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## A COMPILATION OF THE PHYSICAL EQUILIBRIA AND RELATED PROPERTIES OF THE HYDROGEN-CARBON MONOXIDE SYSTEM

BY

D. E. DRAYER AND T. M. FLYNN



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U. S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

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# NATIONAL BUREAU OF STANDARDS

## *Technical Note*

May 1961

A Compilation of the Physical Equilibria

and

Related Properties of the Hydrogen-Carbon Monoxide System

by

Dennis E. Drayer

and

Thomas M. Flynn

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## Abstract

Literature data have been used to calculate K-factors for the hydrogen-carbon monoxide system over the range of 68.2 to 122.2°K and 10 to 225 atmospheres. K-factors are presented graphically for eight isotherms over this range.

Published data on the solid-vapor region are presented separately as composition versus pressure at constant temperature.

A bibliography of approximately 450 references is also presented on related properties for this system and for the pure components.



## 1. Introduction

### 1.1 Purpose

Hydrogen gas for liquefaction purposes frequently contains large amounts of other gases. Typical impurities or contaminants found in hydrogen-source streams include nitrogen, carbon monoxide, methane, ethane, and higher hydrocarbons. Purification of these various sources of hydrogen requires a considerable knowledge of the physical equilibria of the systems involved.

As an initial step in the study of the physical equilibria of hydrogen systems, a review of the literature was undertaken to determine what has been done and is known in this area. In this paper, the carbon monoxide-hydrogen system was so studied. (Previously, the nitrogen-hydrogen system was examined). The purpose of this paper is to determine what is known about the physical equilibria relationships and to present an extensive compilation of known related references for data for this system. It is hoped that this paper will thus provide a firm basis for the conduct of research programs in this area.

Future publications in this series will be concerned with the physical equilibria of hydrogen and other important components. Binary systems will be studied initially. When such a program is completed, it is hoped that the results will be of significant value in the design of cryogenic equipment.

### 1.2 Organization

The information is presented in three principal parts: (1) physical equilibria with major emphasis on vapor-liquid equilibria; (2) properties related to physical equilibria; and (3) a bibliography of references. Some discussion is presented with Part (1). The information of Part (2) is presented in tabular form showing the reference where such data are to be found. Part (3), the Bibliography, lists the references alphabetically by author.

### 1.3 Scope

The scope of this work is as follows: an exhaustive literature search, as summarized in NBS Technical Note No. 56, revealed much of the pertinent data; such data were abstracted and presented in the form of K-factor charts and a concentration-pressure chart and as a bibliography of references for related areas of interest. The areas searched are presented in the above reference and will not be enumerated here. Generally speaking, the literature was searched extensively and includes articles published up to and prior to July of 1960.

### 1.4 Acknowledgements

The authors especially appreciate the aid of the staff of the Data Center of the National Bureau of Standards Cryogenic Engineering Laboratory who provided the majority of the original papers for review.

## 2. Survey of Literature

The literature search revealed three important references for carbon monoxide-hydrogen vapor-liquid equilibria data. These were Akers and Eubanks (4), Ruhemann and Zinn (368), and Verschoyle (423). K-factor charts were prepared from the data of these references. In all cases the data had to be re-interpreted to arrive at K-factors.

Of noteworthy interest is the article by Verschoyle (423) who also presents solid-vapor and solid-liquid-vapor data for this same system. Also, the extensive work of Dokoupil et al. (88) presents solid-gas equilibria data for this system.

No related physical data are actually presented in this report; only references for such material are listed. Other areas so covered include adsorption phenomena, purification processes, solubility relationships, density and compressibility data, equations of state, thermodynamic and transport properties, P-V-T data, critical constants, virial coefficients, Beattie-Bridgeman constants, analytical techniques, and various processing references. Such material for the pure components as well as for mixtures of carbon monoxide and hydrogen is included in many cases. A general phenomena category is also presented to aid in the theoretical study of adsorption, phase equilibria, purification, solubility relationships, and other important

areas.

