

Thermochemical Equations

Enthalpy - an extensive property that measures heat absorbed or evolved in a reaction represented with an H

$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

In thermochemical equations, the enthalpy sign determines whether heat is absorbed or evolved (lost).

If the sign for enthalpy is positive (+), then heat is absorbed.

If the sign for enthalpy is negative (-), then heat is evolved.

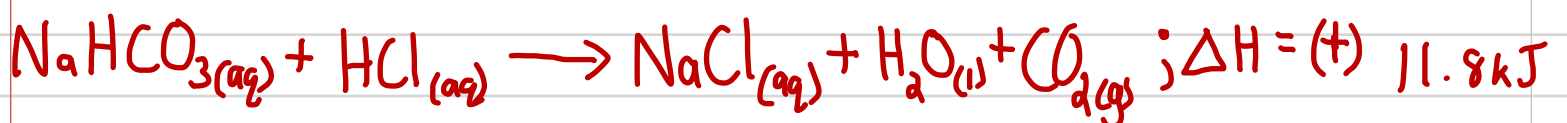
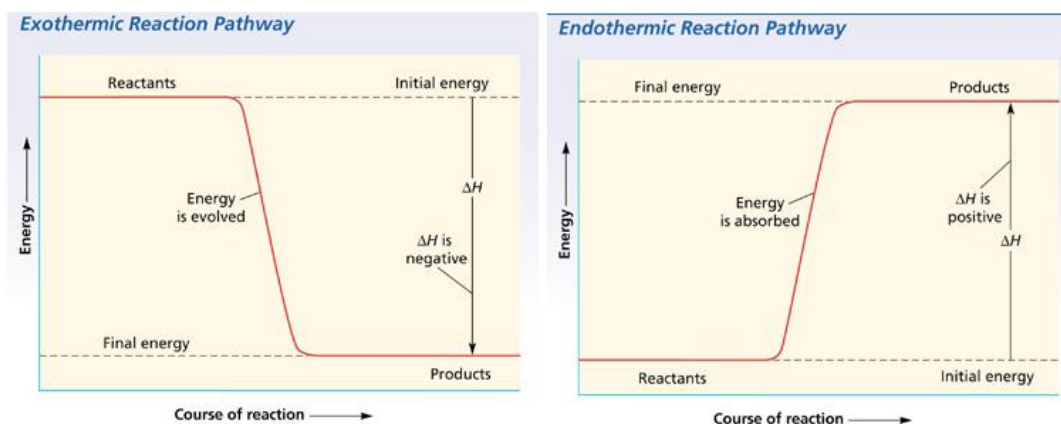
endothermic - heat/energy is absorbed by the system from the surroundings

exothermic - heat/energy is released (evolved) by the system to the surroundings

When...

...product energy > reactant energy, the reaction is endothermic

...product energy < reactant energy, the reaction is exothermic.



The only difference between a chemical equation and a thermochemical equation is the fact that a thermal equation ends in ; (delta) H = . This gives how much heat energy was evolved or absorbed during the reaction.

Manipulating Thermochemical Equations

Rules for manipulation:

1. When an equation is multiplied by a factor, the enthalpy value for the new equation must also be multiplied by that same factor.
2. When a thermochemical equation is written in reverse, the sign of enthalpy is also reversed.

Stoichiometry of Thermochemical Equations

Using the thermochemical equation, you can make a conversion factor to create a ratio of mols to heat evolved/absorbed.

Enthalpy of Formation - The amount of energy absorbed/evolved for an individual molecule in a reaction ΔH_f°

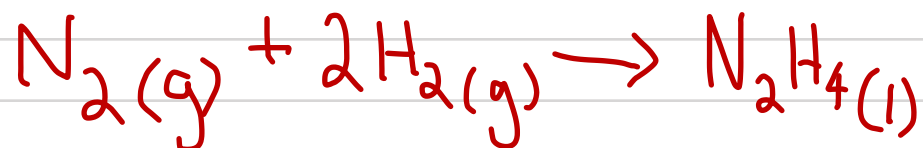
Solving basic Thermochemical Problems using Hess's Law

Rules:

