Chapter 9: Phenomenon

Phenomenon: Below is data from three different reactions carried out with three different amounts of reactants. All reactions were carried out in expandable/contractible containers at 25°C. What patterns do you see in the data? You do not need to know what work, heat, internal energy, or enthalpy are to find patterns in the data.

$C(s) + O_2(g) \rightarrow CO_2(g)$

Starting Amount of C	Starting Amount of O_2	Observations of Container	Work	Heat	Internal Energy	Enthalpy
1.00 mol	1.00 mol	Hot Same Size	0.0 kJ	-394 kJ	-394 kJ	-394 kJ
1.00 mol	2.00 mol	Hot Same Size	0.0 kJ	-394 kJ	-394 kJ	-394 kJ
2.00 mol	2.00 mol	Hot Same Size	0.0 kJ	-788 kJ	-788 kJ	-788 kJ

$CO_2(s) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$

Starting Amount of CO_2	Starting Amount of H_2O	Observations of Container	Work	Heat	Internal Energy	Enthalpy
1.00 mol	1.00 mol	Cold Expanded	-3.7 kJ	485 kJ	481 kJ	485 kJ
1.00 mol	2.00 mol	Cold Expanded	-7.4 kJ	970 kJ	963 kJ	970 kJ
2.00 mol	2.00 mol	Cold Expanded	-7.4 kJ	970 kJ	963 kJ	970 kJ

$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$

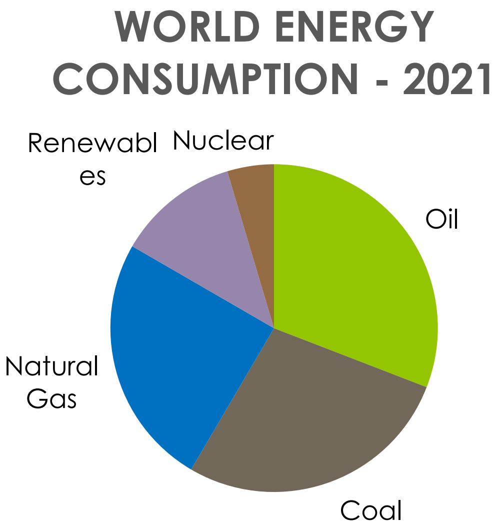
Starting Amount of N_2	Starting Amount of O_2	Observations of Container	Work	Heat	Internal Energy	Enthalpy
1.00 mol	1.00 mol	Cold Contract	1.2 kJ	34 kJ	35 kJ	34 kJ
2.00 mol	1.00 mol	Cold Contract	1.2 kJ	34 kJ	35 kJ	34 kJ
2.00 mol	2.00 mol	Cold Contract	2.5 kJ	68 kJ	71 kJ	68 kJ

Chapter 9 Energy, Enthalpy, & Thermochemistry

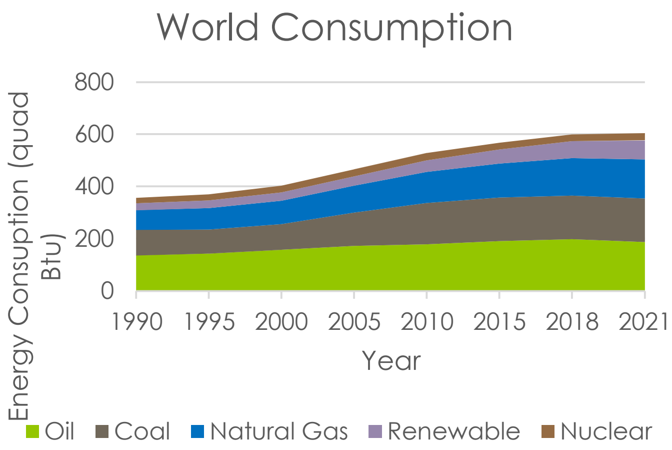
- Energy Facts
- Internal Energy
- Enthalpy
- Hess's Law
- Calorimetry
- H_2 Fuel

Big Idea: Heat and work are equivalent ways of changing the energy of a system. The total energy of an isolated system is constant. The change in enthalpy of a reaction indicates whether a reaction is endothermic or exothermic.

Energy Facts



Source of Energy	Percent
Petroleum	31%
Coal	28%
Natural Gas	25%
Renewable	12%
Nuclear	5%



Source of Energy	Percent Change Since 2018	Percent Change Since 1990
Oil	-6.9%	-24.0%
Coal	-0.5%	0.48%
Natural Gas	3.7%	15.2%
Renewables	11.0%	39.8%
Nuclear	4.9%	-23.1%

