UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2009/2010 Academic Session

April/May 2010

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SIX printed pages and FOUR printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

Booklet of Thermodynamic Tables are provided.
Buku Jadual Termodinamik akan dibekalkan.

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Consider a process that takes superheated steam from an initial state where P = 1 bar and T = 400°C to a state where P = 0.5 bar and T = 200°C. Calculate the change in internal energy for this process using the

Wap panas lampau mengalami satu proses perubahan keadaan dari keadaan permulaannya P = 1 bar dan T = 400°C ke keadaan akhir P = 0.5 bar dan T = 200°C. Sila kirakan perubahan tenaga dalam untuk proses ini dengan menggunakan

[i] steam tables and
jadual wap dan

[ii] ideal gas heat capacity
muatan haba gas unggul

Calculate the discrepancy (if any) between the two answers and explain which result you'll trust most.
Kira juga perbezaan di antara jawapan anda (sekiranya ada) dan cadangkan yang mana jawapan itu adalah lebih tepat.

[10 marks/markah]

[b] A one-component gas at 300 K and 1 bar has a heat capacity C_v = 30 J/mol K. The gas behavior can be best described by the following equation of state (EOS):

Gas satu komponen pada 300 K dan 1 bar memiliki muatan haba C_v = 30 J/mol K. Kelakuan gas ini boleh didefinisikan melalui persamaan matematik berikut:

$PV = aT^2$ where a = 5×10^{-3} J/mol K^2

[i] Calculate the heat capacity C_v at 300 K and 5 and 50 bar.
(Hint: $C_v = (\partial U / \partial T)_V$)

Sila kirakan muatan haba C_v pada 300 K, 5 dan 50 bar.
(Petua yang berguna: $C_v = (\partial U / \partial T)_V$)

[ii] Calculate $(\partial P / \partial N)_{T,\bar{V}}$ for 3 moles of the above mentioned gas at 800 K and 9 bar.

Sila kirakan $(\partial P / \partial N)_{T,\bar{V}}$ untuk 3 mol gas ini pada 800 K dan 9 bar.

Given: Maxwell's equations, $\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$

Turut disertai: Persamaan Maxwell,

[15 marks/markah]

…3/-

2. [a] Working as a chemical engineer at ABC refinery plant, John is responsible in designing and commissioning of a new distillation column which will be utilized to separate 2 chemical species out from water. He knows the feed stream mixture is at 70°C and the new column has a volume of 10 m^3 with operational pressure at 0.7 atm. Under this scenario, is there any extra degree of freedom for John to optimize the separation efficiency by adjusting the column temperature? Explain why.

John berkhidmat sebagai jurutera kimia di loji kimia ABC. Beliau ditugaskan untuk pemasangan satu turus penyulingan baru yang akan digunakan untuk pemisahan dua bahan kimia daripada air. John tahu bahawa bahan kimia campuran tersebut akan memasuki turus penyulingan pada 70°C dan turus penyulingan tersebut mempunyai muatan sebanyak 10 m^3 dengan tekanan operasi pada 0.7 atm. Dalam keadaan ini, adakah John masih mempunyai darjah kebebasan untuk memoptimumkan keberkesanan pemisahan dengan menyelaraskan suhu turus penyulingan tersebut? Terangkan jawapan anda.

[5 marks/markah]

[b] Determine whether the following process violates the first and second laws of thermodynamics. An ideal gas of constant heat capacity (C_p = 30 kJ/kmol·K) at 10 bar and 295 K enters a device which is thermally and mechanically insulated from the surroundings. One-half of the gas leaves the device at 355 K and 1 bar, while the other half leaves at 235 K and 1 bar.

Tentukan sama ada proses berikut telah mencabuli hukum termodinamik pertama dan kedua. Gas unggul dengan muatan haba (C_p = 30 kJ/kmol·K) pada 10 bar dan 295 K memasuki unit pemprosesan yang mengalami penebatan secara haba dan mekanikal. Separuh gas itu meninggalkan unit pemprosesan itu pada 355 K dan 1 bar, dan, separuh lagi keluar dari unit itu pada 235 K dan 1 bar.

