Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

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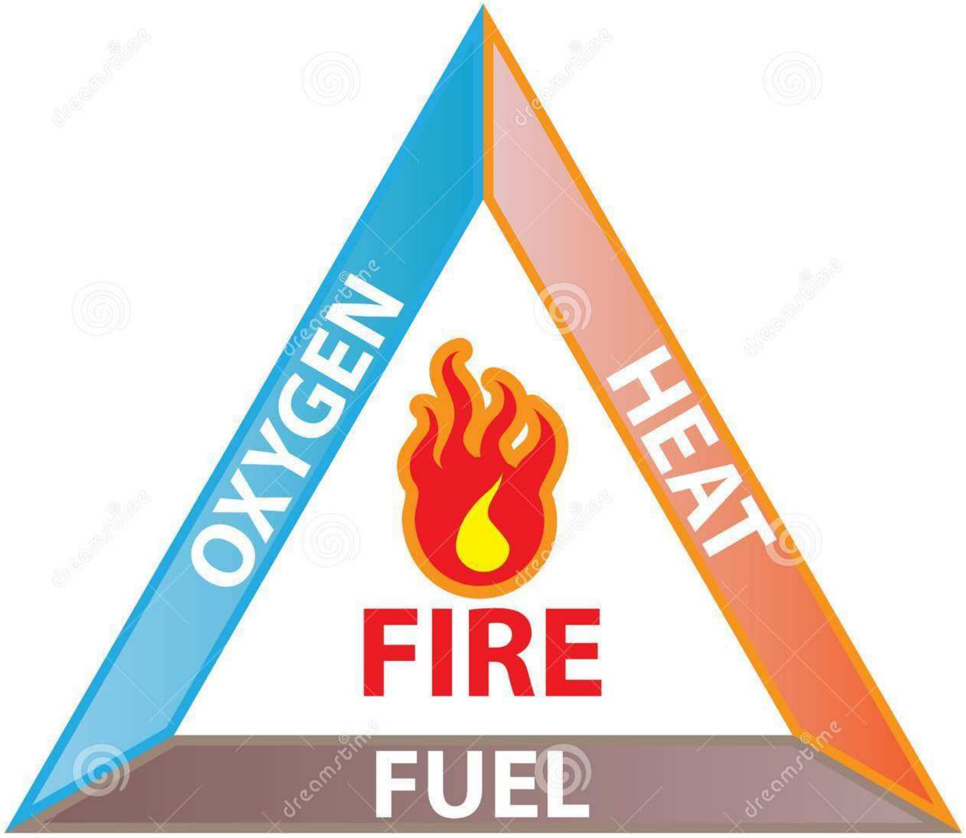
Technologies of combustion

Combustion definition

Combustion is essentially burning, fuels react with oxygen to release energy



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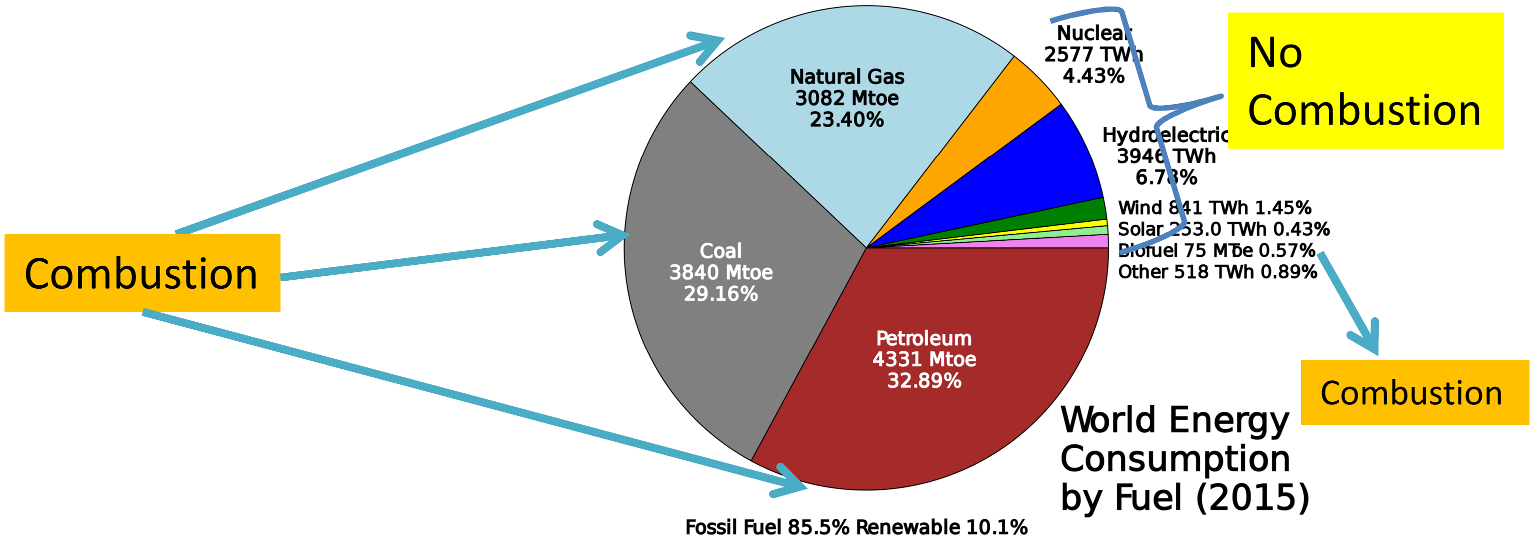
Combustion use in the world



World Energy Consumption by Fuel (2015)

Combustion

No Combustion

Combustion

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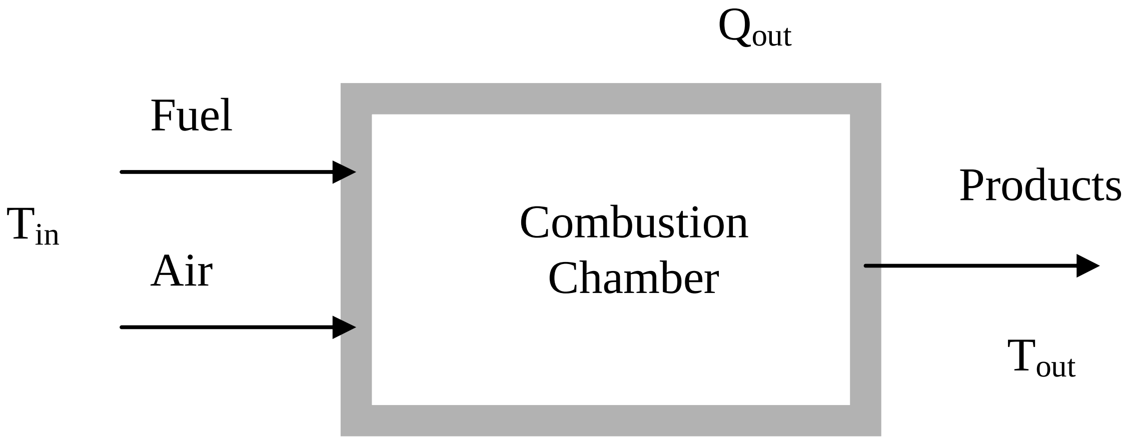
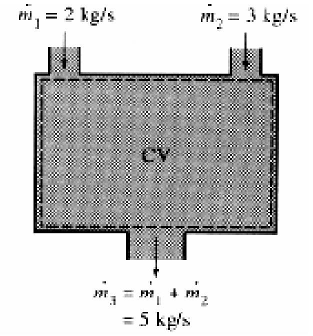
Thermochemistry

$$fuel + oxidizer \rightarrow products$$



Conservation of mass

$$\left(Massa\ que\ entra\right)-\left(Massa\ que\ sai\right)=\left(Variação\ total\ massa\ sistema\right)$$



$$\sum_e \dot{m}_e - \sum_s \dot{m}_s = \frac{dm_{vc}}{dt}$$

Regime permanente/estacionário

$$\boxed{\sum_e \dot{m}_e = \sum_s \dot{m}_s}\ ,\ \frac{dm_{vc}}{dt} = 0$$

Caudal mássico (kg/s)

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Conservation of Energy

1st Law thermodynamics conservation of energy

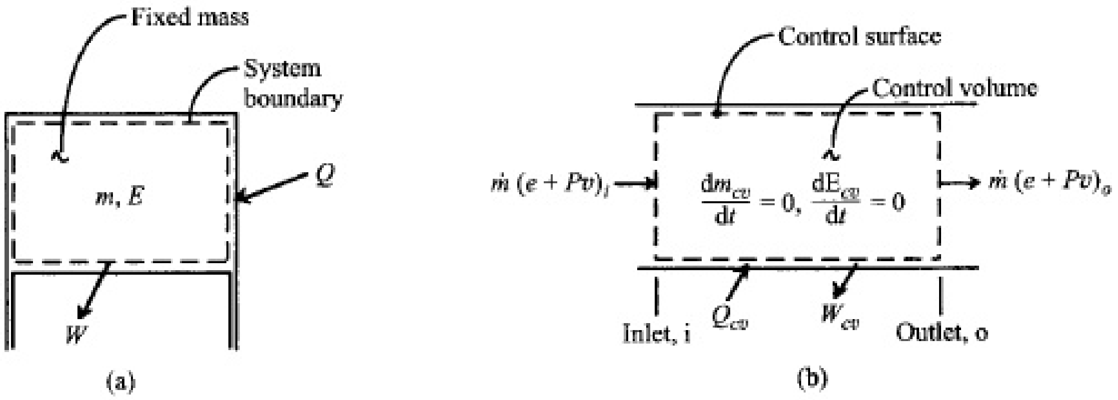

Figure 2.3 (a) Schematic of fixed-mass system with moving boundary above piston. (b) Control volume with fixed boundaries and steady flow.