Energy Facts

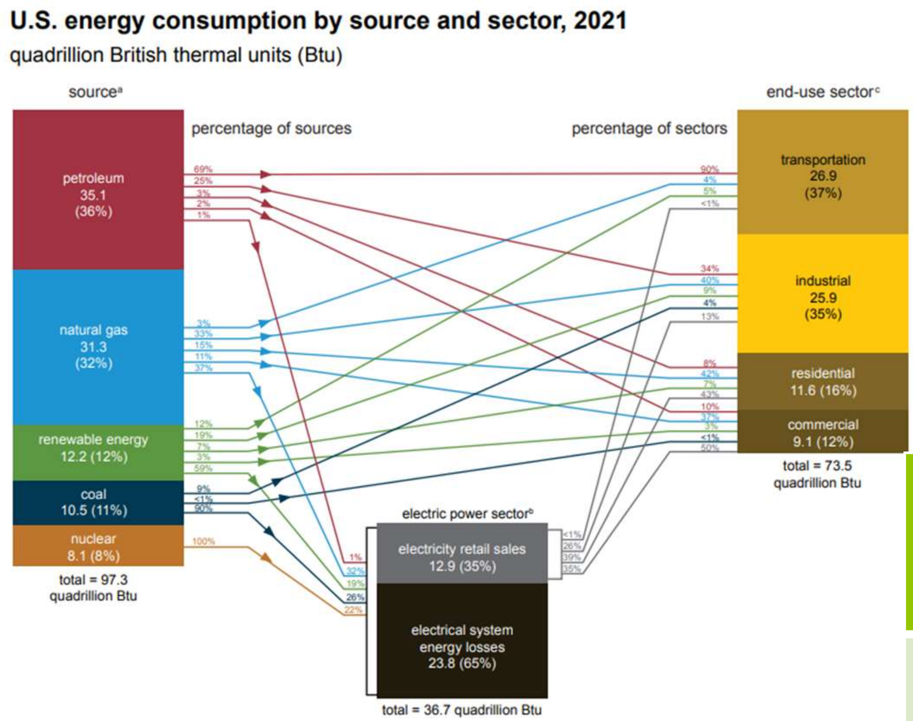
2018

Country	Energy Consumption (Quadrillion Btu)
China	147.6
United States	101.2
Russia	33.3
India	31.3
Japan	19.2
Canada	15.2
Germany	14.9
Brazil	13.8
Korea, South	12.4
Iran	11.7

Country	Energy Consumption/person (MBtu)
Qatar	704
Iceland	681
Singapore	649
Trinidad and Tobago	642
United Arad Emirates	481
Bahrain	460
Brunei	425
Canada	427
Kuwait	398
Luxembourg	316
United States (#11)	309

http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2

Energy Facts



U.S. energy consumption by source and sector, 2021

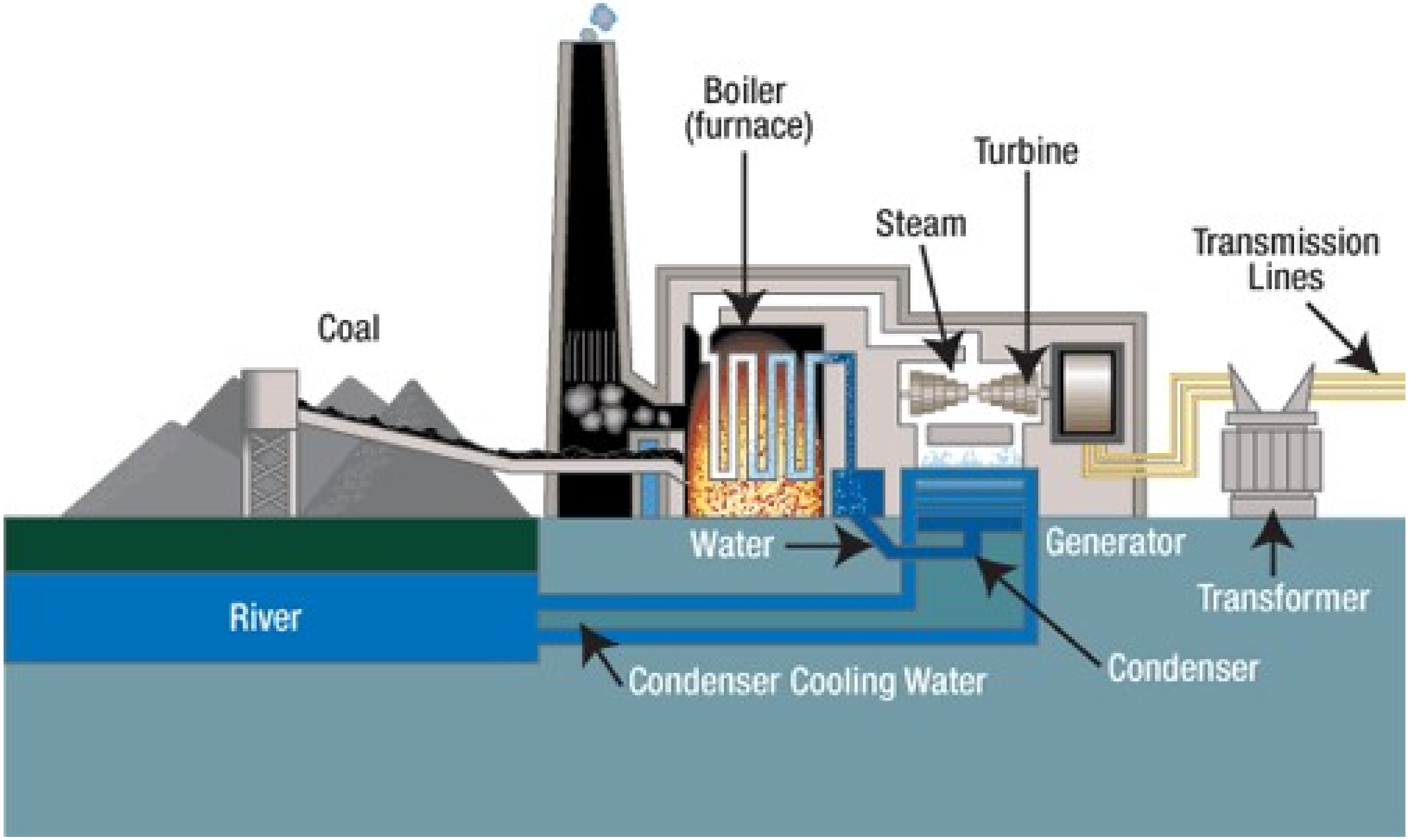
quadrillion British thermal units (Btu)

