PHYSICO-CHEMICAL PROPERTIES FOR CHEMICAL ENGINEERING

化学工学物性定数

Vol. 1

Edited by Physico-Chemical Properties Committee
The Society of Chemical Engineers, Japan

MARUZEN CO., LTD., Tokyo

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PREFACE

The Japanese language edition of "Physical Properties of Matter" came to completion with the publishing of the tenth volume in 1970, however, due to popular request, it has been decided to publish additional works under the title of "Physico - Chemical Properties for Chemical Engineering." The main purpose of the new works is to introduce literatures on experimental data, experimental method of measurements, predictive method and theory ot physico-chemical properties of matter related to equipment design in chemical engineering. Due to printing limitations, it is not possible to record the raw data. However, along with each of the chapter sections, an explanation of the means of measurement, margin of error, method of calculation, and remarks concerning the theory behind these will be included for whatever data can be measured. Great pains have been taken to make sure that the reader will be able to tell whether or not it is necessary to consult the original literature.

The chapter structure and the number of journals summarized are almost identical to those of "Physical Properties of Matter". But for brevity instructive reviews were not included in this publication.

Subsequent publication will be published every other year. One of the reasons for the use of English is that a friend in the U.S.A. suggested strongly that such valuable studies be published in a more widely used language.

At times it is intended to record material which is closely related to the subject under concern, but it may not be possible to go

はしがき

日本語版「物性定数」は，一応1970年度の10巻をもって終刊したが，その後この種の書物を希望される多くの人の要望に答えるため，このたび「化学工学物性定数」の名のもとに本書を出版する運びとなった．本書の使命は，主として化学工業装置設計に関する物性定数のデータおよびその測定法，推算法およびその理論についての論文を広く紹介することである．紙面の都合から原データそのものの収録は不可能となったが，各章の諸項目それぞれについてデータの測定範囲，測定法，誤差，推算法とそれに関する理論の要点 (remarks) を記すことにより，読者が本書によって，原論文を取寄せる必要があるかないかの判定ができるように極力配慮したつもりである．

章の構成と摘録対象としてとりあげた雑誌数は，いままでの「物性定数」と比べてほとんど変わらない．書式を簡潔にするため，総説などは省略した．

本書は引続いて2年ごとに1集と同じ形式で発刊される．英語を用いた理由の一つは，米国の友人が，このような貴重な仕事はもう少し汎用性の多い用語を使用したらどうかと勧めてくれたことである．

時には関連の深い資料も収録する予定であるが，それでも本書に取上げている収録範囲は不十分であるかも知れない．既刊の数値集や便覧類とともに上手に活用して頂ければ，その便は非常に大きい

into sufficient depth. So, the use of other reference materials already on the market such as numerical tables and hand book is recommended for the sufficient use of this book.

For those who would like to refer to the original literature, or would like more detailed information than what is given in the bibliography, please refer to the notice for users (page 4) remarks.

Those who have started this work must be prepared to continue on in it as the field of study opens up along with the expansion of engineering. There's no doubt but that it is valuable work, but it takes a very generous person to take time off from his individual creative work, and devote it to such a non-profitable work as this is. The names of those who have so kindly given their cooperation are listed elsewhere. The fact that this publication has turned out so well is due greatly to the help of the first chairman Prof. Kazuo SATO, and the following chairman Prof. Mitsuho HIRATA, and also of the Editing Department of the Society of Chemical Engineers, Japan, and the Maruzen Co. Ltd. Publishing Department. And we owe typewriting service to Miss Etsuko NAKATA. We would like to express our deepest thanks to these people, and others who have been of help to us.

March 1977

Physico-Chemical Properties
Committee Chairman
Masahiro YORIZANE

ものと信ずる.

なお, 原論文の参照を希望される方とか,「文献一覧表」よりさらに詳しい内容について知りたい方は凡例 (4 ページ) を参照されたい.

このような仕事は, いったんはじめた以上, 学問の進展と工業の開発に伴って永久に続くものと覚悟しなければならないであろう. きわめて大切な仕事であるには相違ないが, 各自の創造的な仕事の他に利益を期待できないこのような仕事に時間をさくことは, きわめて奉仕的精神に富む人でなければできないことである. いままでこの仕事に協力して頂いた方々は別項に挙げたとおりである.