[10 marks/markah]

[c] A bar of aluminum is placed in a large bath of ice and water. Current is passed through the bar until, at steady state, there is a power dissipation of 1000 Watt. A thermocouple on the surface of the aluminum reads 640 K. Film boiling is occurring at the interface with a subsequent, noisy collapse of the bubbles.

Seketul bar aluminum ditempatkan dalam satu tangki yang mengandungi air dan ais. Serahan haba sebanyak 1000 W dijanakan oleh pengaliran elektrik melalui bar aluminum tersebut hingga keadaan mantap. Suhu pada permukaan bar aluminum itu adalah sebanyak 640 K. Pendidihan lapisan filem berlaku pada antara fasa, diikuti dengan kemusnahan bising buih-buih.

[i] Is this a spontaneous process? Explain why?
Adakah proses ini spontan? Terangkan jawapan anda.

[ii] Is this a reversible or irreversible process?
Adakah proses ini boleh atau tidak boleh diterbalikkan?

[iii] Calculate the entropy change ΔS of the bar and water during 2 min of operation? (Assume that the ice melting is insignificant within this period of time).

Sila kirakan perubahan entropi untuk bar aluminum dan air dalam masa dua minit. (Anda boleh menganggap pelarutan ais dalam tempoh masa ini adalah minimum).

[10 marks/markah]

3. [a] Briefly explain the existence of solid, liquid and vapor phase in relation to temperature, pressure and volume using thermodynamics diagrams.

Terangkan dengan ringkas kewujudan fasa pepejal, cecair dan wap dihubungkaitkan dengan suhu, tekanan dan isipadu menggunakan gambarajah termodinamik.

[5 marks/markah]

[b] A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.14 and 0.8 MPa. If the mass flow rate of the refrigerant is 0.5 kg/s, determine

Suatu peti sejuk menggunakan bahan pendingin-134a sebagai bendalir bekerja dan beroperasi pada kitaran penyejukan mampatan wap unggul antara 0.14 dan 0.8 MPa. Jika kadar aliran jisim bahan pendingin ialah 0.5 kg/s, hitungkan

[i] the rate of heat removal from the refrigerated space.
kadar penyingkiran haba dari kawasan penyejukan.

[ii] the power input to the compressor.
kuasa masuk ke pemampat.

[iii] the rate of heat rejection to the environment.
kadar penolakan haba ke persekitaran.

[iv] the coefficient of performance of the refrigerator.
pekali prestasi peti sejuk tersebut.

[10 marks/markah]

[c] Calculate the fugacity of liquid hydrogen sulfide in contact with its saturated vapor at 25.5°C and 20 bar.

Hitungkan fugasiti hidrogen sulfida cecair bersentuhan dengan wap tepunya pada 25.5°C dan 20 bar.

[5 marks/markah]

[d] Cold water at 15°C is throttled from 5 atm to 1 atm, as in a kitchen faucet. Calculate:

Air sejuk pada 15°C telah didikitkan dari 5 atm ke 1 atm seperti dalam paip dapur. Hitungkan:

[i] the temperature change of water.
perubahan suhu air.

[ii] the lost work per kg of water.
kerja hilang untuk setiap kg air.

Given: At 15°C and 1 atm, the volume of expansivity β for liquid water is about 1.5 x 10^{-4} K^{-1}, the surrounding temperature, T_σ is 20°C.

Diberi: Pada 15°C dan 1 atm, keberkembangan isipadu β untuk cecair air ialah 1.5 x 10^{-4} K^{-1}, suhu persekitaran T_σ ialah 20°C.

State carefully any assumption made.
Nyatakan dengan jelas andaian yang dibuat.

[5 marks/markah]

4. [a] Briefly explain the following terms:
Bincangkan secara ringkas terma-terma berikut:

[i] Liquefaction process.
Proses pencecairan.