Source of Energy	% World 2021	% US 2021	% US 2009
Petroleum	31%	36%	37%
Natural Gas	28%	32%	25%
Coal	25%	12%	21%
Renewable	12%	11%	8%
Nuclear	5%	8%	9%

https://www.eia.gov/energyexplained/us-energy-facts/
http://www.eia.gov/totalenergy/data/monthly/

Energy Facts

How do we generate electricity?



Internal Energy

- **System:** The object of study.
- **Surrounding:** The region outside the system.
- **Internal Energy (*E*):** The capacity to do work or to produce heat.
- **Temperature (*T*):** How hot or cold an object is.
- **Heat (*q*):** The energy that is transferred as a result of a temperature difference between a system and its surroundings.

Note: If heat enters the system *q* is positive (endothermic reaction). If heat leaves the system *q* is negative (exothermic reaction).

- **Work (*w*):** The energy expended during the act of moving an object against an opposing force.

Note: If the system expands, *w* is negative. If the system contracts, *w* is positive.

Internal Energy

Student Question

Which of these changes results in an increase in the internal energy of the system?

a) The system **absorbs** heat and **does** work on the surroundings.
b) The system **releases** heat and **does** work on the surroundings.
c) The system **absorbs** heat and **has** work done on it by the surroundings.
d) The system **releases** heat and **has** work done on it by the surroundings.

Internal Energy

Student Question

Helium gas, at a pressure of 2 Pa, is placed in a container with a movable piston. On the other side of the piston is a vacuum. The He gas is allowed to expand such that the volume of the helium goes from 2 m^3 to 4 m^3. How much work does the helium gas do?

a) 8 J
b) 4J
c) 0 J
d) -4 J
e) None of the above

Internal Energy

- **Heat Capacity (C):** The ratio of heat supplied to the temperature rise produced (units $\frac{J}{°C}$)
- **Molar Heat Capacity:** The heat capacity per mole of substance (units $\frac{J}{mol\cdot °C}$)

Note: Many books use C_m for molar heat capacity.

- **Specific Heat Capacity:** The heat capacity per gram of substance (units $\frac{\mathrm{J}}{\mathrm{g}\cdot °\mathrm{C}}$)

Note: Many books use C_S for specific heat capacity.

Note: If the subscript V is added to any of the heat capacities it is the heat capacity at constant volume. If the subscript P is added to any of the heat capacities it is the heat capacity at constant pressure.

Internal Energy

Molar Heat Capacities at 298K			
Gas	**$C_V\left(\frac{J}{mol \cdot K}\right)$**	**$C_P\left(\frac{J}{mol \cdot K}\right)$**	**C_P-$C_V\left(\frac{J}{mol \cdot K}\right)$**
He, Ne, Ar	12.47	20.80	8.33
H_2	20.54	28.86	8.32
N_2	20.71	29.03	8.32
N_2O	30.38	38.70	8.32
CO_2	28.95	37.27	8.32
C_2H_6	44.60	52.92	8.32

$$q = nC\Delta T$$

Specific Heat Capacities	
Substances	**$C\left(\frac{J}{g \cdot K}\right)$**
H_2O(l)	4.18
H_2O(s)	2.03
Al(s)	0.89
Fe(s)	0.45
Hg(l)	0.14
C(s)	0.71

$$q = mC\Delta T$$

Note: The smaller the heat capacity, the faster the transfer of heat.