また, 本書がこのように立派な形で刊行されるようになったのは, 初代委員長の佐藤一雄教授およびその後を引き継がれた平田光穂教授の御尽力に負うところ最も大きく, そのほか化学工学協会編集課, および丸善株式会社出版部の諸氏の御努力のおかげである. また中田悦子女史には原稿のタイプをお願いした. これら多くの方々に対し, ここに深甚の謝意を表する次第である.

1977 年 3 月

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NOTICE FOR USERS

1. Structure of this book:

Each chapter comprises the following tables:

Table 1 : English literature, data and equipment

Table 2 : English literature, predictive method and theory

Table 3 : Russian literature, data and equipment

Table 4 : Russian literature, predictive method and theory

The parts (Part Ⅰ, Ⅱ, etc.) within each table are headed in such a way as to indicate the main points of the chapter.

2. Abbreviations and symbols:

Nomenclature will be explained before Table 1 and 3, if necessary.

Bibliographical notes will be placed by the following rule, and the bibliography itself will follow each individual chapter, without exception.

i) Chapters 1-8 will be indicated by symbols A-H.

ii) When the original literature is in Russian, an S will follow the chapter symbol.

iii) In each table, literature is shown by literature number with initial few letters of the name of author.

3. For those who want to refer to the original literature:

Send requests to···

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2-5, Nagata 2-chome, Chiyoda-ku Tokyo, 100, Japan

Make requests on···

JICST's stipulated request form, making sure to indicate the magazine number found on the right side of page five.

(This committee does not offer copying services.)

4. Concerning the services of this committee:

Those who want more detailed information than given in the bibliograpy should send a stamped selfaddressed envelope to the address below. Replies will be made through the co-operation of the writers and reviewers mentioned elsewhere.

Physico-Chemical Properties Committee
The Society of Chemical Engineers, Japan
6-19, Kobinata 4-chome, Bunkyo-ku Tokyo, 112, Japan

凡　例

1．本文の構成

各章とも次の4つの表で構成されている．

表1：原文が主として英文で，データ装置関係．

表2：原文が主として英文で，推算法，理論に関するもの．

表3：原文がロシア語で，内容は表1に同じ．

表4：原文がロシア語で，内容は表2に同じ．

各表内の項（Part Ⅰ, Ⅱ, etc.）は各章内の特長を生かした見出しがつけられている．

2．略号と記号

Nomenclature は表1の前，または必要に応じ表3の前に記す．

文献記号は各章共通に下記のルールを用い，文献は各章末に添付してある．

i）1～8章をA～Hの記号で代表させる．

ii）原論文がロシア語のときは章記号の次にSをつける．

iii）各表中で文献は，文献番号に著者の最初の数文字を付して示されている．

3．原論文の参照を希望される方へ

申込先・・・

日本科学技術情報センター（JICST）

〒100　東京都千代田区永田町2丁目5-2

申込方法・・・

JICST指定の申込用紙使用のこと．この場合雑誌記号には5ページ右端のJICST No.を明記のこと．

（当委員会では文献コピーサービスは致しません．）

4．本委員会のサービスについて

文献一覧表以上のことをお知りになりたい場合は，原則として封書（返信用封書に宛名と切手同封のこと）で，下記へ連絡下さい．質問には，別項に挙げた執筆，摘録担当者が分担に応じて回答します．