[ii] Activity coefficient.
Pekali keaktifan.

[iii] Fugacity.
Fugasiti.

[iv] Adiabatic expansion process.
Proses pengembangan adiabatik.

[v] Isentropic expansion process.
Proses pengembangan seentropi.

[5 marks/markah]

[b] Explain how a heat pump operates during winter and summer.
Terangkan bagaimana suatu pam haba beroperasi semasa musim panas dan sejuk.

[5 marks/markah]

[c] Calculate the fugacity of each species in the following gases at 290 K and 800 bar:
Hitungkan fugasiti setiap spesis dalam gas berikut pada 290 K dan 800 bar:

[i] Pure oxygen.
Oksigen tulen.

[ii] Pure nitrogen.
Nitrogen tulen.

[iii] A mixture of 30 mol% O_2 and 70 mol% N_2 using Lewis-Randall rule.
Suatu campuran 30 mol% O_2 dan 70 mol% N_2 menggunakan Hukum Lewis-Randall.

[5 marks/markah]

[d] Wilson parameters for mixtures of ethanol (1), 1-propanol (2), and water (3) at 60°C are as follows:
Parameter Wilson untuk campuran etanol (1), 1-propanol (2), dan air (3) pada 60°C adalah seperti berikut:

i. $A_{12} = 1.216$ $A_{21} = 0.617$
ii. $A_{13} = 0.203$ $A_{31} = 0.838$
iii. $A_{23} = 0.048$ $A_{32} = 0.612$

Calculate the fugacity of ethanol in liquid mixture containing 30% ethanol, 20% 1-propanol and 50% water at 60°C and 1 bar.
Hitungkan fugasiti etanol dalam campuran cecair yang menggunakan 30% etanol, 20% 1-propanol dan 50% air pada 60°C dan 1 bar.

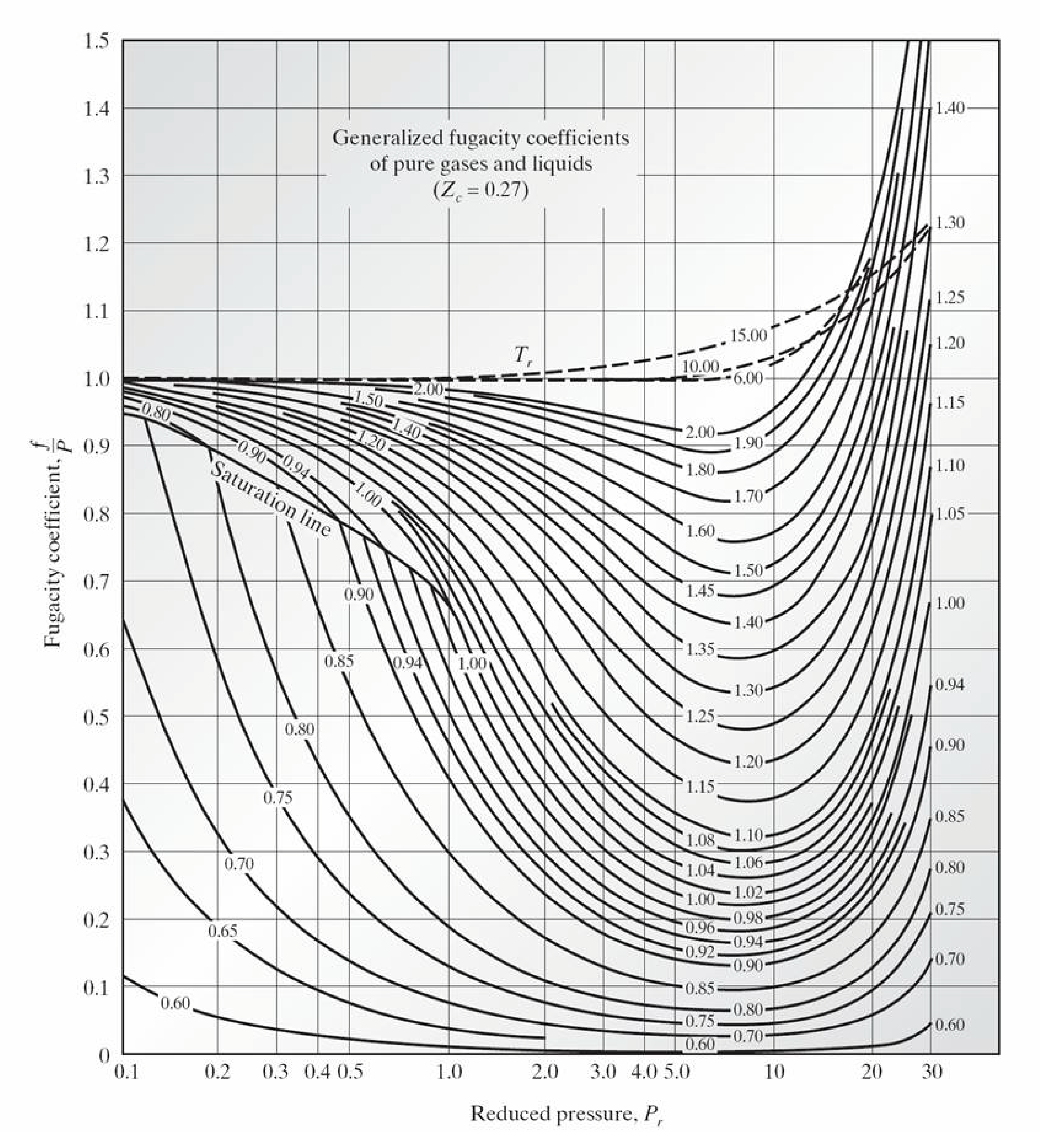
[5 marks/markah]