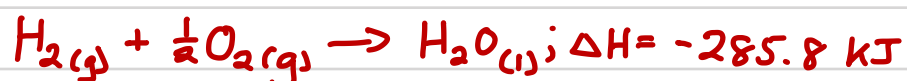
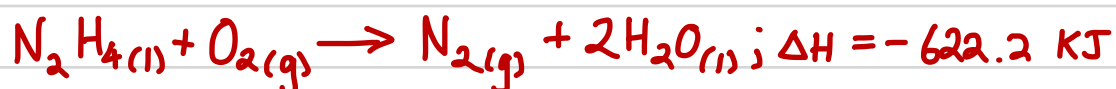
1. When one reactant of one equation is the same as the product of another equation, they can cancel out.
2. When a compound is in two equations but on the same side (both reactants or both products), the molar amounts are added.
3. The thermochemical equations can be manipulated, but the whole equation must be multiplied or divided by the same amount, including the enthalpy.

Hess's Law

The first part of Hess's Law describes how reactions can have multiple steps that are not always listed.



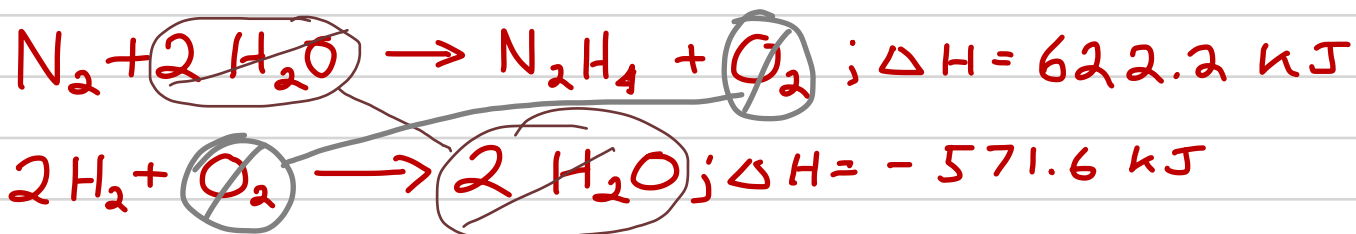
Now, this equation doesn't happen naturally. It is actually a combination of two different reactions:



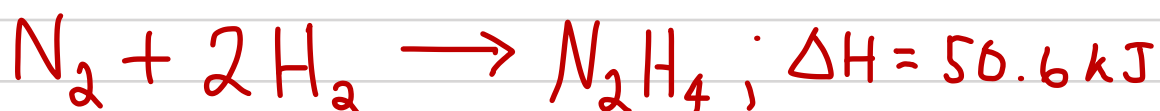
In order to solve this problem, we want to manipulate the two equations so that the components combine or cancel out to form the original equation:

The first equation is reversed.

The second equation is doubled.



Once all factors are added and canceled, all reactants are written on one side and all products are written on the other. To find the net change in enthalpy, just add the two values of enthalpy together.



Hess's Law

The next part of Hess's Law states that the overall enthalpy change of a reaction is equal to the sum of the energy changes in each step.

Mathematically, this can be written:

$$\Delta H = \sum n \Delta H_f^\circ \text{ products} - \sum m \Delta H_f^\circ \text{ reactants}$$

Breaking this equation
 Σ means the sum of
 reactants

$n\Delta H/m\Delta H$ is the coefficient
 reactants respectively
 the n and m before
 formation of each part
 respective number of

So, putting this together
 enthalpy is equal to the
 products minus the sum
 reactants.

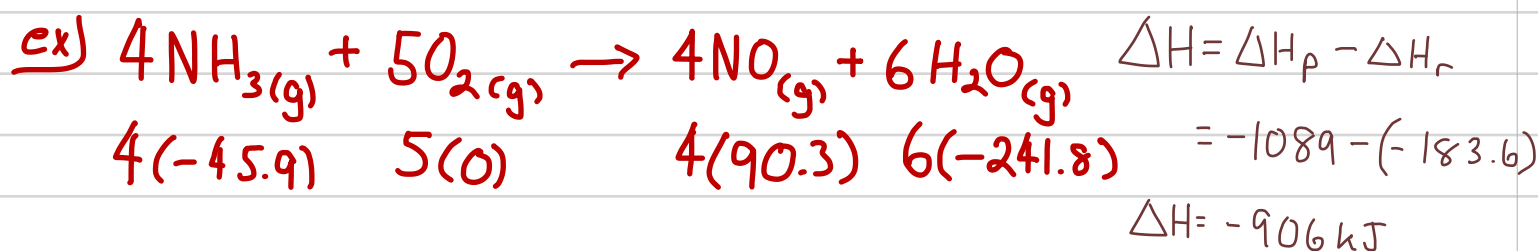
Table A-6
Thermodynamic Properties (at standard states)