宛先・・・

〒112　東京都文京区小日向4丁目6番19号
化学工学協会「物性定数委員会」

INVESTICATED MAGAZINES AND THEIR JICST NUMBER

No.	Full Name of Journal	JICST No.
1	Acta Chemica Scandinavica	A 314A
2	American Institute of Chemical Engineers Journal, New York	A 337A
3	American Institute of Chemical Engineers Symposium Series	B 776A
4	British Chemical Engineering $\xrightarrow{\text{see}}$ Process Technology International	B 086A
5	Bulletin of the Chemical Society of Japan	G 450A
6	Canadian Journal of Chemical Engineering	B 227A
7	Chemical Engineering	B 251A
8	Chemical Engineering Communications	D 482A
9	Chemical Engineering Journal	D 723A
10	Chemical Engineering Science	B 254A
11	Chemie-Ingenieur-Technik	B 260A
12	Chemical Revies	B 256A
13	Colection of Czechoslovak Chemical Comunications	B 288A
14	Denki Kagaku oyobi Kogyo Butsuri Kagaku	G 072A
15	Doklady Akademij Nauk S.S.S.R.	R 025A
16	Tohoku Daigaku Hisuiyoekikagaku Kenkyusho Hokoku	F 342A
17	Hydrocarbon Processing	D 303A
18	Industrial and Engineering Chemistry	(A 531B)
19	Izvestija Akademij Nauk S.S.S.R. (Seriya) Khimicheskaya	R 042A
20	Journal of the American Chemical Society	C 254A
21	Journal of Applied Chemistry and Biotechnology	C 264A
22	Journal of Chemical and Engineering Data	D 035B
23	Journal of Chemical Engineering of Japan	S 629A
24	Journal of Chemical Physics	C 275A
25	Journal of the Chemical Society	C 276A
26	Journal of Chemical Thermodynamics	D 634A
27	Journal de Chimie Physique et de Physicochimie Biologique	C 277A
28	Journal of the Indian Chemical Society	C 296A
29	Journal of Petroleum Technology	C 330A
30	Journal of Physical Chemistry	C 334A
31	Journal of Physical Chemistry of Liquid	—
32	Journal of Physical and Chemical Reference Data	—
33	Journal of Research of the National Bureau of Standards. Sect A	C 340B
34	Kagaku Kōgaku	F 099A
35	Khimiya i tekhnologiya topliva i masel	P 050A
36	Khimicheskaia Promyshlennost	R 049A
37	Nippon Kagaku Kaishi	F 226B
38	Process Technology International	B 086A
39	Review of Physical Chemistry of Japan	S 091A
40	Transactions of the Faraday Society	E 274A
41	Transactions of the Institution of Chemical Engineers, London	E 282A
42	Ukrainskii khimicheskii zhurnal	R 203A
43	Uspekhi Khimii	P 117A
44	Zeitschrift für Physikalische Chemie (Frankfurt)	E 443A
45	Zeitschrift für Physikalische Chemie (Leipzig)	E 444A
46	Zhurnal Fizicheskoi Khimii	R 136A
47	Zhurnal Prikladnoi Khimii	P 140A

CONTENTS

Chapter 1 P-V-T RELATION AND LIQUID DENSITY A 1~38

Table 1 . 1 Data
Part I PVT, Compressibility Factor, Expansion Factor, Virial Coefficient ····· 1
Part II Liquid Density ····· 4
Part III Specific Apparatus of Measurement ····· 17
Table 1 . 2 Theory ····· 17
Part I PVT, Compressibility Factor, Expansion Factor, Virial Coefficient ····· 17
Part II Liquid Density ····· 23
Table 1 . 3 Data (S) ····· 25
Part I . 1 PVT ····· 25
Part I . 2 Virial Coefficient ····· 26
Part II Liquid Density ····· 27
Table 1 . 4 Theory (S) ····· 28
Literature ····· 29
Literature (S) ····· 36

Chapter 2 VAPOR PRESSURE AND HEAT OF VAPORIZATION B 1~12

Table 2 . 1 Data ····· 1
Part I Vapor Pressure ····· 1
Part II Heat of Vaporization ····· 3
Part III Boiling Point, Melting Point, Triple Point, Critical Properties ····· 3
Table 2 . 2 Theory ····· 4
Part I Vapor Pressure ····· 4
Part II Heat of Vaporization ····· 5
Part III Boiling Point, Critical Properties ····· 5
Table 2 . 3 Data (S) ····· 6
Part I Vapor Pressure ····· 6
Part II Heat of Vaporization ····· 7
Part III Boiling Point, Melting Point ····· 8
Table 2 . 4 Theory (S) ····· 8
Vapor Pressure ····· 8
Literature ····· 9
Literature (S) ····· 11