[e] Three moles of water and one mole of sulfuric acid are mixed isothermally at 0°C. How much heat must be absorbed or released to keep the mixture at 0°C?
Tiga mol air dan satu mol asid sulfurik dicampurkan secara sesuhu pada 0°C. Berapakah jumlah haba yang mesti diserapkan atau dibuang untuk mengekalkan campuran pada 0°C?

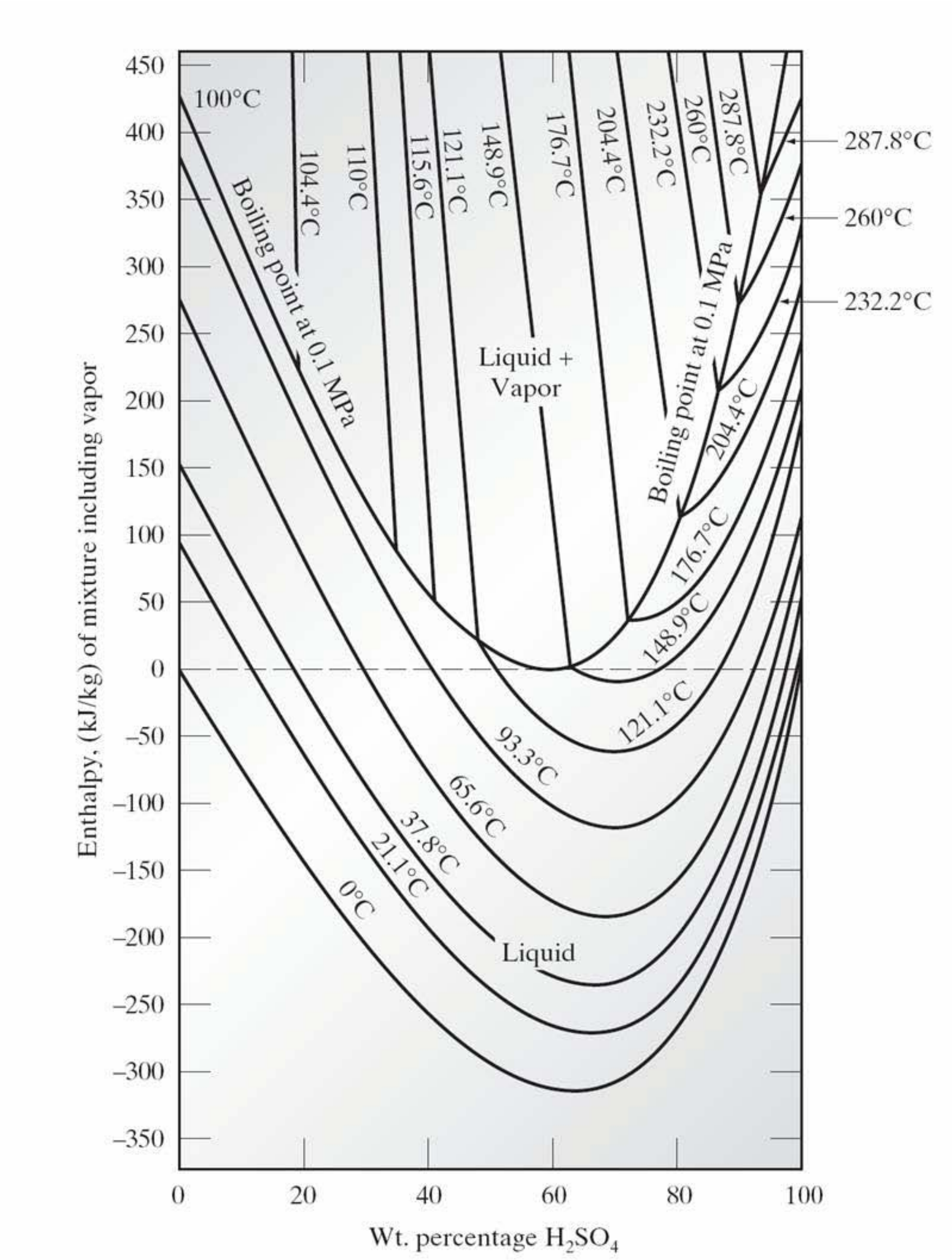
[5 marks/markah]

- oooOooo -

Appendix



Fugacity coefficient of pure gases and liquids ($Z_C = 0.27$)