ΔH_f° in kJ/mol		ΔG_f° in kJ/mol		S° in J/mol·K			
concentration of aqueous solutions is 1 M							
Substance	ΔH_f°	ΔG_f°	S°	Substance	ΔH_f°	ΔG_f°	S°
Ag	0	0	42.7	H ₃ PO ₃	-972	—	—
AgCl	-127	-110	96.1	H ₃ PO ₄	-1280	-1120	110
AgCN	-146	-164	83.7	H ₂ S	-20.1	-33.0	206
Al	0	0	28.3	H ₂ SO ₃ (aq)	-614	-538	232
Al ₂ O ₃	-1670	-1580	51.0	H ₂ SO ₄ (aq)	-908	-742	17.2
BaCl ₂ (aq)	-873	-823	121	HgCl ₂	-230	-177	—
BaSO ₄	-1470	-1350	132	Hg ₂ Cl ₂	-265	-211	196
Be	0	0	9.54	Hg ₂ SO ₄	-742	-624	201
Be ₂ N ₂	-568	-512	—	I ₂	0	0	117
Bi	0	0	56.9	K	0	0	63.6
BiCl ₃	-379	-319	190	KBr	-392	-379	96.4
Bi ₂ S ₃	-183	-164	146	KMnO ₄	-813	-714	172
Br ₂	0	0	152	KOH	-426	—	—
CH ₄	-74.8	-50.8	186	LiBr	-350	—	—
C ₂ H ₄	+52.3	+68.1	219	LiOH	-487	-444	50.2
C ₂ H ₆	-84.7	-32.9	229	Mn	0	0	32.0
C ₂ H ₁₀	-125	-15.7	310	MnCl ₂ (aq)	-655	-491	38.9
CO	-111	-137	198	Mn(NO ₃) ₂ (aq)	-636	-451	218
CO ₂	-393.5	-394.4	214	MnO ₂	-521	-466	53.1
CS ₂	+87.9	+63.6	151	MnS	-214	—	—
Cu	0	0	41.6	N ₂	0	0	192
Ca(OH) ₂	-987	-897	—	NH ₃	-46.2	-16.6	193
Cl ₂	0	0	223	NH ₄ Br	-270	-175	113
CoCO ₃	-723	-650	—	NO	-90.4	—	211
CoO	-239	-213	43.9	NO ₂	-33.8	+51.8	240
Cr ₂ O ₃	-1130	-1050	81.2	Na	0	0	51.0
CsCl(aq)	-415	-371	188	NaBr	-360	—	—
Cs ₂ SO ₄ (aq)	-1400	-1310	283	NaCl	-411	-384	72.4
CuI	-67.8	-69.5	96.7	NaNO ₃ (aq)	-447	—	—
CuS	-53.1	-53.7	66.5	NaOH	-427	—	—
Cu ₂ S	-79.5	-86.2	121	Na ₂ S(aq)	-437	—	—
CuSO ₄	-770	-662	113	Na ₂ SO ₄	-1380	-1270	149
F ₂	0	0	203	O ₂	0	0	205
FeCl ₃	-405	—	—	P ₂ O ₅	-1640	—	—
FeO	-267	—	—	P ₂ O ₁₀	-2980	-2700	229
Fe ₂ O ₃	-822	-741	90.0	PbBr ₂	-277	-260	162
H	+218	—	115	PbCl ₂	-359	-314	136
H ₂	0	0	131	S	0	0	31.9
HBr	-36.2	-53.2	198	SO ₂	-297	-300	249
HCl	-92.3	-95.3	187	SO ₃	-438	-388	95.6
HCl(aq)	-167	-131	56.5	SrO	-590	-580	54.4
HCN(aq)	+151	+172	94.1	Ti	0	0	30.3
HF	-289	-271	174	TiO ₂	—	-853	50.2
HI	+25.9	+1.30	206	TiI	-50.2	-83.3	236
H ₂ O(l)	-286	-237	70.0	UCl ₄	-1050	-962	198
H ₂ O(g)	-242	-229	189	UCl ₅	-1100	-993	259
H ₂ O ₂	—	-118	110	Zn	0	0	41.6
H ₃ PO ₂	-609	—	—	ZnCl ₂ (aq)	-487	-410	3.72
				ZnSO ₄ (aq)	-1063	-892	-92.0

