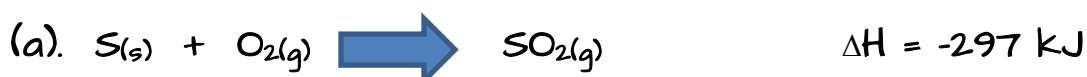


Chemistry Lecture #100: Hess's Law

Hess's law states that the change in enthalpy for a chemical reaction can be found by adding two or more thermochemical equations.

For example, suppose we are given the reactions

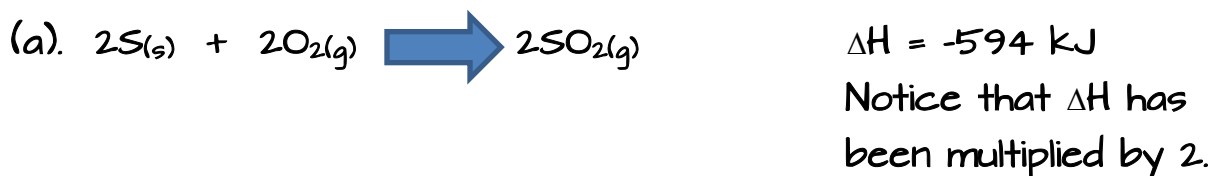
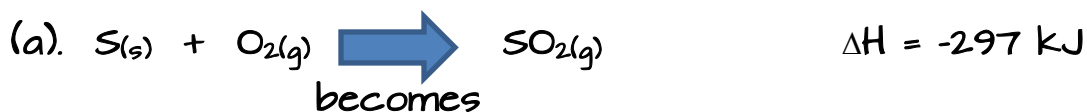


and we want to find the ΔH for the equation



We can add equations (a) and (b) to get the ΔH for equation (c). To do this, we need to modify equations (a) and (b) to make them look more like equation (c). We do this by multiplying and flipping the equations.

For example, equation (c) has a 2 in front of the S, while equation (a) has an implicit 1 in front of the S. So, we multiply equation (a) and its ΔH by 2 so the S matches equation (c).



Next, compare equation (b) with equation (c). Notice that 2SO_3 is on the left side of equation (b), while it is on the right side of equation (c).



To make equation (b) match equation (c), we reverse the equation, and also change the sign of ΔH .



If we add the modified equations (a) and (b) along with their ΔH 's, we get equation (c) and its ΔH .



The ΔH for a reaction can also be found if you know the heat of formation (ΔH°_f) of the product and reactants. The next page is a chart of thermodynamic properties which gives the heat of formation for various substances. Notice that elements have a ΔH°_f equal to zero.

Thermodynamic Properties (at 25°C and 100.000 kPa)

		ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol · K)			ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol · K)		
		(concentration of aqueous solutions is 1M)					(concentration of aqueous solutions is 1M)				
Substance	ΔH_f°	ΔG_f°	S°	Substance	ΔH_f°	ΔG_f°	S°	Substance	ΔH_f°	ΔG_f°	S°
Ag(cr)	0	0	42.55	H ₃ PO ₃ (aq)	-964.4	—	—	H ₃ PO ₃ (aq)	-964.4	—	—
AgCl(cr)	-127.068	-109.789	96.2	H ₃ PO ₄ (aq)	-1279.0	-1119.1	110.50	H ₃ PO ₄ (aq)	-1279.0	-1119.1	110.50
AgCN(cr)	146.0	156.9	107.19	H ₂ S(g)	-20.63	-33.56	205.79	H ₂ S(g)	-20.63	-33.56	205.79
Al(cr)	0	0	28.33	H ₂ SO ₃ (aq)	-608.81	-537.81	232.2	H ₂ SO ₃ (aq)	-608.81	-537.81	232.2
Al ₂ O ₃ (cr)	-1675.7	-1582.3	50.92	H ₂ SO ₄ (aq)	-909.27	-744.53	20.1	H ₂ SO ₄ (aq)	-909.27	-744.53	20.1
BaCl ₂ (aq)	-871.95	-823.21	122.6	HgCl ₂ (cr)	-224.3	-178.6	—	HgCl ₂ (cr)	-224.3	-178.6	—
BaSO ₄ (cr)	-1473.2	-1362.2	132.2	Hg ₂ Cl ₂ (cr)	-265.22	-210.745	192.5	Hg ₂ Cl ₂ (cr)	-265.22	-210.745	192.5
Be(cr)	0	0	9.50	Hg ₂ SO ₄ (cr)	-743.12	-625.815	200.66	Hg ₂ SO ₄ (cr)	-743.12	-625.815	200.66
BeO(cr)	-609.6	-580.3	—	I ₂ (cr)	0	0	116.135	I ₂ (cr)	0	0	116.135
Bi(cr)	0	0	56.74	K(cr)	0	0	64.18	K(cr)	0	0	64.18
BiCl ₃ (cr)	-379.1	-315.0	177.0	KBr(cr)	-393.798	-380.66	95.90	KBr(cr)	-393.798	-380.66	95.90
Bi ₂ S ₃ (cr)	-143.1	-140.6	200.4	KMnO ₄ (cr)	-837.2	-737.6	171.71	KMnO ₄ (cr)	-837.2	-737.6	171.71
Br ₂ (l)	0	0	152.231	KOH(cr)	-424.764	—	—	KOH(cr)	-424.764	—	—
CH ₄ (g)	-74.81	-50.72	186.264	LiBr(cr)	-351.213	—	—	LiBr(cr)	-351.213	—	—
C ₂ H ₂ (g)	+226.73	+209.20	200.94	LiOH(cr)	-484.93	-438.95	42.80	LiOH(cr)	-484.93	-438.95	42.80
C ₂ H ₄ (g)	+52.26	+68.15	219.56	Mn(cr)	0	0	32.01	Mn(cr)	0	0	32.01
C ₂ H ₆ (g)	-84.68	-32.82	229.60	MnCl ₂ (aq)	-555.05	-490.8	38.9	MnCl ₂ (aq)	-555.05	-490.8	38.9
CO(g)	-110.525	-137.168	197.674	Mn(NO ₃) ₂ (aq)	-635.5	-450.9	218	Mn(NO ₃) ₂ (aq)	-635.5	-450.9	218
CO ₂ (g)	-393.509	-394.359	213.74	MnO ₂ (cr)	-520.03	-465.14	53.05	MnO ₂ (cr)	-520.03	-465.14	53.05
CS ₂ (l)	+89.70	+65.27	151.34	MnS(cr)	-214.2	—	—	MnS(cr)	-214.2	—	—
Ca(cr)	0	0	41.42	N ₂ (g)	0	0	191.61	N ₂ (g)	0	0	191.61
Ca(OH) ₂ (cr)	-986.09	-898.49	—	NH ₃ (g)	-46.11	-16.45	192.45	NH ₃ (g)	-46.11	-16.45	192.45
Cl ₂ (g)	0	0	223.066	NH ₄ Br(cr)	-270.83	-175.2	113	NH ₄ Br(cr)	-270.83	-175.2	113
Co ₃ O ₄ (cr)	-891	-774	—	NO(g)	+90.25	86.55	210.761	NO(g)	+90.25	86.55	210.761
CoO(cr)	-237.94	-214.20	52.97	NO ₂ (g)	+33.18	+51.31	240.06	NO ₂ (g)	+33.18	+51.31	240.06
Cr ₂ O ₃ (cr)	-1139.7	-1058.1	81.2	N ₂ O(g)	+82.05	+104.20	219.85	N ₂ O(g)	+82.05	+104.20	219.85
CsCl(cr)	-443.04	-414.53	101.17	Na(cr)	0	0	51.21	Na(cr)	0	0	51.21
Cs ₂ SO ₄ (cr)	-1443.02	-1323.58	211.92	NaBr(cr)	-361.062	—	—	NaBr(cr)	-361.062	—	—
CuI(cr)	-67.8	-69.5	96.7	NaCl(cr)	-411.153	-384.138	72.13	NaCl(cr)	-411.153	-384.138	72.13
CuS(cr)	-53.1	-53.6	66.5	NaNO ₃ (aq)	-447.48	—	—	NaNO ₃ (aq)	-447.48	—	—
Cu ₂ S(cr)	-79.5	-86.2	120.9	NaOH(cr)	-425.609	—	—	NaOH(cr)	-425.609	—	—
CuSO ₄ (cr)	-771.36	-661.8	109	Na ₂ S(aq)	-447.3	—	—	Na ₂ S(aq)	-447.3	—	—
F ₂ (g)	0	0	202.78	Na ₂ SO ₄ (cr)	-1387.08	-1270.16	149.58	Na ₂ SO ₄ (cr)	-1387.08	-1270.16	149.58
FeCl ₃ (cr)	-399.49	—	—	O ₂ (g)	0	0	205.138	O ₂ (g)	0	0	205.138
FeO(cr)	-272.0	—	—	P ₄ O ₆ (cr)	-1640.1	—	—	P ₄ O ₆ (cr)	-1640.1	—	—
Fe ₂ O ₃ (cr)	-824.2	-742.2	87.40	P ₄ O ₁₀ (cr)	-2984.0	-2697.7	228.86	P ₄ O ₁₀ (cr)	-2984.0	-2697.7	228.86
Fe ₃ O ₄ (cr)	-1118.4	-1015.4	146.4	PbBr ₂ (cr)	-278.7	-261.92	161.5	PbBr ₂ (cr)	-278.7	-261.92	161.5
H(g)	+217.965	—	114.713	PbCl ₂ (cr)	-359.41	-314.10	136.0	PbCl ₂ (cr)	-359.41	-314.10	136.0
H ₂ (g)	0	0	130.684	S(cr)	0	0	31.80	S(cr)	0	0	31.80
HBr(g)	-36.40	-53.45	198.695	SO ₂ (g)	-296.830	-300.194	248.22	SO ₂ (g)	-296.830	-300.194	248.22
HCl(g)	-92.307	-95.299	186.908	SO ₃ (g)	-454.51	-374.21	70.7	SO ₃ (g)	-454.51	-374.21	70.7
HCl(aq)	-167.159	-131.228	56.5	SrO(cr)	-592.0	-561.9	54.4	SrO(cr)	-592.0	-561.9	54.4
HCN(aq)	+150.6	+172.4	94.1	Ti(cr)	0	0	30.63	Ti(cr)	0	0	30.63
HCHO(g)	-108.57	-102.53	218.77	TiO ₂ (cr)	-939.7	-884.5	49.92	TiO ₂ (cr)	-939.7	-884.5	49.92
HCOOH(l)	-424.72	-361.35	128.95	TiI ₂ (cr)	-123.8	-125.39	127.6	TiI ₂ (cr)	-123.8	-125.39	127.6
HF(g)	-271.1	-273.2	173.779	UCl ₄ (cr)	-1019.2	-930.0	197.1	UCl ₄ (cr)	-1019.2	-930.0	197.1
HI(g)	+26.48	+1.70	206.594	UCl ₅ (cr)	-1059	-950	242.7	UCl ₅ (cr)	-1059	-950	242.7
H ₂ O(l)	-285.830	-237.129	69.91	Zn(cr)	0	0	41.63	Zn(cr)	0	0	41.63
H ₂ O(g)	-241.818	-228.572	188.825	ZnCl ₂ (aq)	-488.19	-409.50	0.8	ZnCl ₂ (aq)	-488.19	-409.50	0.8
H ₂ O ₂ (l)	—	-120.35	109.6	ZnO(cr)	-348.28	-318.30	43.64	ZnO(cr)	-348.28	-318.30	43.64
H ₃ PO ₂ (l)	-595.4	—	—	ZnSO ₄ (aq)	-1063.15	-891.59	-92.0	ZnSO ₄ (aq)	-1063.15	-891.59	-92.0