### 3. Discussion of Available Data

For this system one could expect the vapor-liquid data, if complete, to range roughly from the triple point temperature of carbon monoxide to the critical temperature of carbon monoxide (68.1 to 132.9°K). The three articles mentioned previously provided data for eight isotherms between 68.2°K and 122.2°K. The isotherms so presented are at temperatures of 68.2°, 73.2°, 78°, 83°-83.3°, 88.2°, 90°, 100°, and 122.2°K. (The vapor-liquid equilibria data for 83°K and for 83.3°K are plotted as one isotherm and so labeled 83°-83.3°K). Thus, the data available do present a rather complete picture of the vapor-liquid equilibria for this system.

The solid-vapor region has been explored at 58.2° and 63.2°K and from 20 to 175 atmospheres by Verschoyle (423) and from 32° to 70°K and 1.3 to 50 atmospheres by Dokoupil et al. (88).

The P-T regions covered by the published data are presented in Figure 1. This figure indicates that this system has been rather well explored in both the vapor-liquid region and the solid-vapor region. (The P-T data of hydrogen and carbon monoxide needed for the construction of Figure 1 were obtained from Johnson (189), Verschoyle (423) and Woolley, Scott and Brickwedde (446)).

The original data were treated to arrive at the corresponding K-factors. K is defined as  $y/x$  where y is the mole fraction of a component in the vapor phase and x is the mole fraction of that component in the liquid phase. K-factors were calculated for each component at a given temperature and pressure. After plotting the K-factors derived from the various investigations, a smooth curve was drawn for the given isotherm. Finally, the smoothed, individual K-factors were transferred to a plot of K versus total pressure with temperature as a parameter.

It is not the purpose of this report to present a test of the data for thermodynamic consistency. However, some general comments regarding the agreement between investigators is in order. Most discrepancies appear to lie in the pressure range from 10 to 30 atmospheres. In this range, there is some inconsistency in the hydrogen data as evidenced by cross-over of the isotherms of different investigators. The carbon monoxide data were not subject to these