- Closed system
- Open system

$$\Delta E = \Delta EP + \Delta EC + \Delta U = Q - W$$

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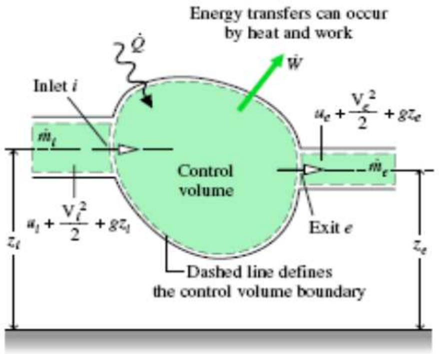
Open system



Usando definição de entalpia

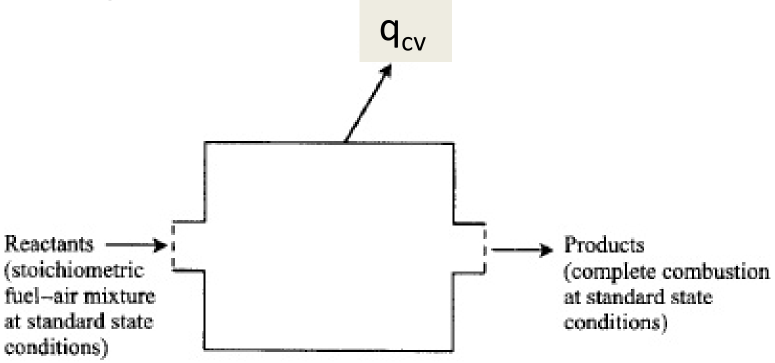
Energia interna e capacidade de fazer trabalho por estar a uma certa pressao e temperatura

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(u_i + p_i v_i + \frac{V_i^2}{2} + gz_i\right) - \dot{m}_e\left(u_e + p_e v_e + \frac{V_e^2}{2} + gz_e\right)$$

$$\boxed{\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)}$$

Thermochemistry

$$reactants(fuel + oxidizer) \rightarrow products$$



$\dot{m}_i = \dot{m}_e$ (kg/s)

Figure 2.7 Steady-flow reactor used to determine enthalpy of combustion.

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{CV}$$

$$\dot{Q}_{net} + \underbrace{\sum \dot{m}_i \left(h_i + \cancel{\frac{\vec{V}_i^2}{2}} + \cancel{g z_i} \right)}_{\text{for each inlet}} - \underset{=0}{\cancel{\dot{W}_{net}}} - \underbrace{\sum \dot{m}_e \left(h_e + \cancel{\frac{\vec{V}_e^2}{2}} + \cancel{g z_e} \right)}_{\text{for each exit}} = \underset{=0}{\cancel{\Delta\dot{E}_{CV}}}$$

(J)

regime estacionário

$q_{cv} = h_{reactants} - h_{products}$ (J/kg)

Thermochemistry

$\overline{R} = 8.314\, kJ / kmol.K$ Constante universal dos gases

$Z = \dfrac{pv}{RT}$ Factor de compressibilidade

$R = \dfrac{\overline{R}}{M}$ kJ/kg.K

Z=1 é gas perfeito

$$pv = RT$$

$$u = u(T)$$

$$h = h(T) = u(T) + RT$$

$$c_p(T) = c_v(T) + R$$

$$u(T_2) - u(T_1) = \int_{T_1}^{T_2} c_v(T)dT$$

$$h(T_2) - h(T_1) = \int_{T_1}^{T_2} c_p(T)dT$$

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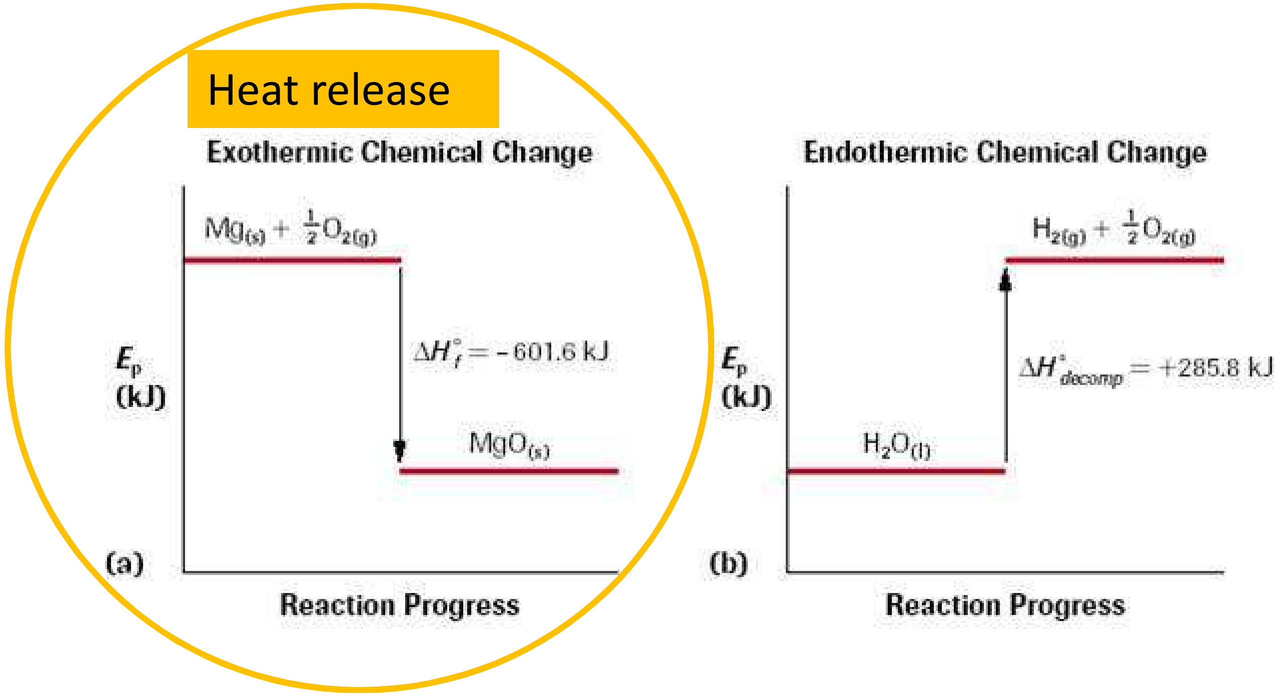
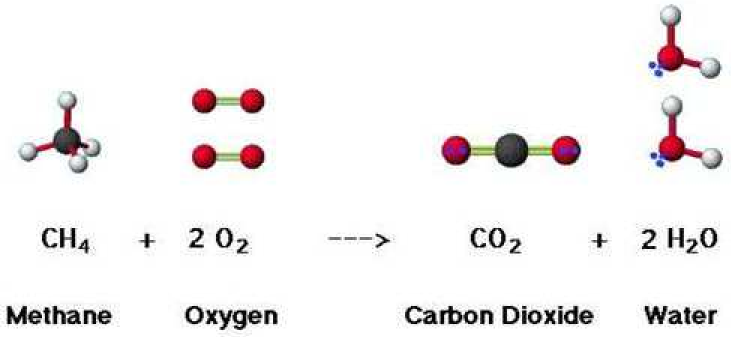
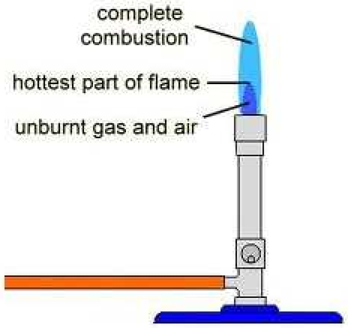
Thermochemistry



In combustion chemical bonds break, others form, but the energy balance is **exothermic**

Thermochemistry





$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{energy}$$

CONCEPT QUESTIONS

Endothermic or Exothermic?

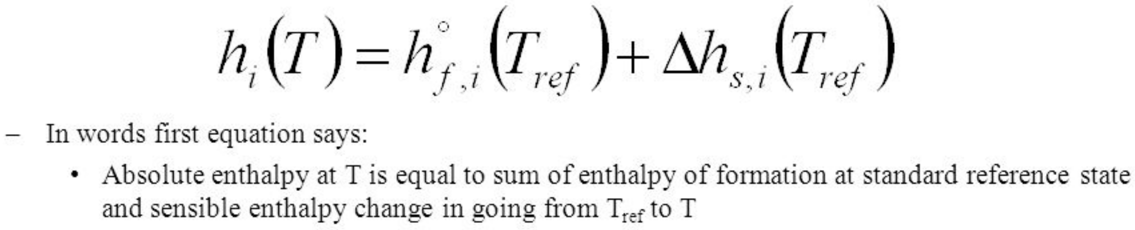
+ΔH or - ΔH ?