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A list of the standard enthalpies of formation can be found at [URL HERE!](#) as well as in the resources tab of the website.

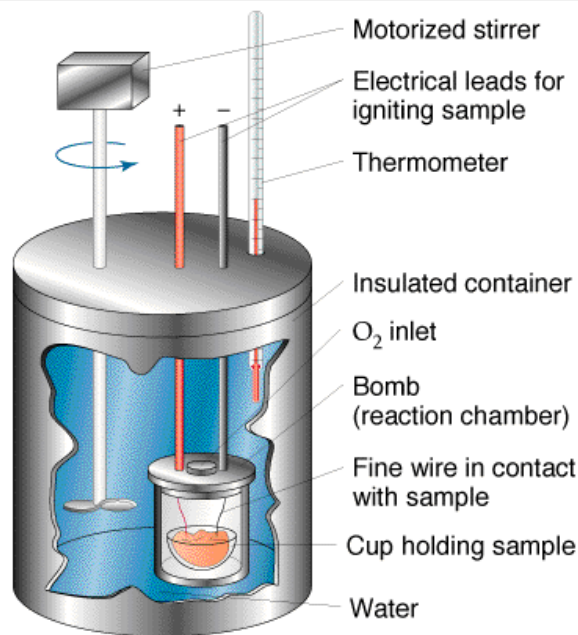
The enthalpies of formation can be written underneath each respective element, and then the above equation is used to find the total enthalpy of the equation.



Calorimetry

Calorimetry - The measure of heat absorbed or evolved in a chemical or physical reaction

Calorimeter - an object used to measure heat absorbed or evolved.



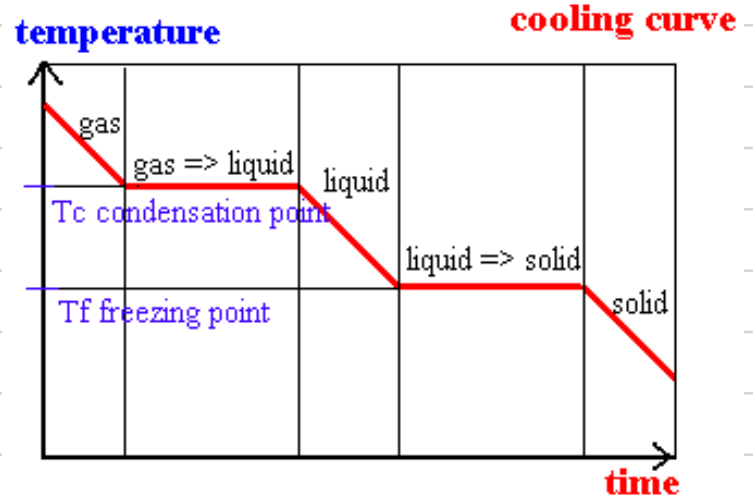
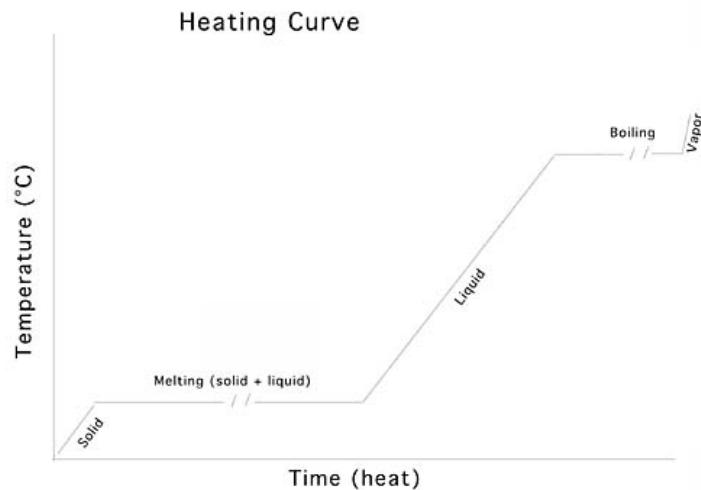
Pictured left is a calorimeter