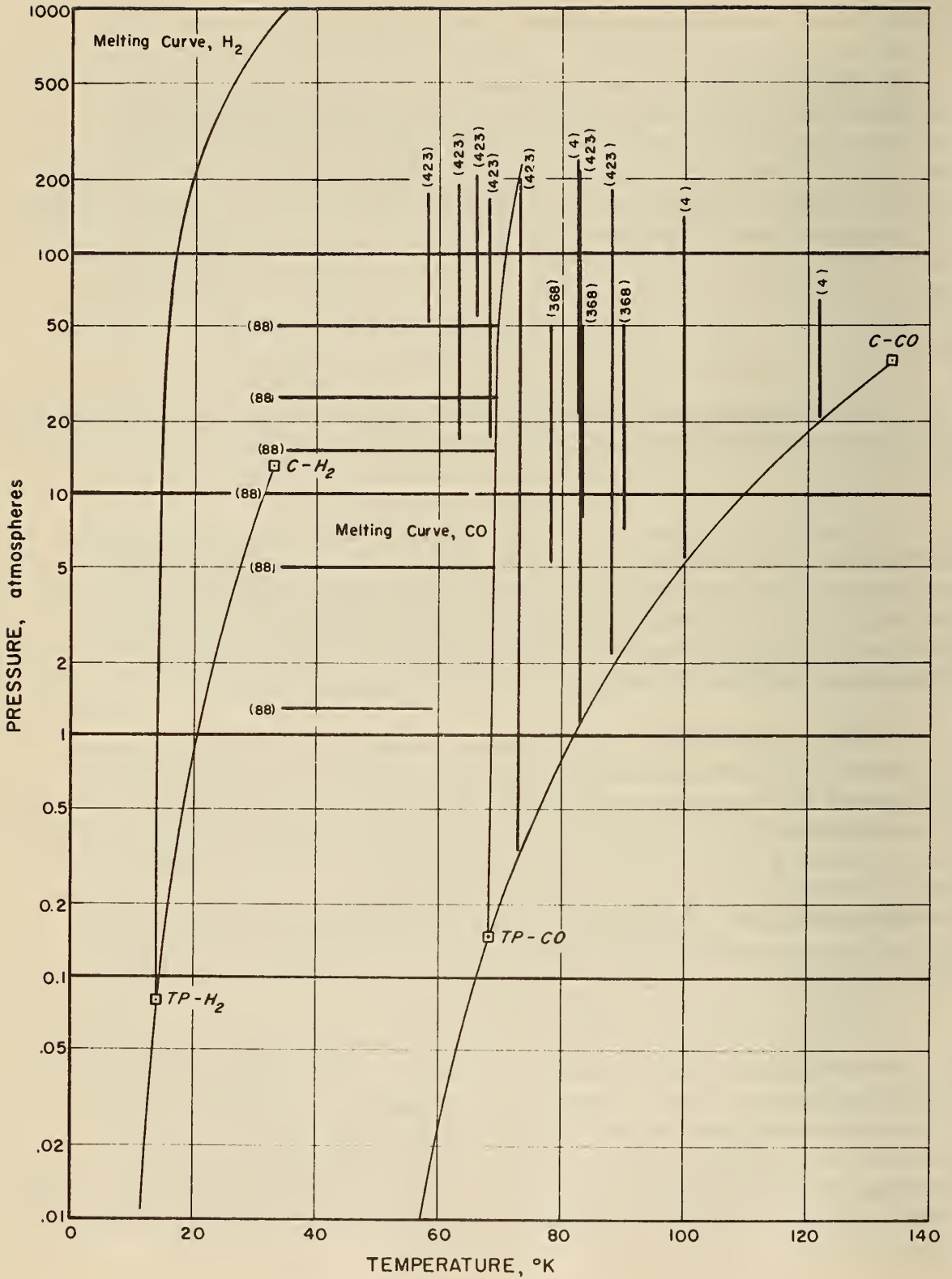


Figure 1. Regions Covered by Published Data. Parenthetical Numbers Refer to Sources in Bibliography.

variations. This scatter of data for hydrogen may stem partly from the analytical techniques used.

The 78° and 90°K isotherms, as contributed by Ruhemann and Zinn, extend only to 50 atmospheres. By using the adjacent isotherms as guide lines, one could, if required, probably make a reasonable extrapolation of these two isotherms to higher pressures.

It must be emphasized that this report is based on the original data of the investigators. These data, in most cases, have not been tested for thermodynamic consistency and should be used only with thorough awareness of this fact.

#### 4. K-Factor Charts

Presented in Tables I, III and IV in the Appendix are the data used in computing K-factors.

Figures 2 and 3 are plots of the K-factors of hydrogen and carbon monoxide, respectively. Dotted portions on these figures indicate extrapolated areas. Figure 4 shows, finally, the curves for both hydrogen and carbon monoxide as taken from Figures 2 and 3. In Figure 4, hydrogen K-factors are situated above the line  $K = 1$  and carbon monoxide K-factors are below this line. The intersection of an isotherm with the line  $K = 1$  is called the plait point for that isotherm. The plait points for the 68.2° and 73.2°K isotherms were estimated by Verschoyle to be at pressures of 380 and 325 atmospheres, respectively. Critical constants for this system have been estimated by Verschoyle (423) and are presented in Table II.

Figure 4 thus contains sufficient information to enable one to calculate the vapor and liquid compositions under given temperature and pressure conditions. After the K-factors are obtained, one simply substitutes into the following formulae to obtain phase compositions:

$$K_1 = y_1/x_1 \quad (1)$$

$$K_2 = y_2/x_2 \quad (2)$$









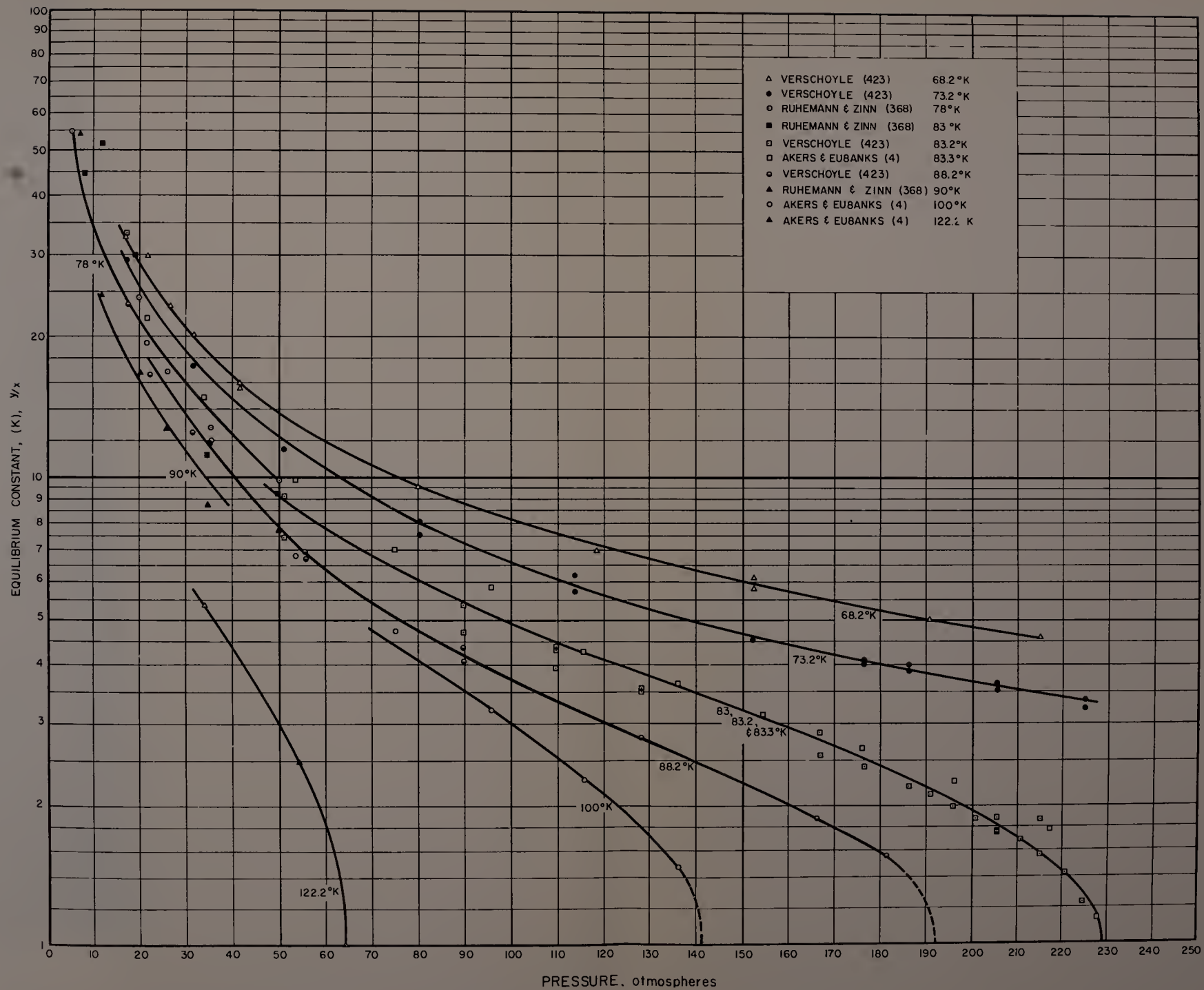


Figure 2. Carbon Monoxide-Hydrogen Vapor-Liquid Equilibria Data. Hydrogen K-Factors. Parenthetical Numbers Refer to Sources in Bibliography.