Heat release

Thermochemistry

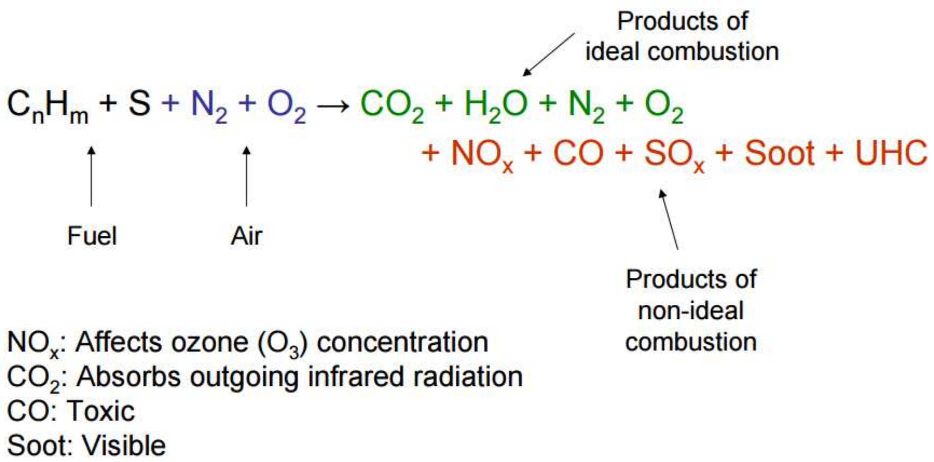
$$q_{cv} = \underbrace{h_{reactants} - h_{products}}_{\text{Enthalpy of reaction } = -\Delta h_R} \qquad (J/kg)$$

q_{cv} = Heat of reaction



$$h_i(T) = h^{\circ}_{f,i}(T_{ref}) + \Delta h_{s,i}(T_{ref})$$

- In words first equation says:
  - Absolute enthalpy at T is equal to sum of enthalpy of formation at standard reference state and sensible enthalpy change in going from T_{ref} to T



Products of ideal combustion

$$C_nH_m + S + N_2 + O_2 \rightarrow CO_2 + H_2O + N_2 + O_2 + NO_x + CO + SO_x + \text{Soot} + \text{UHC}$$

Fuel

Air

Products of non-ideal combustion

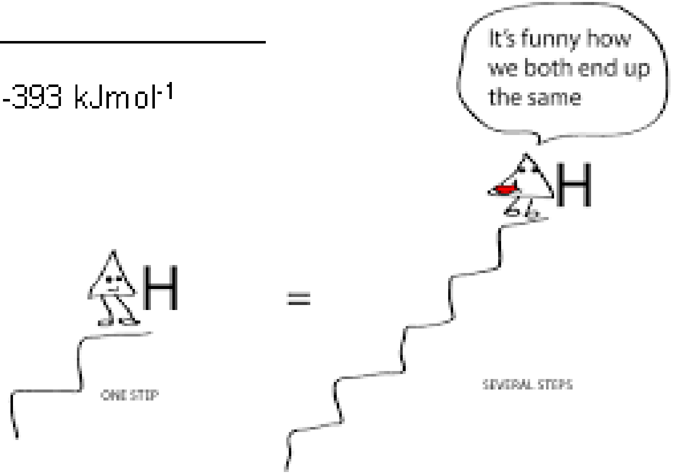
NO_x: Affects ozone (O_3) concentration
CO_2: Absorbs outgoing infrared radiation
CO: Toxic
Soot: Visible

Thermochemistry

HESS LAW

total enthalpy change during the complete course of a chemical reaction is the same whether the reaction is made in one step or in several steps

$$
\begin{array}{lclcl}
C & + & \frac{1}{2} O_2 & \rightarrow & \cancel{CO} \quad \Delta H = -110\ kJmol^{-1} \\
\cancel{CO} & + & \frac{1}{2} O_2 & \rightarrow & CO_2 \quad \Delta H = -283\ kJmol^{-1} \\
\hline
C & + & O_2 & \rightarrow & CO_2 \quad \Delta H = -393\ kJmol^{-1}
\end{array}
$$



Thermochemistry

HEATING VALUE AND ENTHALPY OF REACTION

Constant pressure

25 °C

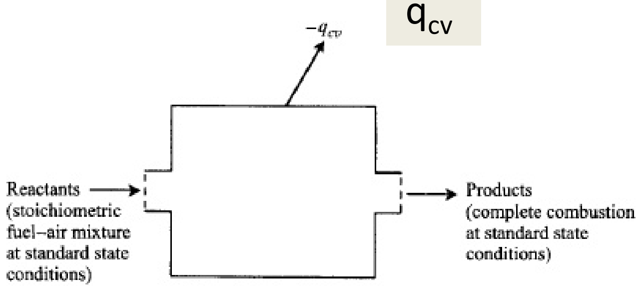


Figure 2.7 Steady-flow reactor used to determine enthalpy of combustion.

q_{cv}

25 °C

$$C_xH_yO_z + n(0.21O_2 + 0.79N_2) \rightarrow xCO_2 + yH_2O + 0.79 * nN_2$$

HHV = maximum heat release condensing water heat of vaporization **(2443 kJ/kg; 44010 kJ/kmol)**

LHV = q_{cv} in the reaction products is not recovered

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Thermochemistry

$$fuel + oxidizer \rightarrow products$$

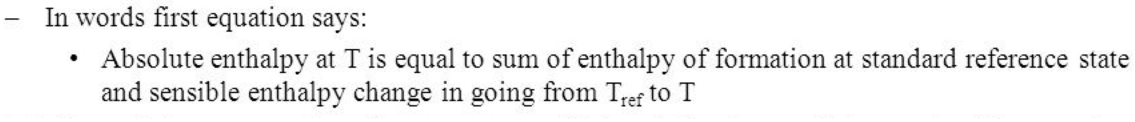
Standard reference state

T_{ref}= 25ºC (298.15 K)

P_{ref}= 1 atm (101.325 kpa = 1 bar)

h_{ref}= $h^{\circ}_{f,i}\left(T_{ref}\right)$ =u+pv (J/kg)

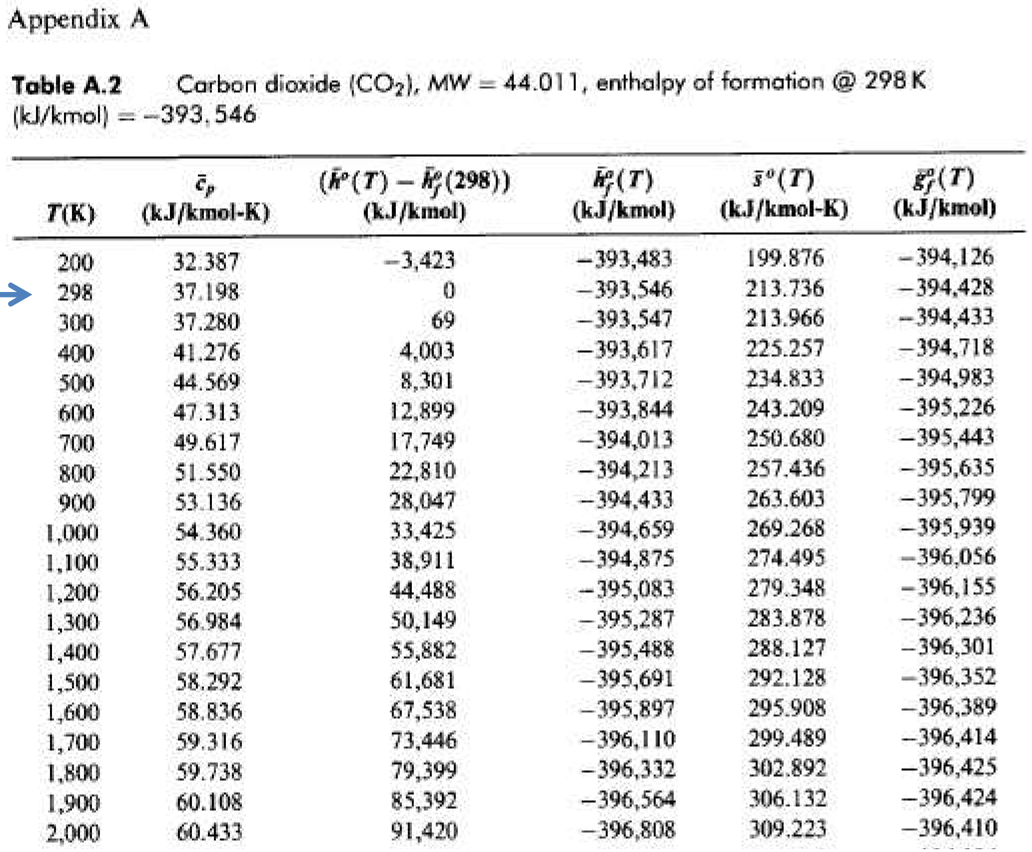
$$h_i\left(T\right) = h^{\circ}_{f,i}\left(T_{ref}\right) + \Delta h_{s,i}\left(T_{ref}\right) \qquad \text{(J/kg)}$$



- In words first equation says:
  - Absolute enthalpy at T is equal to sum of enthalpy of formation at standard reference state and sensible enthalpy change in going from T_{ref} to T

