

liberated

= 0 ✓ =

$$\square \text{ kJ} = \frac{0.113 \text{ mol Na}}{2 \text{ mol Na}} \left| \frac{-368 \text{ kJ}}{2 \text{ mol Na}} \right. = \boxed{-28.8 \text{ kJ}}$$

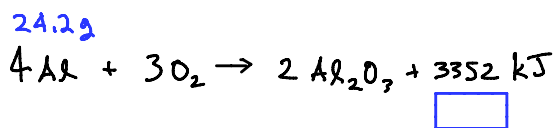
liberated

CAUTION!!! A word problem may not state the value is exothermic, rather, a phrase such as "liberates" or "is given off" may be used.

If one says "I borrowed" or "I gave" you \$20, you are responsible to know whether you need to debit their account ($-\$20$), or credit their acct. ($+\$20$)

(EX) Calculate exotherm from ΔH data

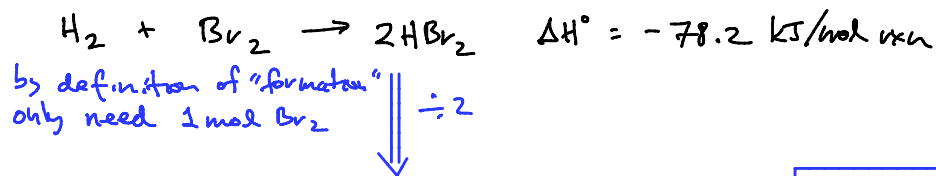
¿How much heat is given off when 24.2 g of Al is oxidized to aluminum oxide at 25 °C and 1 atm? ($\Delta H^\circ = -3352$ kJ/mol rxn)



$$\square \text{ kJ} = \frac{24.2\text{g Al}}{26.98\text{g Al}} \times \frac{1\text{ mol Al}}{4\text{ mol Al}} \times \frac{\text{mol rxn}}{\text{mol rxn}} \times \frac{-3352\text{ kJ}}{\text{mol rxn}} = \boxed{752\text{ kJ}}$$

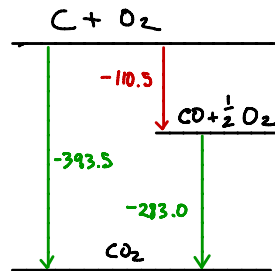
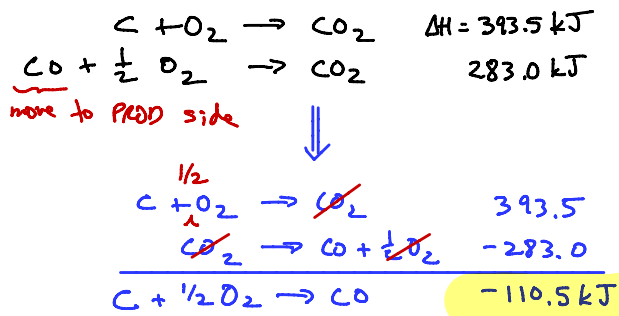
(EX) Calculate ΔH° (formation) data

¿Given the following equation, determine ΔH°_f for HBr?



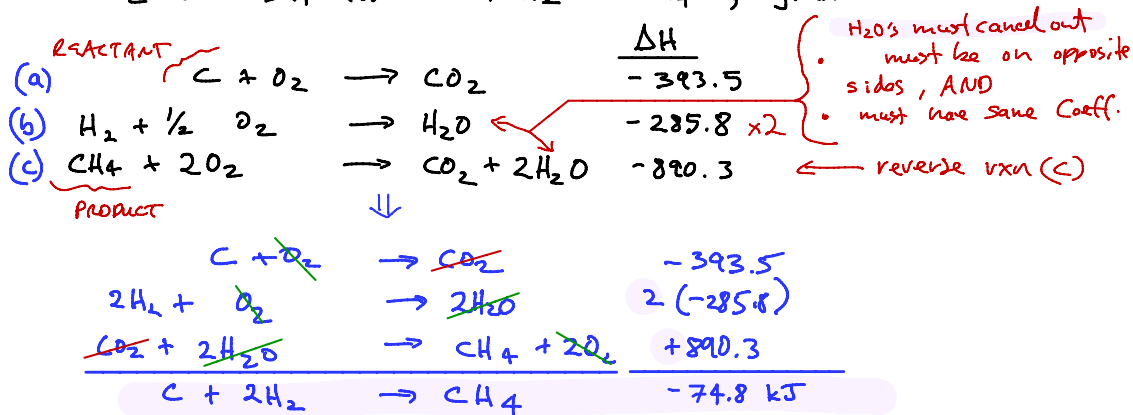
(EX) Hess' Law

¿Calculate ΔH for formation of CO given the following:



EX: HESS (3 tier + reverse + multiplier)

∴ Calc ΔH for: $C + H_2 \rightarrow CH_4$, given:

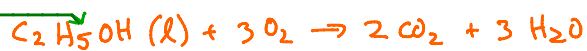


(EX) Hess' Law

Calculate $\Delta H(\text{rxn})$ for the reaction:



need to be given:
on product-side



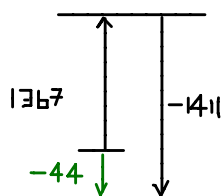
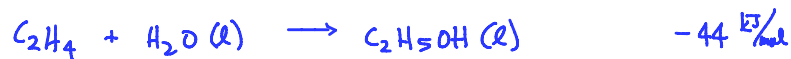
ΔH° (kJ/mol)

-1367



-1411

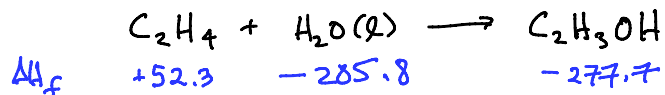
needs to be
on REACT-side



Ex: Calc ΔH_{rxn} from $\Delta H_{formation}$ Data

i Calc ΔH_{rxn} for the following rxn, using ΔH_f values from a data table?

$$\Delta H_f(C_2H_5OH) = -277.7 \text{ kJ/mol}; (C_2H_4) =$$



$$\Delta H_{rxn} = [-277.7] - [(52.3) + (-285.8)]$$

$$\Delta H_{rxn} = [-277.7] - [-233.5]$$

$$\Delta H_{rxn} = -44.2 \text{ kJ/mol}$$

(1) ΔH_{rxn} ΔH for species
out of reactant

(2) ΔH_{rxn} known ΔH for
the reactant.