Capter 3 HEAT CAPACITY AND ENTHALPY C 1~15

Table 3 . 1 Data ····· 1
Part I . 1 Heat Capacity (Element and Inorganic Substance) ····· 1
Part I . 2 Heat Capacity (Organic Substance) ····· 2
Part II . 1 Enthalpy etc. (Element and Inorganic Substance) ····· 3
Part II . 2 Enthalpy etc. (Organic Substance) ····· 4
Table 3 . 2 Theory ····· 5
Pure Substance ····· 5
Table 3 . 3 Data (S) ····· 8
Part I Heat Capacity ····· 8
Part II Thermodynamic Diagram ····· 10
Part III Specific Apparatus of Measurement ····· 10
Table 3 . 4 Theory (S) ····· 10
Heat Capacity ····· 10
Literature ····· 10
Literature (S) ····· 14

Capter 4 VAPOR-LIQUID EQUILIBRIUM D 1~52

Table 4 . 1 Data ····· 1
Part I Binary Systems ····· 1
Part II Ternary and More Component Systems ····· 12
Part III Salt Containing Systems ····· 14
Part IV Gas Solubility ····· 16
Part V Activity Coefficients and Infinite Dilution ····· 18
Table 4 . 2 Theory ····· 20
Table 4 . 3 Data (S) ····· 32
Part I Binary Systems ····· 32
Part II Three-, Four-and Five-Component Systems ····· 37
Part III Salt Containing Systems ····· 38
Part IV Specific Apparatus of Measurement ····· 39
Part V Miscellaneous ····· 40
References ····· 40
Table 4 . 4 Theory (S) ····· 41
Literature ····· 42
Literature (S) ····· 49

Chapter 5 SOLUBILITY AND HEAT OF SOLUTION E 1~52

Table 5 . 1 Data ····· 1
Part I Solubility (Gas) ····· 1
Part II Solubility (Liquid) ····· 5

Part III Solubility (Solid) ····12
Part IV Heat of Solution ····15
Part V Specific Apparatus of Measurement ····26
Table 5 . 2 Theory ····27
Table 5 . 3 Data (S) ····31
Part I Solubility (Gas) ····31
Part II Solubility (Liquid) ····31
Part III Solubility (Solid) ····35
Part IV Heat of Solution ····40
Table 5 . 4 Theory (S) ····41
Literature ····41
Literature (S) ····48

Chapter 6 VISCOSITY F 1～22

Table 6 . 1 Data ····1
Part I Gas ····1
Part II Liquid ····2
Part III Specific Apparatus of Measurement ····10
Table 6 . 2 Theory ····11
Part I . 1 Gas (Pure) ····11
Part I . 2 Gas (Mixture) ····12
Part II . 1 Liquid (Pure) ····12
Part II . 2 Liquid (Mixture) ····13
Table 6 . 3 Data (S) ····14
Part I Gas ····14
Part II Liquid ····14
Part III Specific Apparatus of Measuement ····17
Table 6 . 4 Theory (S) ····17
Literature ····17
Literature (S) ····21

Chapter 7 THERMAL CONDUCTIVITY G 1～6

Table 7 . 1 Data ····1
Part I Gas ····1
Part II Liquid ····2
Part III Specific Apparatus of Measurement ····2
Table 7 . 2 Theory ····2
Part I . 1 Gas (Pure) ····2
Part I . 2 Gas (Mixture) ····3
Part II . 1 Liquid (Pure) ····4
Part II . 2 Liquid (Mixture) ····4
Part III Gas and Liquid ····4

Table 7 . 3 Data (S) ····· 4
Part I Gas ····· 4
Part II Liquid ····· 4
Part III Method of Calculation ····· 5
Literature ····· 5
Literature (S) ····· 6

Chapter 8 MOLECULAR DIFFUSIVITY H 1~13

Table 8 . 1 Data ····· 1
Part I Gaseous Phase ····· 1
Part II Liquid Phase ····· 2
Part III Specific Apparatus of Measurement ····· 6
Table 8 . 2 Theory and Correlation ····· 7
Part I Gaseous Phase ····· 7
Part II Liquid Phase ····· 8
Table 8 . 3 Data (S) ····· 10
Liquid Phase ····· 10
Literature ····· 10
Literature (S) ····· 13

CHAPTER 1 P-V-T RELATION AND LIQUID DENSITY

Nomenclature:

B; second virial coefficient
C; third virial coefficient
c; molar concentration
d; molecular diameter
m; Stockmayer parameter
n; refractive index
P; pressure
R; gas constant
T; temperature
V; molar volume
x; liquid mole fraction
Z; compressibility factor

(Greek letters)

ε; well depth
ρ; density
ϕ; fugacity coefficient
ω; acentric factor

(Subscripts)

c; critical
m; mixture
r; reduced
s; saturated

(Superscripts)

E; excess
-; partial

Table 1.1 Data

Part I PVT, Compressibility Factor, Expansion Factor, Virial Coefficient

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
$AlCl_3$	188∿296		Saturated PVT	138
$CdCl_2$	600	1[bar]	Z	202
CO_2	0,16	30∿100[bar]	Critical region	157
Cs	704∿1863	64∿124	PVT	76E
D_2O	5∿65	1∿34 [bar]	Z	184
H_2	80.6 [°F]	2000∿13000 [psia]	Z	163 LOE
He	70.0 [°F]	500∿10000 [psia]	Z	"
Hg	30∿150	8000[bar]	Thermal expansivity	97G
H_2O	25∿150	"	"	"
H_2O	5∿35	100∿300	PVT	250
IF_5	10∿71		Z,B	192
KCl	800	1[bar]	Z	202
KNO_3	400,500	1∿5000[bar]	Z	"
Kr	-153∿-53	5∿3680	Gas expansion method	230
Kr	-128∿-33	680	In dense fluid	231
N_2	80.6 [°F]	1500∿13000 [psia]	Z	163 LOE
Ne	-193∿-143	2000	Z	229

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
NH_3	-20∿+40	1∿1800	PVT	149
SF_6	-33∿+46	∿37.11	Critical region	241
Benzene	20∿140		B	5AM
1-Bromopropane	-75∿+35	1∿6000 [Kg/cm^2]	Z	127 JEN
1-Bromopentane	-25∿+125	"	"	"
Butylaldehyde	30,40,50,60	5000∿40000 [psig]	Z	212 RUN
CCl_4	376.76∿ 1211.67[°R]	0∿600 [psia]	PVT	178 MAR
CCl_4	-19∿+24	16[kbar]	PVT,Shock experiment	167
Dichlorodifluoromethane	30∿75		PVT,Z,B	148
Diethyl ether,Dibutyl-ether,Diamyl ether, Dihexyl ether	20∿35	∿1000 [psia]	Thermal pressure co-efficients	67 DRI
Ethylene	50,100,150		B	29B
Ethylbenzene	10∿90		Thermal expansivity	117
Isopropanol	200∿300	1000∿8000 [psia]	Z	245 TSE
Methane	0∿225	20∿600	PVT,Z	193
Methane	-182∿-28	350[bar]	PVT	96G
Methane	0∿225	1∿350	Z	237
Methyl ethyl ketone	20∿60		Thermal expansivity	79F
Octane	-15∿+85	1∿1500	PVT	20B
Octane,Decane,Dodecane, Tetradecane,Hexadecane	-15∿+80	∿4000	PVT	19 BEN
Propane,Propene	-20∿+100 [°F]	21∿223 [psia]	Z	173 MAN
n-Propanol	25∿263.56		Saturated PVT	146
Tetra-n-butylammonium tetra-n-butylborate, Tetraethylammonium tetra-n-propylborate, Tetra-n-propylammonium tetraethylborate	90∿160	∿5200	Z	98 GRI
Ar+CO_2	15	∿150	PVT,Z	214
Ar+KCl,Ar+KI,Ar+$CaCl_2$,H_2+KOH,O_2+KOH,Ethane+KCl, Methane+KCl,Tetramethyl-ammonium bromide+Ar, Tetrabutylammonium bromide+Ar,Tetramethyl-	25		$\bar{V}$	240 TIE