º Pressao atmosferica

Thermochemistry



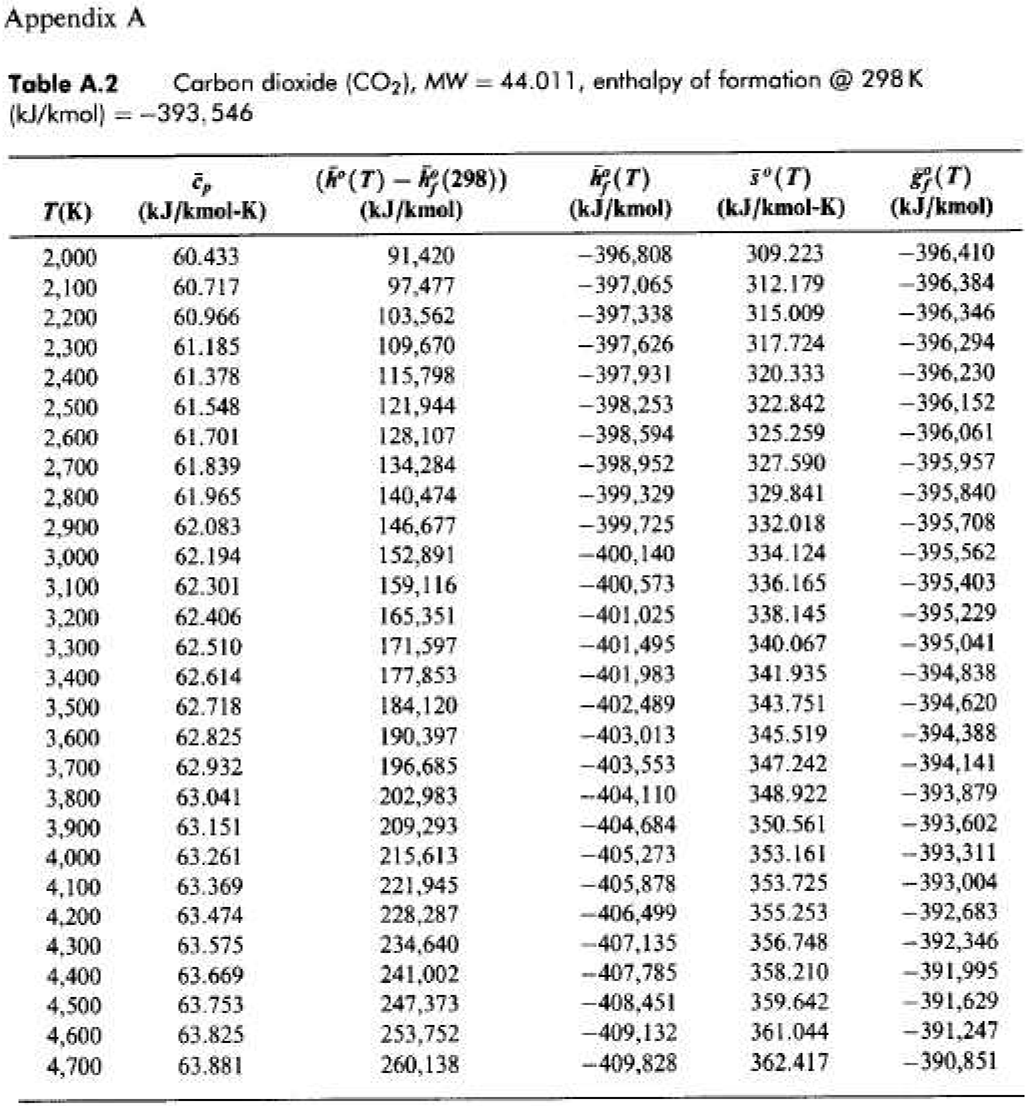
Appendix A

Table A.2 Carbon dioxide (CO_2), MW = 44.011, enthalpy of formation @ 298 K (kJ/kmol) = −393, 546

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	32.387	−3,423	−393,483	199.876	−394,126
298	37.198	0	−393,546	213.736	−394,428
300	37.280	69	−393,547	213.966	−394,433
400	41.276	4,003	−393,617	225.257	−394,718
500	44.569	8,301	−393,712	234.833	−394,983
600	47.313	12,899	−393,844	243.209	−395,226
700	49.617	17,749	−394,013	250.680	−395,443
800	51.550	22,810	−394,213	257.436	−395,635
900	53.136	28,047	−394,433	263.603	−395,799
1,000	54.360	33,425	−394,659	269.268	−395,939
1,100	55.333	38,911	−394,875	274.495	−396,056
1,200	56.205	44,488	−395,083	279.348	−396,155
1,300	56.984	50,149	−395,287	283.878	−396,236
1,400	57.677	55,882	−395,488	288.127	−396,301
1,500	58.292	61,681	−395,691	292.128	−396,352
1,600	58.836	67,538	−395,897	295.908	−396,389
1,700	59.316	73,446	−396,110	299.489	−396,414
1,800	59.738	79,399	−396,332	302.892	−396,425
1,900	60.108	85,392	−396,564	306.132	−396,424
2,000	60.433	91,420	−396,808	309.223	−396,410

CO_2

Thermochemistry



Appendix A

Table A.2 Carbon dioxide (CO_2), MW = 44.011, enthalpy of formation @ 298 K (kJ/kmol) = −393,546

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
2,000	60.433	91,420	−396,808	309.223	−396,410
2,100	60.717	97,477	−397,065	312.179	−396,384
2,200	60.966	103,562	−397,338	315.009	−396,346
2,300	61.185	109,670	−397,626	317.724	−396,294
2,400	61.378	115,798	−397,931	320.333	−396,230
2,500	61.548	121,944	−398,253	322.842	−396,152
2,600	61.701	128,107	−398,594	325.259	−396,061
2,700	61.839	134,284	−398,952	327.590	−395,957
2,800	61.965	140,474	−399,329	329.841	−395,840
2,900	62.083	146,677	−399,725	332.018	−395,708
3,000	62.194	152,891	−400,140	334.124	−395,562
3,100	62.301	159,116	−400,573	336.165	−395,403
3,200	62.406	165,351	−401,025	338.145	−395,229
3,300	62.510	171,597	−401,495	340.067	−395,041
3,400	62.614	177,853	−401,983	341.935	−394,838
3,500	62.718	184,120	−402,489	343.751	−394,620
3,600	62.825	190,397	−403,013	345.519	−394,388
3,700	62.932	196,685	−403,553	347.242	−394,141
3,800	63.041	202,983	−404,110	348.922	−393,879
3,900	63.151	209,293	−404,684	350.561	−393,602
4,000	63.261	215,613	−405,273	353.161	−393,311
4,100	63.369	221,945	−405,878	353.725	−393,004
4,200	63.474	228,287	−406,499	355.253	−392,683
4,300	63.575	234,640	−407,135	356.748	−392,346
4,400	63.669	241,002	−407,785	358.210	−391,995
4,500	63.753	247,373	−408,451	359.642	−391,629
4,600	63.825	253,752	−409,132	361.044	−391,247
4,700	63.881	260,138	−409,828	362.417	−390,851

CO_2

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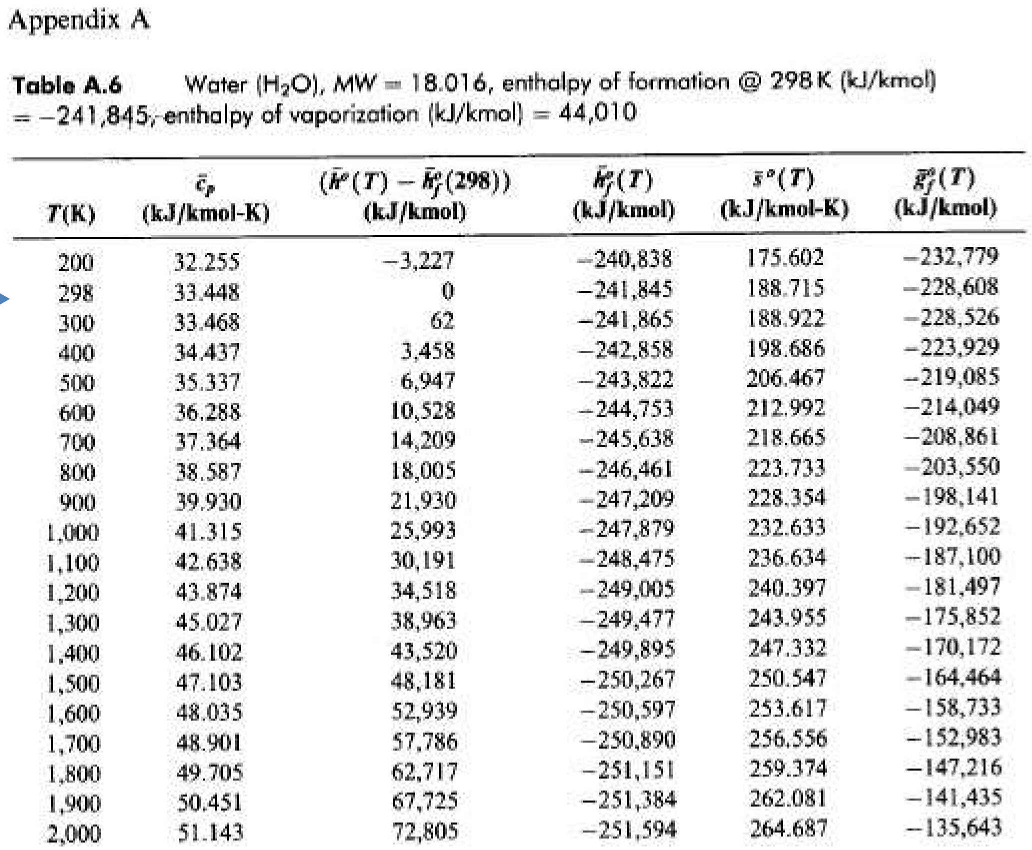
Thermochemistry



Appendix A

Table A.6 Water (H_2O), MW = 18.016, enthalpy of formation @ 298 K (kJ/kmol) = −241,845, enthalpy of vaporization (kJ/kmol) = 44,010

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	32.255	−3,227	−240,838	175.602	−232,779
298	33.448	0	−241,845	188.715	−228,608
300	33.468	62	−241,865	188.922	−228,526
400	34.437	3,458	−242,858	198.686	−223,929
500	35.337	6,947	−243,822	206.467	−219,085
600	36.288	10,528	−244,753	212.992	−214,049
700	37.364	14,209	−245,638	218.665	−208,861
800	38.587	18,005	−246,461	223.733	−203,550
900	39.930	21,930	−247,209	228.354	−198,141
1,000	41.315	25,993	−247,879	232.633	−192,652
1,100	42.638	30,191	−248,475	236.634	−187,100
1,200	43.874	34,518	−249,005	240.397	−181,497
1,300	45.027	38,963	−249,477	243.955	−175,852
1,400	46.102	43,520	−249,895	247.332	−170,172
1,500	47.103	48,181	−250,267	250.547	−164,464
1,600	48.035	52,939	−250,597	253.617	−158,733
1,700	48.901	57,786	−250,890	256.556	−152,983
1,800	49.705	62,717	−251,151	259.374	−147,216
1,900	50.451	67,725	−251,384	262.081	−141,435
2,000	51.143	72,805	−251,594	264.687	−135,643