Internal Energy

C_V (Monatomic Ideal Gas)

Know

$$\Delta E = q + w = \Delta PE + \Delta KE$$

Potential Energy

Kinetic Energy

Work

Heat

Putting it together

Only true for ideal monatomic gases

Internal Energy

C_P (Monatomic Ideal Gas)

Know

$\Delta E = q + w = \Delta PE + \Delta KE$

Potential Energy

Kinetic Energy

Work

Heat

Putting it together

Only true for ideal monatomic gases

Internal Energy

- **State Function:** A property of a substance that is independent of how a substance was prepared.

- Are ΔE, q, and w state functions?
- <u>1 mol of monatomic ideal gas</u>
  - Path A
    - 1.0 atm, 1.0 L → 1.0 atm, 2.0 L → 2.0 atm, 2.0 L
  - Path B
    - 1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

Internal Energy

Path B (Monatomic Ideal Gas)

1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

- Step 1 (Constant Volume)

Heat

- $q = nC_V\Delta T$
  - $C_V = \frac{3}{2}R$

    (For monatomic ideal gas)
- $q = n\frac{3}{2}R\Delta T$

Problem: We do not know T

  - $(\Delta P)V = nR\Delta T$
- $q = \frac{3}{2}(\Delta P)V = \frac{3}{2}\left(P_f - P_i\right)V$
- $q = \frac{3}{2}(2.0\ atm - 1.0\ atm)(1.0\ L)$
- $q = 1.5\ L \cdot atm = 150\ J$

Work

- $w = -P_{ex}\Delta V = 0.0\ J$

  (ΔV=0)

Internal Energy

- $\Delta E = q + w$
- $\Delta E = 150\ J + 0.0\ J$
- $\Delta E = 150\ J$

Internal Energy

Path B (Monatomic Ideal Gas)

1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

- Step 2 (Constant Pressure)

Heat

- $q = nC_P\Delta T$
  - $C_P = \frac{5}{2}R$

  (For monatomic ideal gas)
- $q = n\frac{5}{2}R\Delta T$

Problem: We do not know T

  - $P\Delta V = nR\Delta T$
- $q = \frac{5}{2}P\Delta V = \frac{5}{2}P\left(V_f - V_i\right)$
- $q = \frac{5}{2}(2.0\ atm)(2.0\ L - 1.0\ L)$
- $q = 5.0\ L \cdot atm$
- $q = 5.0 \times 10^2\ J$

Work

- $w = -P_{ex}\Delta V$
- $\mathrm{w} = -P_{ex}\left(V_f - V_i\right)$
- $\mathrm{w} = -(2.0\ atm)(2.0\ L - 1.0\ L)$
- $w = -2.0\ L \cdot atm = -2.0 \times 10^2\ J$

Internal Energy

- $\Delta E = q + w$
- $\Delta E = 5.0 \times 10^2\ J + -2.0 \times 10^2\ J$
- $\Delta E = 3.0 \times 10^2\ J$

Internal Energy

- **Path A**

  1.0 atm, 1.0 L → 1.0 atm, 2.0 L → 2.0 atm, 2.0 L

- **Path B**

  1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

Path B (totals)	Path A (totals)
$q = 150\ J + 5.0 \times 10^2\ J$ $\mathrm{q} = 650\ J$	$\mathrm{q} = 550\ \mathrm{J}$
$w = 0.0\ J + -2.0 \times 10^2\ J$ $\mathrm{w} = -2.0 \times 10^2\ J$	$w = -1.0 \times 10^2\ J$
$\Delta E = 150\ J + 3.0 \times 10^2\ J$ $\Delta E = 450\ J$	$\Delta E = 450\ J$

Enthalpy

- Path A (Monatomic ideal gas)

  1.0 atm, 1.0 L → 1.0 atm, 2.0 L → 2.0 atm, 2.0 L

  - **Step 1:** q = 250 J w = -1.0×10^2 J ΔE=150 J
  - **Step 2:** q = 3.0×10 J w = 0.0J ΔE=3.0×10^2 J

- Path B (Monatomic ideal gas)

  1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

  - **Step 1:** q = 150 J w = 0.0J ΔE=150 J
  - **Step 2:** q = 5.0×10^2 J w = -2.0×10^2 J ΔE=3.0×10^2 J

These values were calculated in class.