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
ammonium bromide+Methane, Tetrabutylammonium bromide+Methane	25		$\bar{V}$	240 TIE
CO_2+H_2O, N_2O+H_2O, Ethane+H_2O, Ar+H_2O	25,50,75, 100	22.4∿50.8	Cross B from solubility data	55 COA
$KNO_3+Ca(NO_3)_2$	150∿200	0∿1500[bar]	Z	202
N_2+H_2, Methane+Ar+N_2+H_2	-173∿+17	150	Joule-Thomson coeff.	93G
N_2, He, He+N_2	38∿177	100∿5000 [psia]	Z	179 MAT
$PbBr_2+KBr$, $PbBr_2+CsBr$	1055∿1164	22∿43[mmHg]	Gas PVT	243
Tetrachloroformammonium-bromide+H_2O, Tetramethylammonium-bromide+H_2O, Tetraisopropylammonium-bromide+H_2O	5.7,24.2		Thermal expansivity	166 LUC
Ar+CF_4	100		Cross virial coeff.	220
Ar+Neopentane	50	10∿247	Saturated PVT	211
CO_2+N_2, Methane+CO_2	-20,0,20	20∿150	PVT,Z	9AR
Difluorochloromethane+H_2O	49.9∿151.8	1∿1800	B	235
Ethane+H_2S	50∿125	5000[psia]	Z	242
Ethylene+Ar	50		B	29B
Ethylene+NH_3	30,41		B	208
Methanol+N_2, Methanol+Ar, Methanol+Methane, Methanol +Ethylene, Methanol +Ethane, Methanol+CO_2, Methanol+H_2O	15,25,37, 50,60		Cross B from solubility data	112 HEM
Pyridine Hydrochloride +$ZnCl_2$	120∿170	0∿1500 [bar]	Z	202 POL
SF_6+CF_4	-1.5∿+150	0∿27	Z,B,C	221
SF_6+CF_4, SF_6+CF_4	"	"	"	"
Benzene+Cyclohexane	25		Z	77E
Benzene+Isopropanol+H_2O	-10∿+80	1∿2800[bar]	PVT	115
1-Chlorooctane, 1-Chloro-decane, Capronitrile, Caprylonitrile, Capri-nitrile, Lauronitrile	16∿153		PVT	181 MEY
Ethane+Methane	-59∿+35[°F]	50∿950 [psia]	Joule-Thomson coeff.	4 ALK
Ethylene+Methanol	31,60		B	208 RAT

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
Formic acid+H_2O,Acetic acid+H_2O,Propionic acid+H_2O,Isobutyric acid+H_2O	25∿55	500∿2500	Z	143 KOR
Glycine+H_2O,Glycolamide+H_2O,Alanine+H_2O,Lactamide+H_2O,Glycylglycine+H_2O	25	∿1000	PVT	254 YAY
Hexane+Diethylether	39,60		B	208
Hexane+Methanol	50		Z,B	62D
Hexane+Propane	40∿220	800[psia]	PVT	132
Methane+CF_4,Butane+C_4F_{10}	25,50,100		Cross virial coeff.	220
Ethane+CF_4,Butane+CF_4, Hexane+CF_4,Methane+C_2F_6	50		"	220 SIE
Ethane+C_2F_6	50,100		"	"
Butane+C_2F_6,Pentane+C_2F_6	50		"	"
Propane+C_3F_8	50,100		"	"
Methane+C_4F_{10},Ethane+C_4F_{10},Hexane+C_4F_{10}	50		"	"
Methane+C_5F_{12}	100		"	"
Pentane+C_5F_{12}	50,100		"	"
Methane+C_6F_{14}	100		"	"
Hexane+C_6F_{14}	50,100		"	"
Neopentane+CF_4,CF_4+SF_6	50		"	"
Methane+Neopentane	25	11∿149	Saturated PVT	211
Neopentane,bicyclo[2,2,2]-Octane,Adamantane	25		Z	33 BRE
Pentane+Methanol	31,40		B	208
p-Xylene+Benzene, p-Dioxane+Benzene	25,40		Z^E	135 KHA
Binary gas-gas mixtures			Review, V^E data	17 BAT
Part II Liquid Density				
$AgNO_3$,$TlNO_3$	433∿583[K]		Density equation	125
$AlCl_3$	188∿296		Saturated values	138
$AlCl_3$	180∿360		Density equation	219
N_2	-182∿-173			162
ND_3	-25∿+30			3
Fluorobenzene	30,60,100	1∿2000[bar]		ALE
$NiCl_2$	1015∿1058			84G
Pb	344∿652		Density equation	217
XeF_2	90∿115		Density equation	191
XeF_4	50∿110		"	"