H_2O

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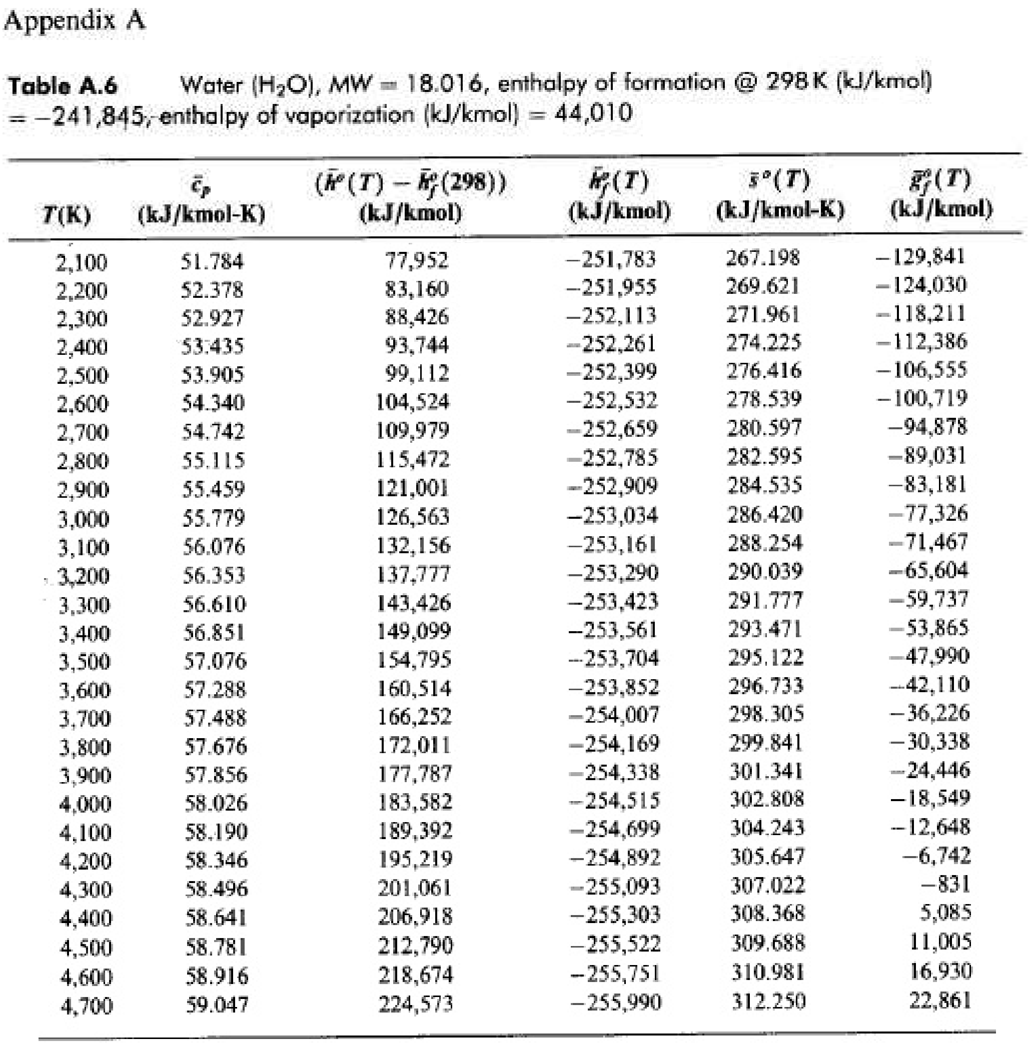
Thermochemistry



Appendix A

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T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}_f^o(298))$ (kJ/kmol)	$\bar{h}_f^o(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}_f^o(T)$ (kJ/kmol)
2,100	51.784	77,952	−251,783	267.198	−129,841
2,200	52.378	83,160	−251,955	269.621	−124,030
2,300	52.927	88,426	−252,113	271.961	−118,211
2,400	53.435	93,744	−252,261	274.225	−112,386
2,500	53.905	99,112	−252,399	276.416	−106,555
2,600	54.340	104,524	−252,532	278.539	−100,719
2,700	54.742	109,979	−252,659	280.597	−94,878
2,800	55.115	115,472	−252,785	282.595	−89,031
2,900	55.459	121,001	−252,909	284.535	−83,181
3,000	55.779	126,563	−253,034	286.420	−77,326
3,100	56.076	132,156	−253,161	288.254	−71,467
3,200	56.353	137,777	−253,290	290.039	−65,604
3,300	56.610	143,426	−253,423	291.777	−59,737
3,400	56.851	149,099	−253,561	293.471	−53,865
3,500	57.076	154,795	−253,704	295.122	−47,990
3,600	57.288	160,514	−253,852	296.733	−42,110
3,700	57.488	166,252	−254,007	298.305	−36,226
3,800	57.676	172,011	−254,169	299.841	−30,338
3,900	57.856	177,787	−254,338	301.341	−24,446
4,000	58.026	183,582	−254,515	302.808	−18,549
4,100	58.190	189,392	−254,699	304.243	−12,648
4,200	58.346	195,219	−254,892	305.647	−6,742
4,300	58.496	201,061	−255,093	307.022	−831
4,400	58.641	206,918	−255,303	308.368	5,085
4,500	58.781	212,790	−255,522	309.688	11,005
4,600	58.916	218,674	−255,751	310.981	16,930
4,700	59.047	224,573	−255,990	312.250	22,861

H_2O

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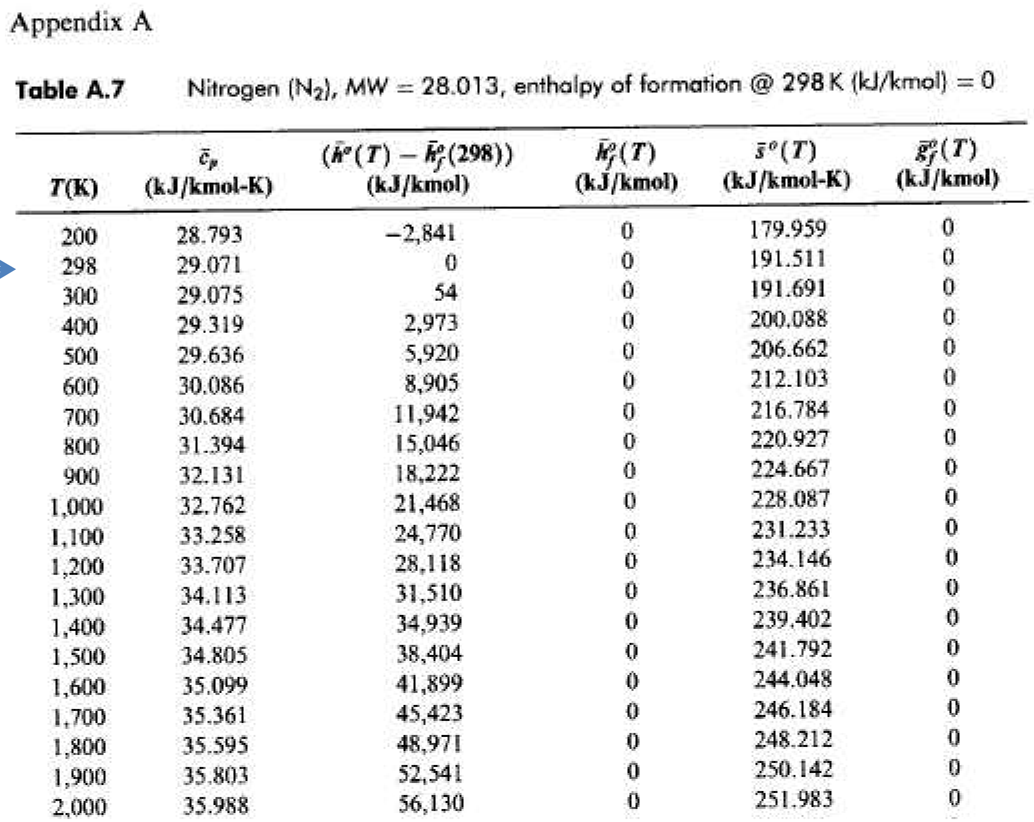
Thermochemistry



Appendix A

Table A.7 Nitrogen (N_2), MW = 28.013, enthalpy of formation @ 298 K (kJ/kmol) = 0

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	28.793	−2,841	0	179.959	0
298	29.071	0	0	191.511	0
300	29.075	54	0	191.691	0
400	29.319	2,973	0	200.088	0
500	29.636	5,920	0	206.662	0
600	30.086	8,905	0	212.103	0
700	30.684	11,942	0	216.784	0
800	31.394	15,046	0	220.927	0
900	32.131	18,222	0	224.667	0
1,000	32.762	21,468	0	228.087	0
1,100	33.258	24,770	0	231.233	0
1,200	33.707	28,118	0	234.146	0
1,300	34.113	31,510	0	236.861	0
1,400	34.477	34,939	0	239.402	0
1,500	34.805	38,404	0	241.792	0
1,600	35.099	41,899	0	244.048	0
1,700	35.361	45,423	0	246.184	0
1,800	35.595	48,971	0	248.212	0
1,900	35.803	52,541	0	250.142	0
2,000	35.988	56,130	0	251.983	0