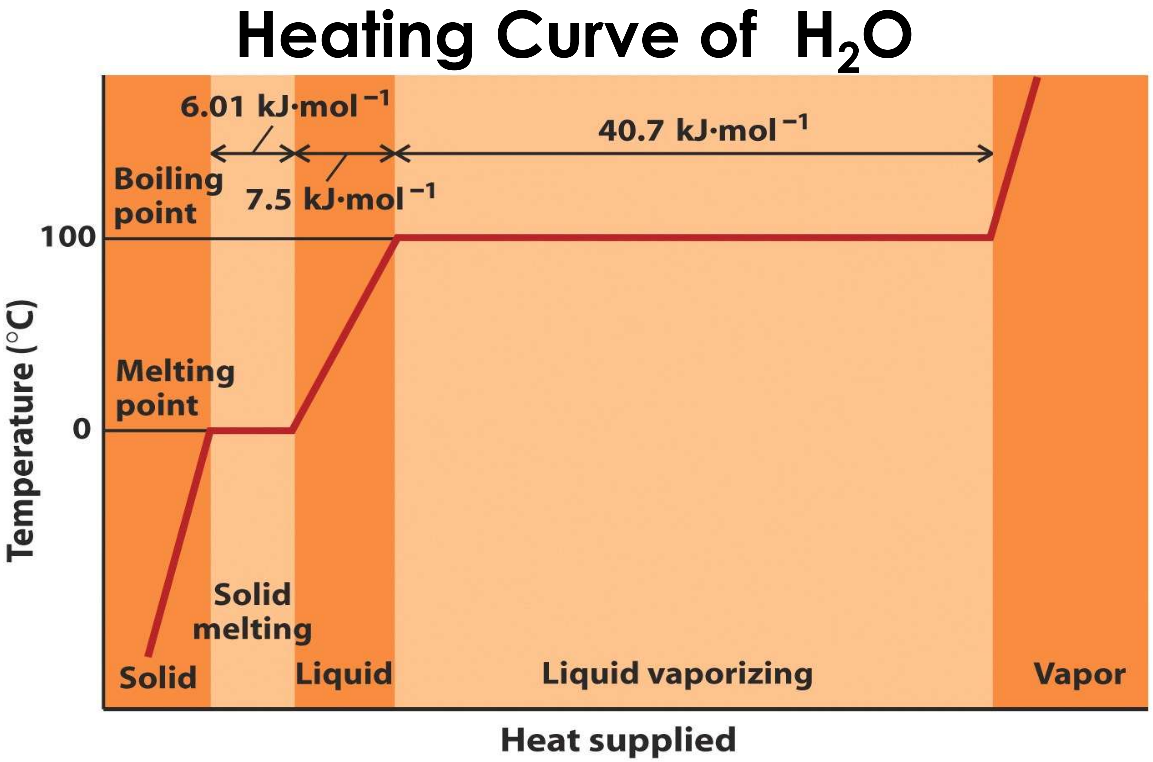
Enthalpy

Path B (Monatomic Ideal Gas)

1.0 atm, 1.0 L → 2.0 atm, 1.0 L → 2.0 atm, 2.0 L

- *Step 1 (Constant Volume)*
  - $\Delta H = \Delta E + \Delta(PV) = \Delta E + V\Delta P$
  - $V\Delta P = (1.0\ L)(2.0\ atm - 1.0\ atm) = 1.0\ L \cdot atm$
  - $V\Delta P = 1.0\ L \cdot atm\left(\frac{101.325\ J}{1\ L \cdot atm}\right) = 1.0 \times 10^2\ J$
  - $\Delta H = 150\ J + 1.0 \times 10^2\ J = 250\ J$
- *Step 2 (Constant Pressure)*
  - $\Delta H = q = 5.0 \times 10^2\ J$
- *Total ΔH*
  - $\Delta H_{tot} = 250\ J + 5.0 \times 10^2\ J = 750\ J$

Enthalpy



- **Heat of Fusion (ΔH_{fus}):** The amount of heat that needs to be supplied to turn a solid into a liquid.
- **Heat of Vaporization (ΔH_{vap}):** The amount of heat that needs to be supplied to turn a liquid into a gas.

Enthalpy

Standard State (°)

- For a gas, the standard state is exactly 1 atm.
- For a substance in solution, the standard state is exactly 1 M.
- For a pure substance in a condensed state (liquid or solid), the standard state is the pure liquid or solid.
- For an element, the standard state is the form in which the element exists (is most stable) under conditions of 1 atm and the temperature of interest.

Note: The temperature of the system is usually noted as a subscript. If no temperature is stated, assume 25°C.

Note: Only the change in enthalpy is important, therefore, the standard state of elements are set to 0.

Enthalpy

Standard Enthalpy of formation ($\Delta H_f°$):

- The standard reaction enthalpy per mole of compound for the compound's synthesis from its elements in their most stable form at 1 atm and the specified temperature.

Note: The reaction must be written such that only 1 mole of product forms.

Enthalpy

Student Question

For which reaction is $\Delta H^{\circ}_{rxn} = \Delta H^{\circ}_{f}$?

a) $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
b) $2C(graphite) + H_2(g) \rightarrow C_2H_2(g)$
c) $C(diamond) + O_2(g) \rightarrow CO_2(g)$
d) $NO(g) + \frac{1}{2}O_2(g) \rightarrow NO_2(g)$
e) None of the above

Enthalpy

Standard Enthalpy of Combustion (ΔH_C°):

- The change of enthalpy per mole of substance when it burns (reacts with oxygen) completely under standard conditions.

Note: The reaction is written such that 1 mole of substance combusts.

Note: When carbon is in the reactants, CO_2 forms, and when H is in the reactants, H_2O forms. For standard enthalpies of combustion water is always assumed to be in the liquid phase.