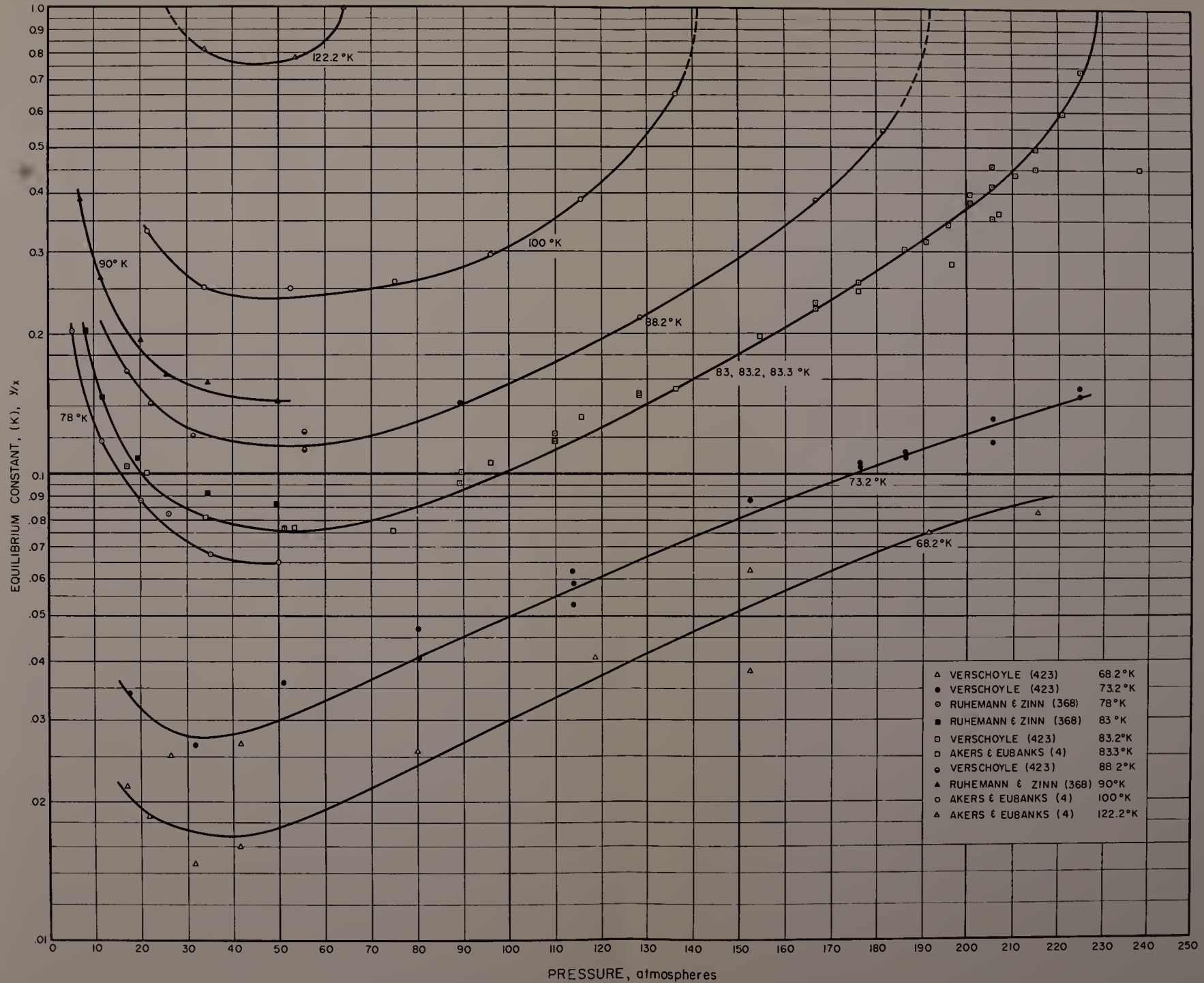


Figure 3. Carbon Monoxide-Hydrogen Vapor-Liquid Equilibria Data. Carbon Monoxide K-Factors. Parenthetical Numbers Refer to Sources in Bibliography.