N_2

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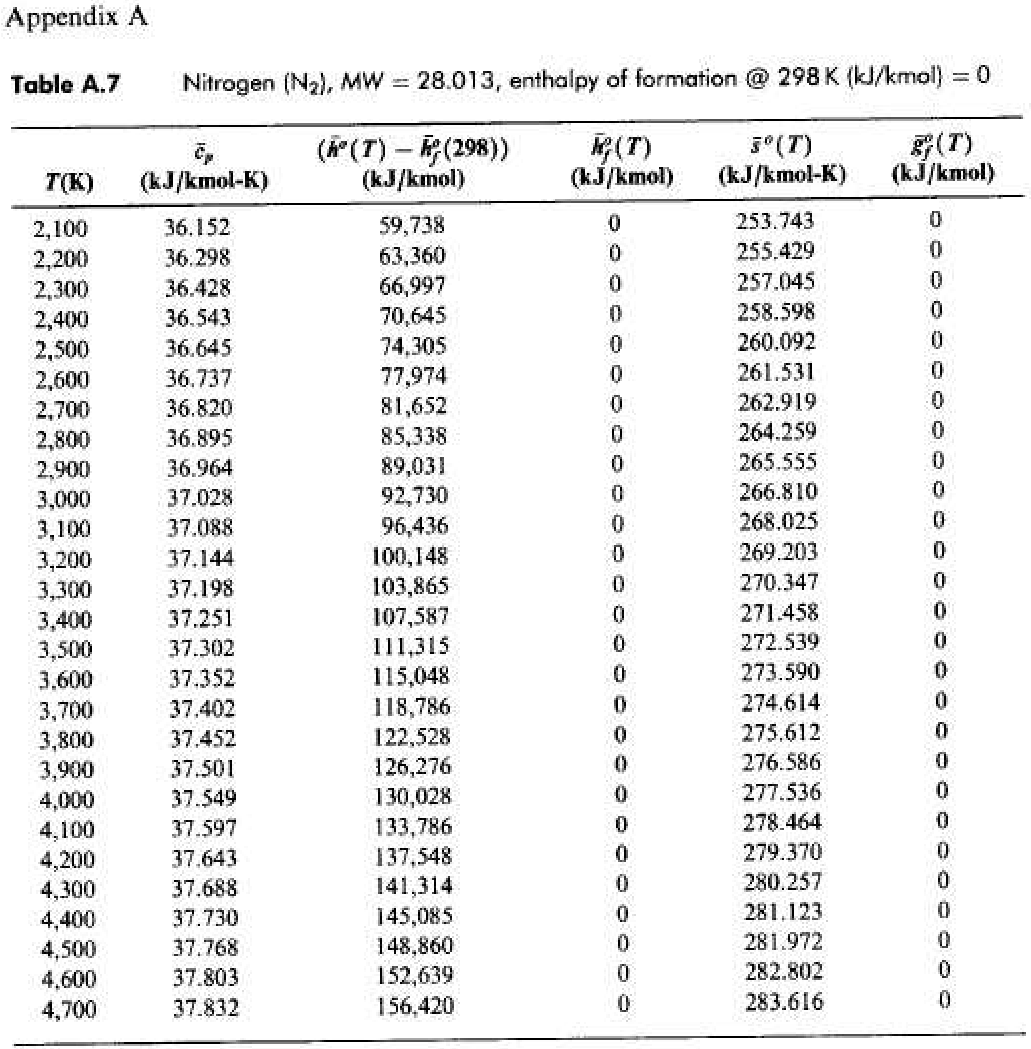
Thermochemistry



Appendix A

Table A.7 Nitrogen (N_2), MW = 28.013, enthalpy of formation @ 298 K (kJ/kmol) = 0

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
2,100	36.152	59,738	0	253.743	0
2,200	36.298	63,360	0	255.429	0
2,300	36.428	66,997	0	257.045	0
2,400	36.543	70,645	0	258.598	0
2,500	36.645	74,305	0	260.092	0
2,600	36.737	77,974	0	261.531	0
2,700	36.820	81,652	0	262.919	0
2,800	36.895	85,338	0	264.259	0
2,900	36.964	89,031	0	265.555	0
3,000	37.028	92,730	0	266.810	0
3,100	37.088	96,436	0	268.025	0
3,200	37.144	100,148	0	269.203	0
3,300	37.198	103,865	0	270.347	0
3,400	37.251	107,587	0	271.458	0
3,500	37.302	111,315	0	272.539	0
3,600	37.352	115,048	0	273.590	0
3,700	37.402	118,786	0	274.614	0
3,800	37.452	122,528	0	275.612	0
3,900	37.501	126,276	0	276.586	0
4,000	37.549	130,028	0	277.536	0
4,100	37.597	133,786	0	278.464	0
4,200	37.643	137,548	0	279.370	0
4,300	37.688	141,314	0	280.257	0
4,400	37.730	145,085	0	281.123	0
4,500	37.768	148,860	0	281.972	0
4,600	37.803	152,639	0	282.802	0
4,700	37.832	156,420	0	283.616	0

N_2

Thermochemistry

P#3 Determine the reference enthalpy of combustion of methane, CH_4, with air with λ=1. what is the lower and higher heating value for methane combustion?

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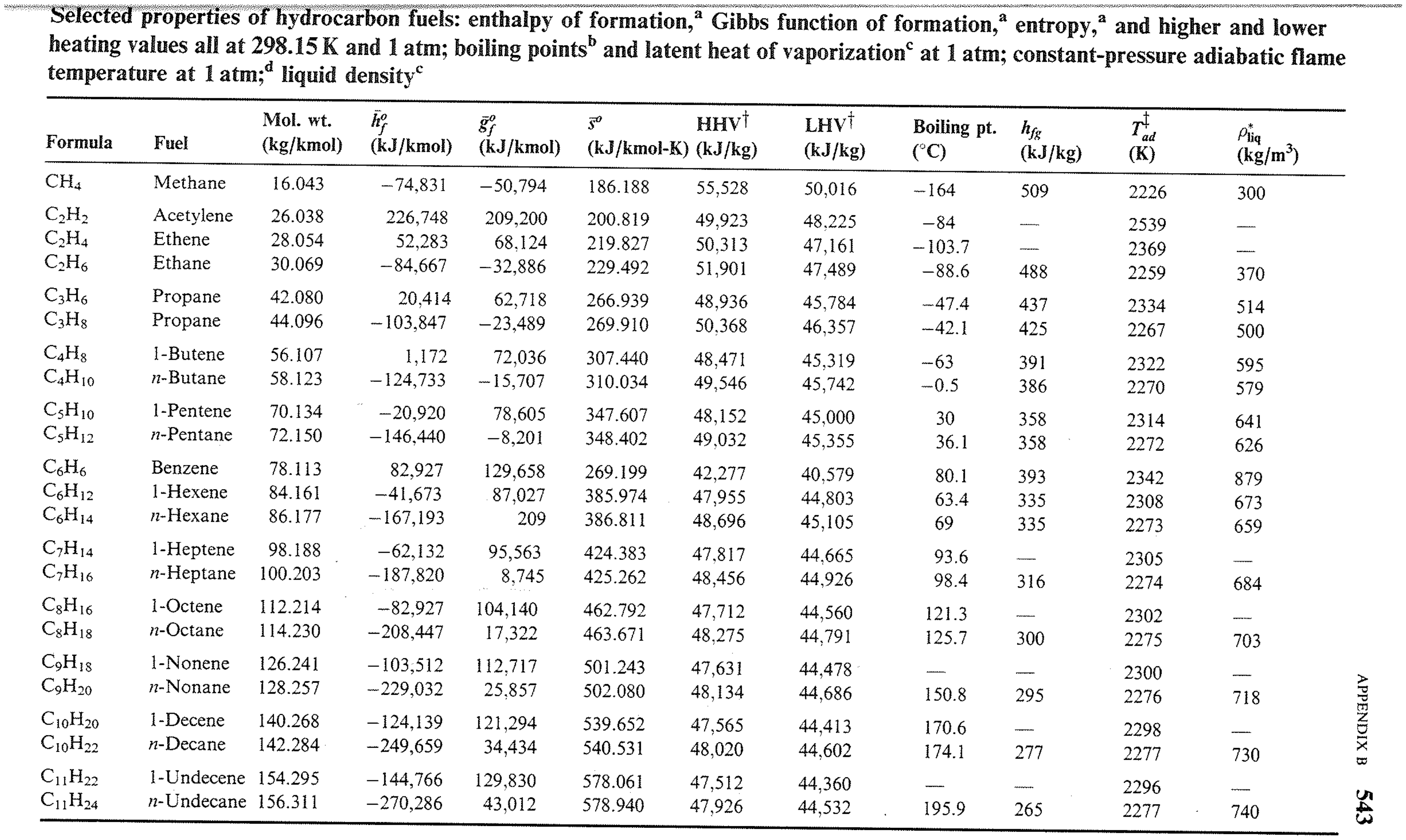
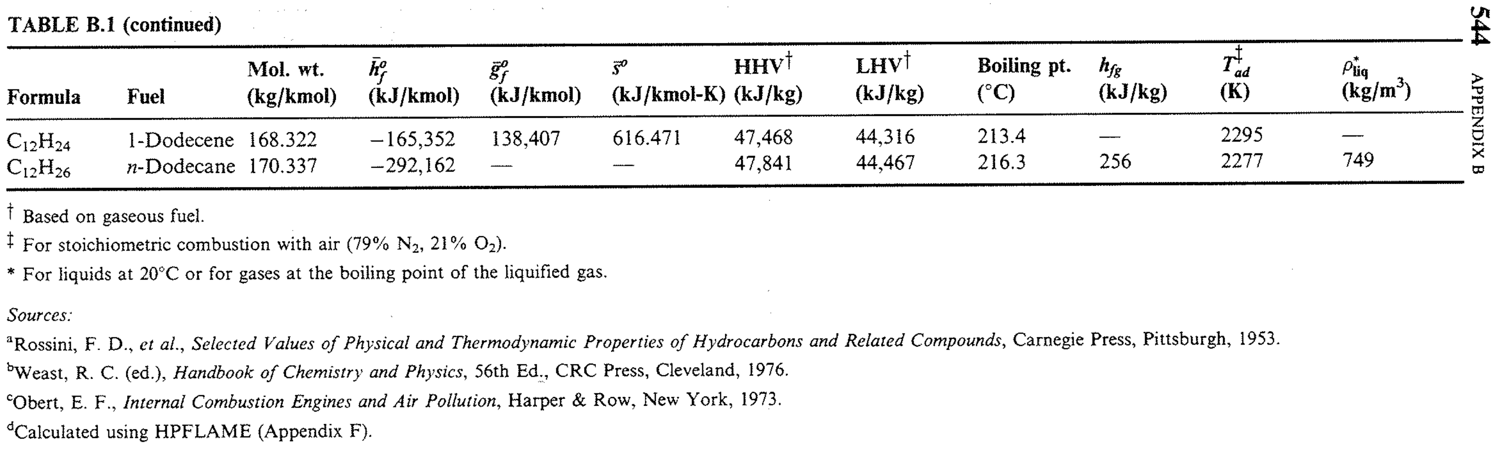
Thermochemistry