Example:

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

Hess's Law

Hess's Law:

- A reaction's enthalpy is the sum of the enthalpies of any sequence of reactions (at the same temperature and pressure) into which the overall reaction can be divided.

- Things to remember
  - If you add reactions together, add ΔH's.
  - If you flip a reaction, flip the sign of ΔH.
  - If you multiply a reaction by a constant, multiply ΔH by the same constant.

Hess's Law

1. $CCl_4(g) + 4HCl(g) \rightarrow CH_4(g) + 4Cl_2(g)$
   $\Delta H_1 = 397.0$ kJ
2. $\frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g) \rightarrow HCl(g)$
   $\Delta H_2 = -92.3$ kJ
3. $C(\text{graphite}) + 2H_2(g) \rightarrow CH_4(g)$
   $\Delta H_3 = -74.81$ kJ

Calculate the standard enthalpy of formation of $CCl_4(g)$ using the thermochemical equations.

Hess's Law

- **Given**

$$Na(s) + \tfrac{1}{2}H_2(g) + C(graphite) + \tfrac{3}{2}O_2(g) \rightarrow NaHCO_3(s) \qquad \Delta H^\circ_f(NaHCO_3)$$

$$2Na(s) + C(graphite) + \tfrac{3}{2}O_2(g) \rightarrow Na_2CO_3(s) \qquad \Delta H^\circ_f(Na_2CO_3)$$

$$C(graphite) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H^\circ_f(CO_2)$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H^\circ_f(H_2O)$$

- **What is ΔH°_{rxn} of**
  $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(l)$

$$2NaHCO_3(s) \rightarrow \boxed{2Na(s)} + \boxed{H_2(g)} + \boxed{2C(graphite)} + \boxed{3O_2(g)} \qquad -2\Delta H^\circ_f(NaHCO_3)$$

$$\boxed{2Na(s)} + \boxed{C(graphite)} + \boxed{\tfrac{3}{2}O_2(g)} \rightarrow Na_2CO_3(s) \qquad \Delta H^\circ_f(Na_2CO_3)$$

$$\boxed{C(graphite)} + \boxed{O_2(g)} \rightarrow CO_2(g) \qquad \Delta H^\circ_f(CO_2)$$

$$\boxed{H_2(g)} + \boxed{\tfrac{1}{2}O_2(g)} \rightarrow H_2O(l) \qquad \Delta H^\circ_f(H_2O)$$

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

$$\Delta H^\circ_{rxn} = \Delta H^\circ_f(Na_2CO_3) + \Delta H^\circ_f(CO_2) + \Delta H^\circ_f(H_2O) - 2\Delta H^\circ_f(NaHCO_3)$$

Hess's Law

$$\Delta H^\circ_{rxn} = \sum \Delta H^\circ_f\,(products) - \sum \Delta H^\circ_f\,(reactants)$$

Thermodynamic Data at 298 K

Substance	$\Delta H_f^\circ\ \left(\frac{kJ}{mol}\right)$	$\Delta G_f^\circ\ \left(\frac{kJ}{mol}\right)$	$\Delta S^\circ\ \left(\frac{J}{mol \cdot K}\right)$
$C_2H_4(g)$	52	68	219
$CH_4(g)$	-75	-51	186
$CO_2(g)$	-393.5	-394	214
$C_2H_6(g)$	-84.7	-32.9	229.5
$O(g)$	-110.5	-137	198
$CH_3CO_2H(l)$	-484	-389	160.
$CH_3OH(g)$	-201	-163	240.
$CH_3CH_2OH(l)$	-278	-175	161
$C_6H_{12}O_6(s)$	-1275	-911	212
$HCl(g)$	-92	-95	187
$H_2(g)$	0	0	131
$H_2O(l)$	-286	-237	70
$H_2O(g)$	-242	-229	189
$Fe(s)$	0	0	27
$Fe_2O_3(s)$	-826	-740.	90.

Thermodynamic Data at 298 K

Substance	$\Delta H_f^\circ\ \left(\frac{kJ}{mol}\right)$	$\Delta G_f^\circ\ \left(\frac{kJ}{mol}\right)$	$\Delta S^\circ\ \left(\frac{J}{mol \cdot K}\right)$
$N_2(g)$	0	0	192
$NO_2(g)$	34	52	240.
$NO(g)$	90.	87	211
$N_2O_4(g)$	10.	98	304
$NH_3(g)$	-46	-17	193
$HNO_3(l)$	-174	-81	156
$NH_4Cl(s)$	-314	-203	96
$O_2(g)$	0	0	205
$P_4O_{10}(s)$	-2984	-2698	229
$H_3PO_4(s)$	-1279	-1119	110
$S_{rhombic}(s)$	0	0	32
$H_2S(g)$	-21	-34	206
$SO_2(g)$	-297	-300	248
$SO_3(g)$	-396	-371	257

* Other ΔH°_f can be found in appendix 4 in the back of your book.