The heat of formation for a reaction can be calculated using the formula

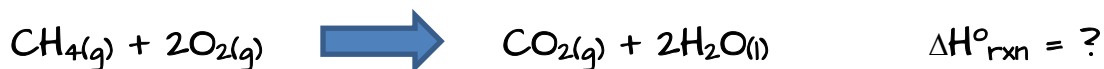
$$\Delta H^{\circ}_{\text{rxn}} = \sum \Delta H^{\circ}_{\text{f}} (\text{products}) - \sum \Delta H^{\circ}_{\text{f}} (\text{reactants})$$

$\Delta H^{\circ}_{\text{rxn}}$ = change in enthalpy for a reaction

$\sum \Delta H^{\circ}_{\text{f}} (\text{products})$ = sum of the $\Delta H^{\circ}_{\text{f}}$ of the products

$\sum \Delta H^{\circ}_{\text{f}} (\text{reactants})$ = sum of the $\Delta H^{\circ}_{\text{f}}$ of the reactants

Using the chart of thermodynamic properties, find the $\Delta H^\circ_{\text{rxn}}$ for the reaction



Solution

Using the thermodynamic properties chart, list the ΔH°_f of each product and reactant.

ΔH°_f products (kJ/mole)

$$\text{CO}_2(g) = -394$$

$$\text{H}_2\text{O}(l) = -286 \times 2 = -572$$

ΔH°_f reactants (kJ/mole)

$$\text{CH}_4(g) = -74.8$$

$$\text{O}_2(g) = 0.0 \times 2 = 0$$

Notice that the for H_2O and O_2 , we multiplied the values by 2. This is because there is a 2 in front of these substances in the balanced equation.

Next, add the ΔH°_f of the products and reactants.

$$\sum \Delta H^\circ_f (\text{products}) = -394 + (-572) = -966$$

$$\sum \Delta H^\circ_f (\text{reactants}) = -74.8 + 0 = -74.8$$

Finally, subtract $\sum \Delta H^\circ_f$ (reactants) from $\sum \Delta H^\circ_f$ (products) to get $\Delta H^\circ_{\text{rxn}}$.

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

$$\Delta H^\circ_{\text{rxn}} = -966 - (-74.8)$$

$$\Delta H^\circ_{\text{rxn}} = -891.2 \text{ or } -891 \text{ kJ}$$

Thus, the combustion of one mole of $\text{CH}_4(g)$ produces 891 kJ of energy.