Selected properties of hydrocarbon fuels: enthalpy of formation,[a] Gibbs function of formation,[a] entropy,[a] and higher and lower heating values all at 298.15 K and 1 atm; boiling points[b] and latent heat of vaporization[c] at 1 atm; constant-pressure adiabatic flame temperature at 1 atm;[d] liquid density[c]

Formula	Fuel	Mol. wt. (kg/kmol)	$\bar{h}_f^o$ (kJ/kmol)	$\bar{g}_f^o$ (kJ/kmol)	$\bar{s}^o$ (kJ/kmol-K)	HHV† (kJ/kg)	LHV† (kJ/kg)	Boiling pt. (°C)	h_{fg} (kJ/kg)	$T_{ad}^{\ddagger}$ (K)	ρ_{liq}^* (kg/m³)
CH_4	Methane	16.043	−74,831	−50,794	186.188	55,528	50,016	−164	509	2226	300
C_2H_2	Acetylene	26.038	226,748	209,200	200.819	49,923	48,225	−84	—	2539	—
C_2H_4	Ethene	28.054	52,283	68,124	219.827	50,313	47,161	−103.7	—	2369	—
C_2H_6	Ethane	30.069	−84,667	−32,886	229.492	51,901	47,489	−88.6	488	2259	370
C_3H_6	Propane	42.080	20,414	62,718	266.939	48,936	45,784	−47.4	437	2334	514
C_3H_8	Propane	44.096	−103,847	−23,489	269.910	50,368	46,357	−42.1	425	2267	500
C_4H_8	1-Butene	56.107	1,172	72,036	307.440	48,471	45,319	−63	391	2322	595
C_4H_{10}	*n*-Butane	58.123	−124,733	−15,707	310.034	49,546	45,742	−0.5	386	2270	579
C_5H_{10}	1-Pentene	70.134	−20,920	78,605	347.607	48,152	45,000	30	358	2314	641
C_5H_{12}	*n*-Pentane	72.150	−146,440	−8,201	348.402	49,032	45,355	36.1	358	2272	626
C_6H_6	Benzene	78.113	82,927	129,658	269.199	42,277	40,579	80.1	393	2342	879
C_6H_{12}	1-Hexene	84.161	−41,673	87,027	385.974	47,955	44,803	63.4	335	2308	673
C_6H_{14}	*n*-Hexane	86.177	−167,193	209	386.811	48,696	45,105	69	335	2273	659
C_7H_{14}	1-Heptene	98.188	−62,132	95,563	424.383	47,817	44,665	93.6	—	2305	—
C_7H_{16}	*n*-Heptane	100.203	−187,820	8,745	425.262	48,456	44,926	98.4	316	2274	684
C_8H_{16}	1-Octene	112.214	−82,927	104,140	462.792	47,712	44,560	121.3	—	2302	—
C_8H_{18}	*n*-Octane	114.230	−208,447	17,322	463.671	48,275	44,791	125.7	300	2275	703
C_9H_{18}	1-Nonene	126.241	−103,512	112,717	501.243	47,631	44,478	—	—	2300	—
C_9H_{20}	*n*-Nonane	128.257	−229,032	25,857	502.080	48,134	44,686	150.8	295	2276	718
$C_{10}H_{20}$	1-Decene	140.268	−124,139	121,294	539.652	47,565	44,413	170.6	—	2298	—
$C_{10}H_{22}$	*n*-Decane	142.284	−249,659	34,434	540.531	48,020	44,602	174.1	277	2277	730
$C_{11}H_{22}$	1-Undecene	154.295	−144,766	129,830	578.061	47,512	44,360	—	—	2296	—
$C_{11}H_{24}$	*n*-Undecane	156.311	−270,286	43,012	578.940	47,926	44,532	195.9	265	2277	740

Thermochemistry



544 APPENDIX B

TABLE B.1 (continued)

Formula	Fuel	Mol. wt. (kg/kmol)	$\bar{h}_f^o$ (kJ/kmol)	$\bar{g}_f^o$ (kJ/kmol)	$\bar{s}^o$ (kJ/kmol-K)	HHV[†] (kJ/kg)	LHV[†] (kJ/kg)	Boiling pt. (°C)	h_{fg} (kJ/kg)	$T_{ad}^{\ddagger}$ (K)	ρ_{liq}^* (kg/m^3)
$C_{12}H_{24}$	1-Dodecene	168.322	−165,352	138,407	616.471	47,468	44,316	213.4	—	2295	—
$C_{12}H_{26}$	*n*-Dodecane	170.337	−292,162	—	—	47,841	44,467	216.3	256	2277	749

[†] Based on gaseous fuel.

[‡] For stoichiometric combustion with air (79% N_2, 21% O_2).

[*] For liquids at 20°C or for gases at the boiling point of the liquified gas.

Sources:

[a]Rossini, F. D., *et al.*, *Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds*, Carnegie Press, Pittsburgh, 1953.

[b]Weast, R. C. (ed.), *Handbook of Chemistry and Physics*, 56th Ed., CRC Press, Cleveland, 1976.

[c]Obert, E. F., *Internal Combustion Engines and Air Pollution*, Harper & Row, New York, 1973.

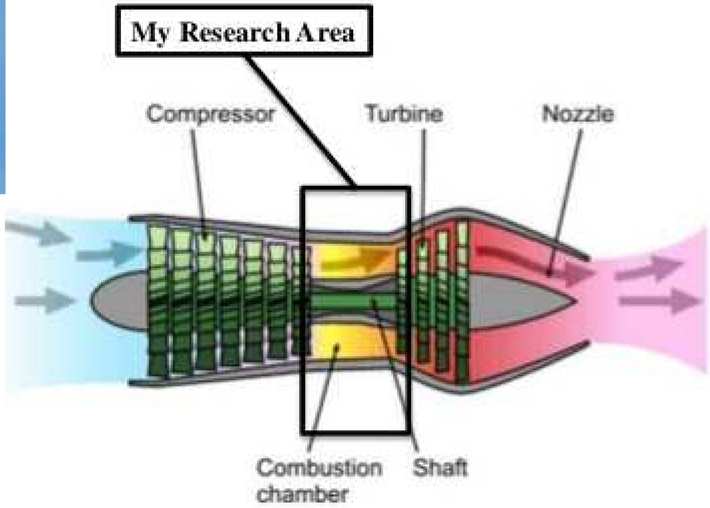
[d]Calculated using HPFLAME (Appendix F).

Thermochemistry

Fuel	Chemical formula	LHV (MJ/kg)	Density (kg/L)	LHV (MJ/L)	CO_2 (kg/L)	CO_2 (g/MJ)
Gasolina	$C_nH_{1.87n}$	44	0.72-0.78	31.7	2.28	66.6-72.1
Gasóleo	$C_nH_{1.8n}$	42.5	0.84-0.88	35.7	2.68	75.0
Etanol	C_2H_6O	26.9	0.785	21.1	1.50	71.1
Biodiesel	$C_nH_{2n}O_2$	37.1	0.88	32.6	2.47-2.80	75.8-85.8
Gás natural	~ CH_4	50	0.72 (kg/m^3)*	36.0 (MJ/m^3)	1.98 (kg/m^3)	55.0
GPL	~ C_3H_8	46.4	0.51 (2 kg/m^3)*	23.7	1.53	64.7

Thermochemistry

P#4 A small, low-emission, stationary gas-turbine engine (see Fig. 2.4) operates at full load (3950 kW) at an equivalence ratio of 0.286 with an air flowrate of 15.9 kg/s. The equivalent composition of the fuel (natural gas) is $C_{1.16}H_{4.32}$. Determine the fuel mass flowrate and the operating air–fuel ratio for the engine.



Thermochemistry

P#5 Determine the upper and lower heating values at 298 K of gaseous n-decane, $C_{10}H_{22}$, per mol of fuel and per kg of fuel, and (A/F)st (molar and mass basis). If the enthalpy of vaporization of n-decade is 359 kJ/kgfuel at 298 K, what are the upper and lower heating values of liquid n-decane?

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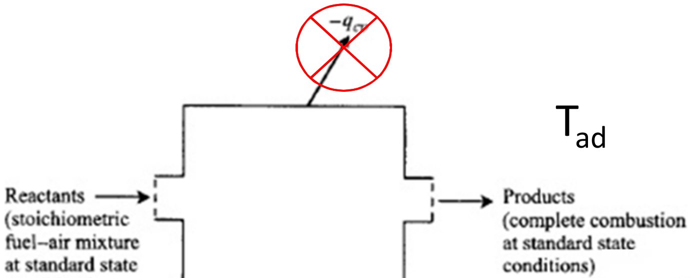
Thermochemistry