Enthalpy-Concentration Diagram for H_2SO_4 at 0.1 Mpa

Antoine Equation is of the form: $ln(P^{sat}[bar]) = A - \frac{B}{T[K]+C}$

Formula	Name	$MW_{[g/mol]}$	T_c [K]	P_c [bar]	ω	A	B	C	T_{min}	T_{max}
CH_2O	Formaldehyde	30.026	408	65.86	0.253	9.8573	2204.13	−30.15	185	271
CH_4	Methane	16.042	190.6	46.00	0.008	8.6041	597.84	−7.16	93	120
CH_4O	Methanol	32.042	512.6	80.96	0.559	11.9673	3626.55	−34.29	257	364
C_2H_4	Acetylene	26.038	308.3	61.40	0.184	9.7279	1637.14	−19.77	194	202
C_2H_3N	Acetonitrile	41.052	548	48.33	0.321	9.6672	2945.47	−49.15	260	390
C_2H_4	Ethylene	28.053	282.4	50.36	0.085	8.9166	1347.01	−18.15	120	182
C_2H_4O	Acetaldehyde	44.053	461	55.73	0.303	9.6279	2465.15	−37.15	210	320
C_2H_4O	Ethylene oxide	44.053	469	71.94	0.200	10.1198	2567.61	−29.01	300	310
$C_2H_4O_2$	Acetic acid	60.052	594.4	57.86	0.454	10.1878	3405.57	−56.34	290	430
C_2H_6	Ethane	30.069	305.4	48.74	0.099	9.0435	1511.42	−17.16	130	199
C_2H_6O	Ethanol	46.068	516.2	63.83	0.635	12.2917	3803.98	−41.68	270	369
C_3H_6	Propylene	42.080	365.0	46.20	0.148	9.0825	1807.53	−26.15	160	240
C_3H_6O	Acetone	58.079	508.1	47.01	0.309	10.0311	2940.46	−35.93	241	350
C_3H_8	Propane	44.096	370.0	42.44	0.152	9.1058	1872.46	−25.16	164	249
C_3H_8O	1-Propanol	60.095	536.7	51.68	0.624	10.9237	3166.38	−80.15	285	400
Formula	Name	$MW_{[g/mol]}$	T_c [K]	P_c [bar]	ω	A	B	C	T_{min}	T_{max}
Ar	Argon	39.948	150.8	48.74	−0.004	8.6128	700.51	−5.84	81	94
BCl_3	Boron trichloride	117.169	451.95	38.71	0.148	9.0985	2242.71	−38.99	182	286
B_2H_6	Diborane	27.670	289.80	40.50	0.138	8.7074	1377.84	−22.18	118	181
Br_2	Bromine	159.808	584	103.35	0.132	9.2239	2582.32	−51.56	259	354
CCl_3F	Trichlorofluoromethane	137.367	471.2	44.08	0.188	9.2314	2401.61	−36.3	240	300
CF_4	Carbon tetrafluoride	88.004	227.6	37.39	0.191	9.4341	1244.55	−13.06	93	148
C_2F_6	Hexafluoroethane	138.012	292.8	30.42	0.255	9.1646	1559.11	−24.51	180	195
$CHCl_3$	Chloroform	119.377	536.4	54.72	0.216	9.3530	2696.79	−46.16	260	370
CO	Carbon monoxide	28.010	132.9	34.96	0.049	7.7484	530.22	−13.15	63	108
CO_2	Carbon dioxide	44.010	304.2	73.76	0.225	15.9696	3103.39	−0.16	154	204
CS_2	Carbon disulfide	76.143	552	79.03	0.115	9.3642	2690.85	−31.62	228	342
Cl_2	Chlorine	70.905	417	77.01	0.073	9.3408	1978.32	−27.01	172	264
F_2	Fluorine	37.997	144.3	52.18	0.048	9.0498	714.10	−6.00	59	91
H_2	Hydrogen	2.016	33.2	12.97	−0.22	7.0131	164.90	3.19	14	25
HBr	Hydrogen bromide	80.912	363.2	85.52	0.063	7.8485	1242.53	−47.86	184	221
HCN	Hydrogen cyanide	27.025	456.8	53.90	0.407	9.8936	2585.80	−37.15	234	330
HCl	Hydrogen chloride	36.461	324.6	83.09	0.12	9.8838	1714.25	−14.45	137	200
H_2O	Water	18.015	647.3	220.48	0.344	11.6834	3816.44	−46.13	284	441
H_2S	Hydrogen sulfide	34.082	373.2	89.37	0.100	9.4838	1768.69	−26.06	190	230

Table : Heat Capacities of Gases in the Ideal-Gas State[†]

Constants in equation $C_P^{ig}/R = A + BT + CT^2 + DT^{-2}$ T (kelvins) from 298 to T_{max}