Hess's Law

Student Question

Calculate ΔH°_{rxn} (kJ) for the following reaction from the listed standard enthalpies of formation:

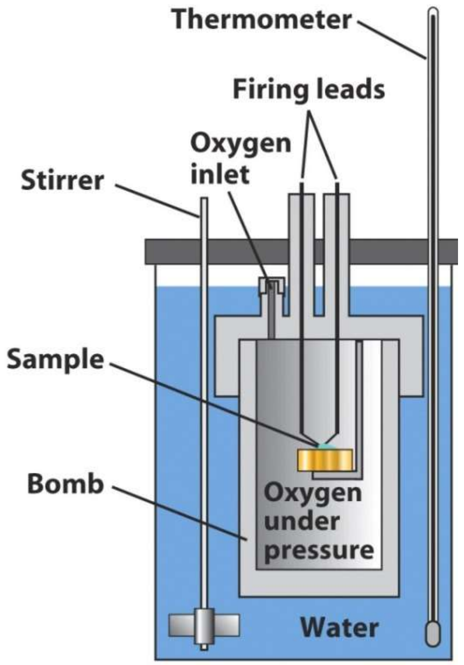
$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

Substance	**ΔH°_f ($\frac{kJ}{mol}$)**
$NH_3(g)$	-46
NO(g)	90.
$H_2O(g)$	-242

a) -862 kJ
b) -908 kJ
c) -1,276 kJ
d) Not enough information
e) None of the above

Calorimetry

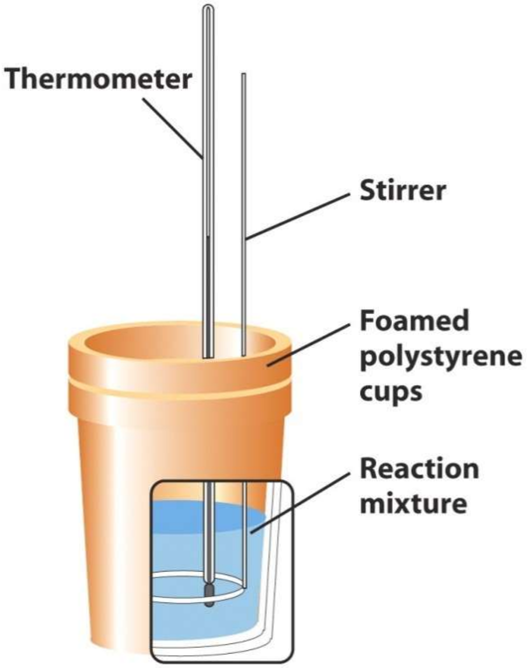
Constant Volume Calorimetry (Bomb)



Used to find ΔE_{com}

- No matter is exchanged
- No heat is exchanged

Constant Pressure Calorimetry (Coffee Cup)



Used to find ΔH (ΔH_{fus} and ΔH_{rxn}) and C

- No heat is exchanged

Calorimetry

- In a constant pressure calorimeter 200. g of ice (T_i(ice) = 0.0°C) is combine with 440. g of water (T_i(water) = 80.0°C). The final temperature of the system is 30.1°C. What is ΔH_{fus} of water in $\frac{kJ}{mol}$? $C_{H_2O(l)} = 4.18\,\frac{J}{g{\cdot}°C}$

Calorimetry

- 100. mL of 0.500 M HCl (0.0500 mol HCl) was mixed with 75.0 mL of 0.500 M NaOH (0.0375 mol NaOH) in a constant-pressure calorimeter of negligible heat capacity. The initial temperature of the HCl and NaOH solution was the same, 22.50°C, and the final temperature of the mixed solution was 25.86°C. Calculate the heat change for the neutralization reaction on a molar basis.
  - Assume the density and specific heat of the solution are the same as for water (1.00 $\frac{g}{mL}$ and 4.184 $\frac{J}{g°C}$, respectively)

H_2 Fuel

Energy Released from Different Fuel Sources

- **Natural Gas**

  $CH_4(l) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

  51 $\frac{kJ}{g}$

- **Coal**

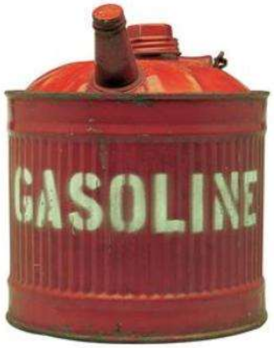
  $C(s) + O_2(g) \rightarrow CO_2(g)$

  17 - 33 $\frac{kJ}{g}$ *Depending on impurities*

- **Gasoline**

  $C_xH_y(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$ *unbalanced*

  48 $\frac{kJ}{g}$



- **Hydrogen**

  $H_2(g) + O_2(g) \rightarrow H_2O(l)$

  141 $\frac{kJ}{g}$

H_2 Fuel

Although there is an abundance of hydrogen containing compounds on earth, very little is free hydrogen.

Where do we get H_2 from?

- ***Natural Gas:***
  - $CH_4(g) + H_2O(g) \xrightarrow{1000℃} 3H_2(g) + CO(g)$

Problem: Uses fossil fuels, need heat (energy), more economical to burn the CH_4.