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
Acetic acid	20,30,40			16B
Benzene	20∿289	0.1∿48.0		5AM
Benzene,Toluene,o-Xylene, m-Xylene,p-Xylene,Ethyl benzene,Isopropyl benzene, Naphthalene,2-Methyl naphthalene	20∿217		Density equation	104 HAL
CF_3PCl_2,CF_3PBr_2	20∿69			131
1,2-Dichloroethane	35∿65			47C
1,4-Dichlorobutane	"			"
1,6-Dichlorohexane	"			"
1,8-Dichlorooctane	"			"
1,10-Dichlorodecane	"			"
2,3-Dimethyl-2-butene, 3,3-Dimethyl-1-butene	20∿50		Density equation	15 BAG
Dimethyl-3,5-pyridine	20,25,35,45			182
Dimethyl-2,6-pyridine	"			"
Ethylacetate, Isoamyl alcohol, Benzyl alcohol, 1,4-Dioxane	0∿70		Density equation	1 ABR
Ethane,Ar+Kr,Ar+Xe	110.77[K]			54C
Ethane,Kr+Xe	161.36[K]			"
Hexadecane,1-Chlorobutane, 1-Chloropentane,1-Chloro-octane,1-Chlorodecane, 1-Chlorohexane,1-Chloro-dodecane,1-Chlorotetra-decane,1-Chlorohexadecane ,1-Chlorooctadecane	25			113 HER
Hexafluoroacetone			Tr=0.58∿0.82	186
Hexafluorobenzene	20,25,35,45			182
Methane	-182∿-153			162
2-Methyl-2,4-pentanediol, Dipropylene glycol, 2-Ethyl-1,3-hexanediol, Thiodiglycol	20∿50			124 IKA
Methyl-2-pyridine	20,25,35,45			182
Methyl-4-pyridine	20,25,35,45			"
Octane	-27∿+122	1		50C

Substance	Temperature °C	Pressure atm	Remarks	Lit. (A)
Octamethylcyclotetra-siloxane	503.1∿579.8 [K]			256 YOU
cis-Pentene-2	-129.72∿+25			58C
Pentane	-151.39∿+25			"
Polystyrene	20∿110		Density equation	116
Propionic acid, Butyric-acid, Isobutyric acid, Valeric acid	0,10,20,30 40			16 BAR
n-Propanol	25∿263.56		Saturated properties	146
Pyridine	20,25,35,45			182
Tetrahydrofuran+H_2O, Tetrahydropyran+H_2O, 2-Methyltetrahydrofuran+H_2O, 2,5-Dimethyltetra-hydrofuran+H_2O, 1,3-Dioxolane+H_2O, 1,4-Dioxane+H_2O, Aziridine+H_2O, Azetidine+H_2O, Pyrrolidine+H_2O, Piperidine+H_2O, Hexamethylenimine+H_2O, Heptamethylenimine+H_2O, 1-Methylpyrrolidine+H_2O, 1-Methylpiperidine+H_2O	25			37C
Trifluoroacetonitrile			Tr=0.61∿0.92	186
Trifluoroacetyl fluoride	-93∿-62		Density equation	194
Trimethyl-2,4,6-pyridine	20,25,35,45			182
Ba+$BaBr_2$	882∿999			100
Ba+$BaCl_2$	986∿1026			"
Bi+$BiBr_2$	589[K]		V^E	234
Bi+$BiCl_3$	604[K]		"	"
Bi+BiI_3	815[K]		"	"
$CaCl_2$+$MgCl_2$, $SrCl_2$+$MgCl_2$, $BaCl_2$+$MgCl_2$	900			21 BER
Catechol+Resorcinol	110,115,120			189
Cd+$CdCl_2$, Cd+$CdBr_2$	1009[K]		V^E	234
Cd+CdI_2	793[K]		"	"
CsCl+$BaCl_2$	965∿1018			100
$CuCl_2$+HCl+H_2O	30,50,70,90			99G
KCl+$LaCl_3$	765∿996		Density equation	53C