Chemical species		T_{max}	$C_{P_{298}}^{ig}/R$	A	$10^3 B$	$10^6 C$	$10^{-5} D$
Paraffins:							
Methane	CH_4	1500	4.217	1.702	9.081	−2.164	
Ethane	C_2H_6	1500	6.369	1.131	19.225	−5.561	
Propane	C_3H_8	1500	9.011	1.213	28.785	−8.824	
n-Butane	C_4H_{10}	1500	11.928	1.935	36.915	−11.402	
iso-Butane	C_4H_{10}	1500	11.901	1.677	37.853	−11.945	
n-Pentane	C_5H_{12}	1500	14.731	2.464	45.351	−14.111	
n-Hexane	C_6H_{14}	1500	17.550	3.025	53.722	−16.791	
n-Heptane	C_7H_{16}	1500	20.361	3.570	62.127	−19.486	
n-Octane	C_8H_{18}	1500	23.174	4.108	70.567	−22.208	
1-Alkenes:							
Ethylene	C_2H_4	1500	5.325	1.424	14.394	−4.392	
Propylene	C_3H_6	1500	7.792	1.637	22.706	−6.915	
1-Butene	C_4H_8	1500	10.520	1.967	31.630	−9.873	
1-Pentene	C_5H_{10}	1500	13.437	2.691	39.753	−12.447	
1-Hexene	C_6H_{12}	1500	16.240	3.220	48.189	−15.157	
1-Heptene	C_7H_{14}	1500	19.053	3.768	56.588	−17.847	
1-Octene	C_8H_{16}	1500	21.868	4.324	64.960	−20.521	
Miscellaneous organics:							
Acetaldehyde	C_2H_4O	1000	6.506	1.693	17.978	−6.158	
Acetylene	C_2H_2	1500	5.253	6.132	1.952	......	−1.299
Benzene	C_6H_6	1500	10.259	−0.206	39.064	−13.301	
1,3-Butadiene	C_4H_6	1500	10.720	2.734	26.786	−8.882	
Cyclohexane	C_6H_{12}	1500	13.121	−3.876	63.249	−20.928	
Ethanol	C_2H_6O	1500	8.948	3.518	20.001	−6.002	
Ethylbenzene	C_8H_{10}	1500	15.993	1.124	55.380	−18.476	
Ethylene oxide	C_2H_4O	1000	5.784	−0.385	23.463	−9.296	
Formaldehyde	CH_2O	1500	4.191	2.264	7.022	−1.877	
Methanol	CH_4O	1500	5.547	2.211	12.216	−3.450	
Styrene	C_8H_8	1500	15.534	2.050	50.192	−16.662	
Toluene	C_7H_8	1500	12.922	0.290	47.052	−15.716	
Miscellaneous inorganics:							
Air		2000	3.509	3.355	0.575	......	−0.016
Ammonia	NH_3	1800	4.269	3.578	3.020	......	−0.186
Bromine	Br_2	3000	4.337	4.493	0.056	......	−0.154
Carbon monoxide	CO	2500	3.507	3.376	0.557	......	−0.031
Carbon dioxide	CO_2	2000	4.467	5.457	1.045	......	−1.157
Carbon disulfide	CS_2	1800	5.532	6.311	0.805	......	−0.906
Chlorine	Cl_2	3000	4.082	4.442	0.089	......	−0.344
Hydrogen	H_2	3000	3.468	3.249	0.422	......	0.083
Hydrogen sulfide	H_2S	2300	4.114	3.931	1.490	......	−0.232
Hydrogen chloride	HCl	2000	3.512	3.156	0.623	......	0.151
Hydrogen cyanide	HCN	2500	4.326	4.736	1.359	......	−0.725
Nitrogen	N_2	2000	3.502	3.280	0.593	......	0.040
Nitrous oxide	N_2O	2000	4.646	5.328	1.214	......	−0.928
Nitric oxide	NO	2000	3.590	3.387	0.629	......	0.014
Nitrogen dioxide	NO_2	2000	4.447	4.982	1.195	......	−0.792
Dinitrogen tetroxide	N_2O_4	2000	9.198	11.660	2.257	......	−2.787
Oxygen	O_2	2000	3.535	3.639	0.506	......	−0.227
Sulfur dioxide	SO_2	2000	4.796	5.699	0.801	......	−1.015
Sulfur trioxide	SO_3	2000	6.094	8.060	1.056	......	−2.028
Water	H_2O	2000	4.038	3.470	1.450	......	0.121

[†]Selected from H. M. Spencer, *Ind. Eng. Chem.*, vol. 40, pp. 2152–2154, 1948; K. K. Kelley, *U.S. Bur. Mines Bull. 584*, 1960; L. B. Pankratz, *U.S. Bur. Mines Bull. 672*, 1982.