Heat Capacity - The amount of heat required to raise a substance 1 degree celsius

Specific Heat Capacity - The amount of heat required to raise 1 gram of a substance 1 degree celsius

Latent heat of fusion / vaporization - The amount of energy required to cause an amount of a substance to undergo a phase change.

Heating and Cooling Curves



To any heating and cooling curve, there are generally five parts that need to be observed:

1. The initial up/down slope
2. The first flat line (melting/condensation point)
3. The upward/downward slope in the middle
4. The second flat line (evaporation/freezing point)
5. The final upward/downward slope

Using this information, it is possible to calculate the energy needed throughout phase changes.

Parts 1, 3, and 5 (with an upward/downward slope) can be calculated with the equation:

$$Q = mct$$

Where m is the mass of the substance

c is the object's specific heat

and t is the change in temperature (final - initial)

Parts 2 and 4 cannot be calculated with this equation, because there is no change in temperature. Instead, they need to be calculated using their latent heats of vaporization/fusion. The equation used for this is:

$$Q = mL$$

where m is the mass of the substance (or the molar amount, depending on what is available)

and L is the latent heat.

Solving Cooling Curve Problems

Calculate the energy required to raise the temperature of 18.0 grams of ice at -20 C to steam at 120 C . You have exactly one mole of water.

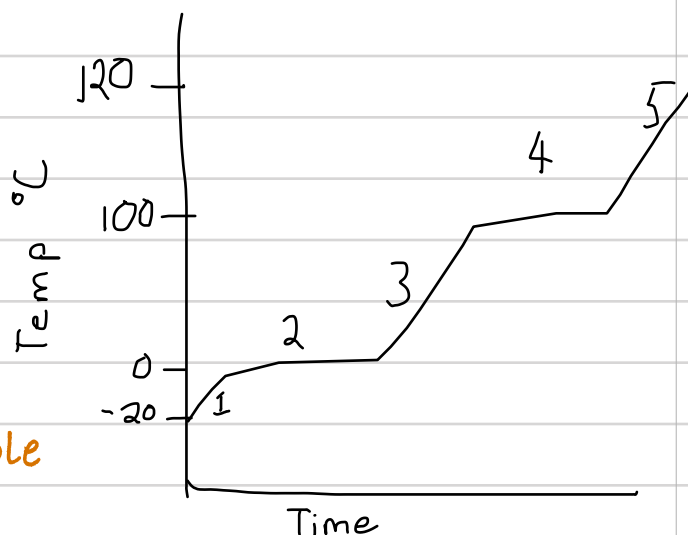
Spec. Heat of ice: 2.092 J/g C

Spec. Heat of water: 4.18 J/g C

Spec. Heat of steam: 2.092 J/g C

Heat of Fusion: 6020 J/mole

Heat of Vaporization: $40,700\text{ J/mole}$



$$Q = mc\Delta t$$

$$Q_1 = (2.092)(18)(0 - (-20)) = 753.12\text{ J}$$

$$Q_3 = (4.18)(18)(100 - 0) = 7524\text{ J}$$

$$Q_5 = (2.092)(18)(120 - 100) = 753.12\text{ J}$$

$$Q = mL$$

$$Q_2 = \frac{6020\text{ J}}{\text{mole}} \times 1\text{ mole} = 6020\text{ J}$$

$$Q_4 = \frac{40,700\text{ J}}{\text{mole}} \times 1\text{ mole} = 40,700\text{ J}$$

Once all values have been individually calculated, they are all added together to find the total energy added.

So, the total energy added in this case is 55,750.24 Joules.