- ***Electrolysis of Water:***
  - If a current is passed through H_2O the water breaks down into its elements.

Problem: The price of electricity is too high to make this competitive as a fuel. Most electricity is generated from fossil fuels.

H_2 Fuel

- ***Thermal Decomposition:***
  - $H_2O \rightarrow H_2 + \frac{1}{2}O_2$ (T=3000°C ~ $\frac{1}{2}H_2O$ dissociates)

$$\begin{array}{ll}
2HI \rightarrow I_2 + H_2 & (435°C) \\
2H_2O + SO_2 + I_2 \rightarrow H_2SO_4 & (90°C) \\
H_2SO_4 \rightarrow SO_2 + H_2O + \frac{1}{2}O_2 & (825°C) \\
\hline
H_2O \rightarrow H_2 + \frac{1}{2}O_2 &
\end{array}$$

Problem: Still needs very high temperatures

- ***Biological Hydrogen Production:***
  - If certain algae are deprived of sulfur they will switch from producing O_2 during photosynthesis to H_2.

Problem: Currently the yields are to small to be a viable commercial option.

H_2 Fuel

- Other Problems:
  - How to transport H_2?
    - H_2 decomposes on metal surfaces
    - H atoms are so small they can migrate into metal weakening it.

Take Away from Chapter 9

- **Big Idea:** Heat and work are equivalent ways of changing the energy of a system. The total energy of an isolated system is constant. The change in enthalpy of a reaction indicates whether a reaction is endothermic or exothermic.

- **Energy Facts**
- **Internal Energy**
  - Know the 1st law of thermodynamics and its implications (1)
    - *The energy of the universe is constant*
  - Be able to calculate internal energy (E) (24&25)
    - $\Delta E = q + w = \Delta KE + \Delta PE$
  - Be able to calculate work (w) (10,20&103)
    - $w = -P_{ex}\Delta V$
  - Be able to calculate heat (q) *(11)*
    - $q = C\Delta T$

Numbers correspond to end of chapter questions.

Take Away from Chapter 9

- **Enthalpy**
  - Be able to calculate change in enthalpy (ΔH) (37,38,39,42&125)
    - $\Delta H = \Delta E + \Delta(PV)$
    - *$\Delta H = q$ (At constant pressure)*
  - Know implications of sign of ΔH (16,32)
    - *ΔH is -, exothermic reaction*
    - *ΔH is +, endothermic reaction*
  - Be able to draw heating curves
    - Know the implications/meaning of ΔH_{fus} and ΔH_{vap}
  - Be able to draw reaction coordinates diagrams
  - Know how to use change in enthalpy as a conversion factor (35,36&85)
- **Hess's Law**
  - Know how to get ΔH°_{rxn} from other known ΔH°_{rxn} (66,67,68,69&70)
  - Know how to get ΔH°_{rxn} from ΔH°_{f} (71,76,77,81,82,88&107)
    - $\Delta H^{\circ}_{rxn} = \sum \Delta H^{\circ}_{f}\,(prod) - \sum \Delta H^{\circ}_{f}\,(reac)$

Numbers correspond to end of chapter questions.

Take Away from Chapter 9

- **Calorimetry**
  - Understand the differences/limitations between constant volume and constant pressure calorimetry (43)
  - Be able to solve bomb calorimeter (constant volume) problems (57,58)
    - $\Delta E_{com} = -C_{cal}\Delta T$
  - Be able to solve coffee cup calorimeter (constant pressure) problems
    - *Solve for C of non soluble substance (44,46&48)*
      - $q_{H_2O} = -q_{substance}$ (if needed add heat q_{cal} to q_{H_2O})
      - $m_{H_2O}C_{H_2O}\Delta T_{H_2O} = -m_{sub}C_{sub}\Delta T_{sub}$
    - *Solve for* ΔH_{fus}
      - $q_{solid} = -q_{liquid}$ (if needed add heat q_{cal} to q_{liquid})
      - $q_{s(T_{i_s} \to T_{m_s})} + q_{fus} + q_{l(that\ was\ s)(T_{m_s} \to T_f)} = -q_l$
      - $m_s C_s(T_{m_s} - T_{i_s}) + n_s \Delta H_{fus} + m_s C_l(T_f - T_{m_s}) = -m_l C_l(T_f - T_{i_l})$

Numbers correspond to end of chapter questions.

Take Away from Chapter 9

- **Calorimetry** (Continued)
  - Be able to solve coffee cup calorimeter problems
    - *Solve for ΔH_{rxn} (51,54,55&56)*
      - $\Delta H_{rxn} = -q_{solution}$ (if needed add heat q_{cal} to $q_{solution}$)
      - $\Delta H_{rxn} = -m_{solution} C_{H_2O} \Delta T_{solution}$ (Most times need to divide by number of moles. Be careful many of these are limiting reagent problems.)
- **H_2 Fuel**

Numbers correspond to end of chapter questions.