Adiabatic flame temperature = T_{ad}

Constant pressure

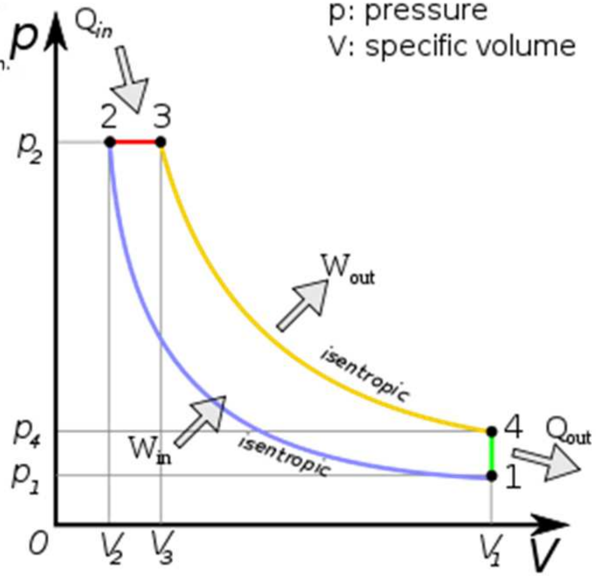
Ti

T_{ad}

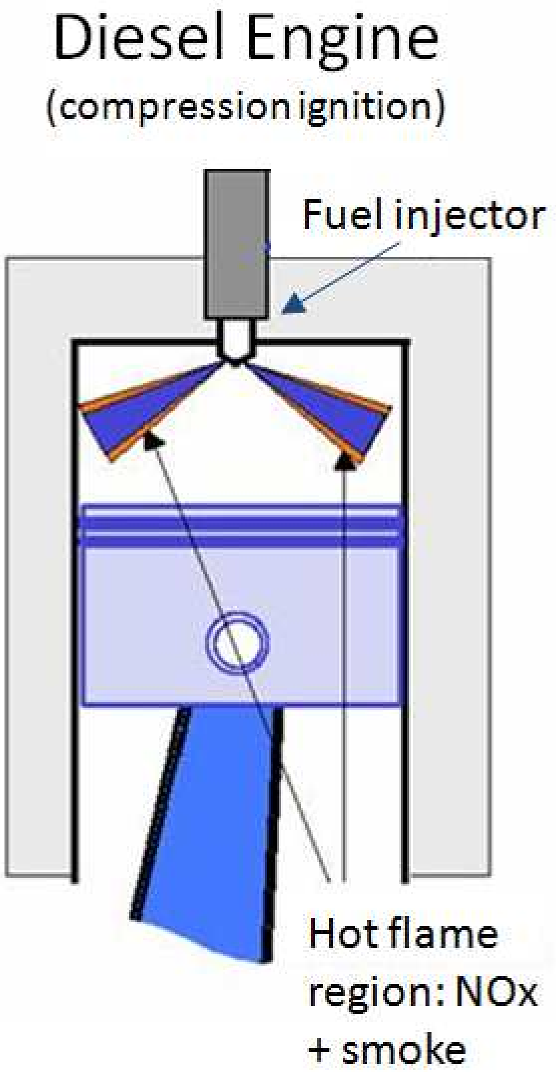


Steady-flow reactor used to determine enthalpy of combustion.

ΔH=0 for constant pressure



p: pressure
V: specific volume

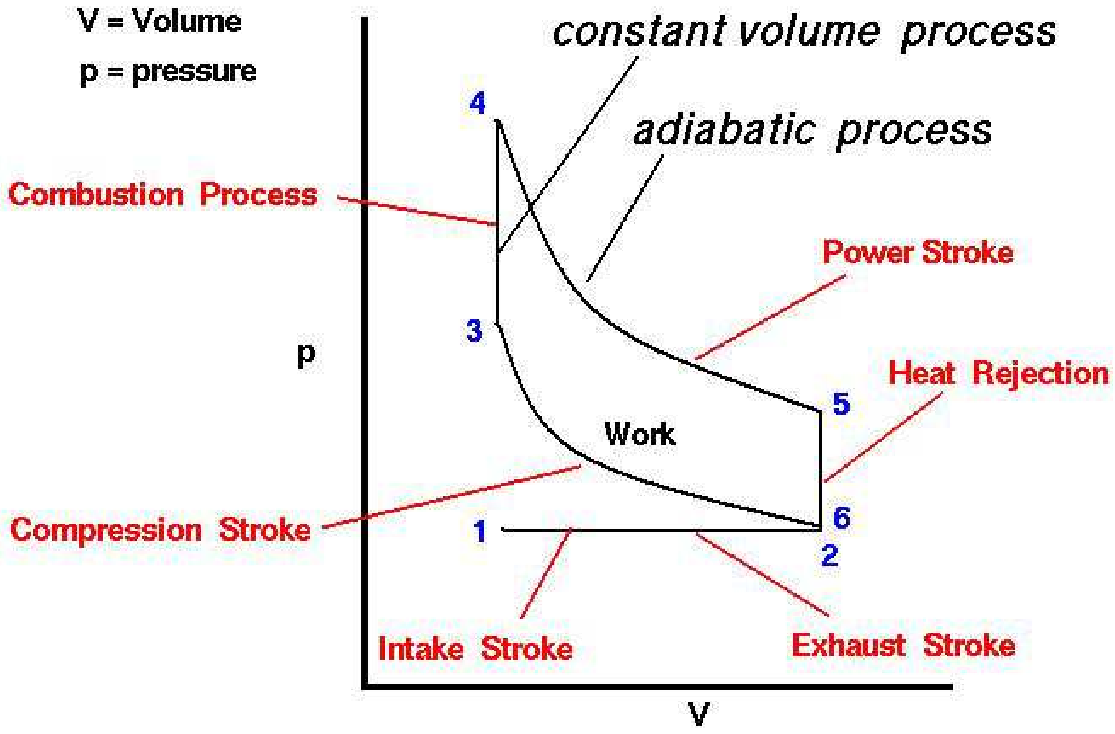


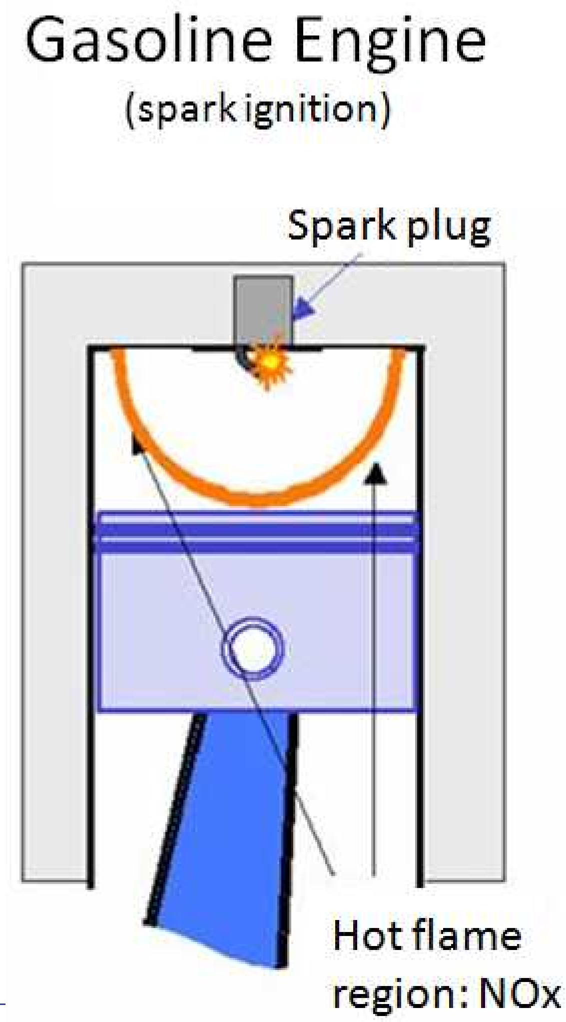
Thermochemistry

Adiabatic flame temperature = T_{ad}

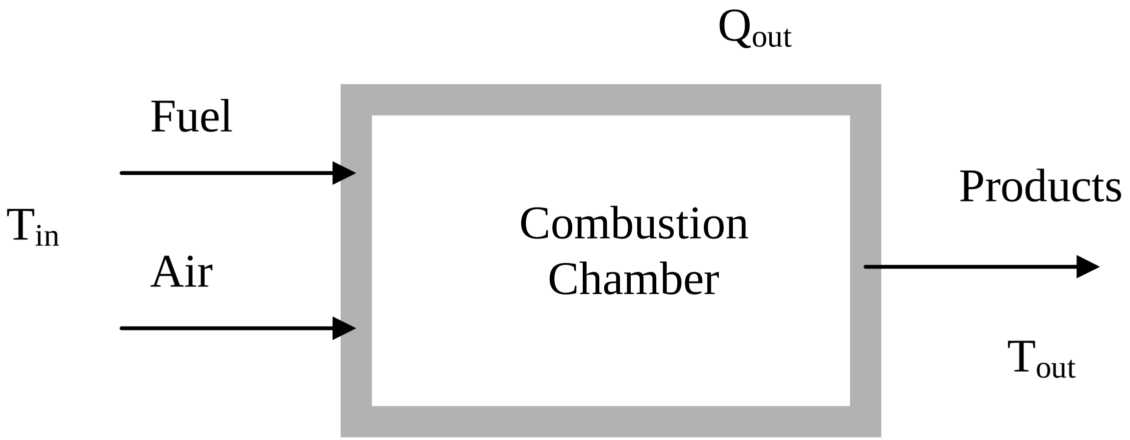
$\Delta U=0$ for constant volume

Constant volume





Thermochemistry



Q_{out}

Fuel

T_{in}

Air

Combustion Chamber

Products

T_{out}

- Maximum heat release, max Q_{out}: $T_{out}=T_{in}$
- Maximum flame temperature, adiabatic combustion chamber, T_{ad}:

$\text{Hreag}(T_{in})=\text{Hprod}\ (T_{ad})$(constant pressure, e.g. Diesel engine, gas turbine, furnace)

$$\text{Hreag}(T_{in})=\text{Hprod}\ (T_{ad})-\underbrace{R(n_{prod}T_{ad}-n_{reag}T_{in})}_{\text{Volume const} \Rightarrow \text{nao consigo aproveitar capacidade de gerar trabalho } U_{reag}=U_{prod}}$$

(constant volume, e.g. gasoline engine)

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Thermochemistry

P#6 Estimate the constant-pressure adiabatic flame temperature for the combustion of a stoichiometric CH_4-air mixture. The pressure is 1 atm and the initial reactant temperature is 298 K. Make the necessary assumptions.

i) Linear interpolation

ii) Perfect gas constant pressure $h(T_2) - h(T_1) = \int_{T_1}^{T_2} c_p(T)\,dT$

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Thermochemistry

P#7 Estimate the constant-volume adiabatic flame temperature for the combustion of a stoichiometric CH_4-air mixture. The initial pressure is 1 atm and the initial reactant temperature is 298 K. Make the necessary assumptions.

Thanks

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