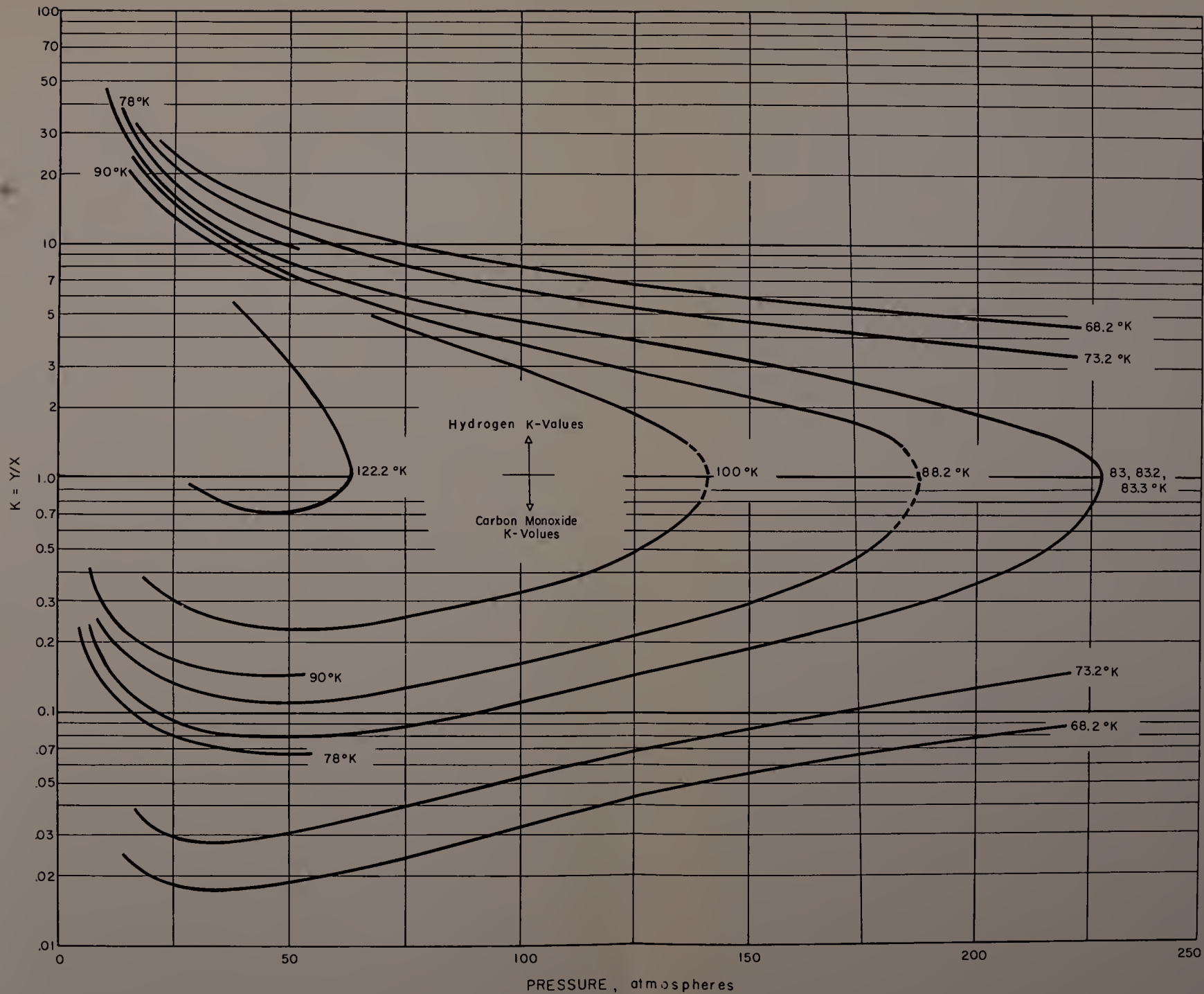


Figure 4. Vapor-Liquid Equilibria. Carbon Monoxide-Hydrogen System.



$$y_1 + y_2 = 1.0 \quad (3)$$

$$x_1 + x_2 = 1.0 \quad (4)$$

The subscripts refer to hydrogen and carbon monoxide. For example, at a system pressure of 100 atm., the phase compositions at 88.2°K could be found as follows:

$$K_{\text{CO}} = 0.159 = y_{\text{CO}}/x_{\text{CO}} \quad ; \quad y_{\text{CO}} = 0.159 x_{\text{CO}}$$

$$K_{\text{H}_2} = 3.72 = y_{\text{H}_2}/x_{\text{H}_2} \quad ; \quad y_{\text{H}_2} = 3.73 x_{\text{H}_2}$$

Solving equations (3) and (4), one obtains

$$y_{\text{CO}} = 0.122 \quad ; \quad x_{\text{CO}} = 0.764$$

$$y_{\text{H}_2} = 0.878 \quad ; \quad x_{\text{H}_2} = 0.236$$

Similarly, dew points and bubble points of given hydrogen-carbon monoxide mixtures can be calculated.

### 5. Solid-Vapor Equilibria

The data of Verschoyle (423) are given in Table V. These data have been plotted in Figure 5 to show vapor phase composition versus total pressure for the isotherms of 58.2° and 63.2°K.

The extensive solid-gas equilibria data of Dokoupil et al. (88) are given in Table VI. These data have been replotted (not shown) to arrive at P-y curves at 5°K temperature intervals from 35° to 65°K. The derived data are shown in Table VII and also on Figure 5. Of noteworthy interest is the minimum shown by each isotherm. The locus of these minimum points in the y-P curves thus allow the selection of the optimum total pressure at a given temperature to yield a minimum CO concentration in the gas phase.

### 6. Three-Phase Equilibria

Verschoyle has also presented data showing the locus of the three-phase curve. Table VIII contains this information.

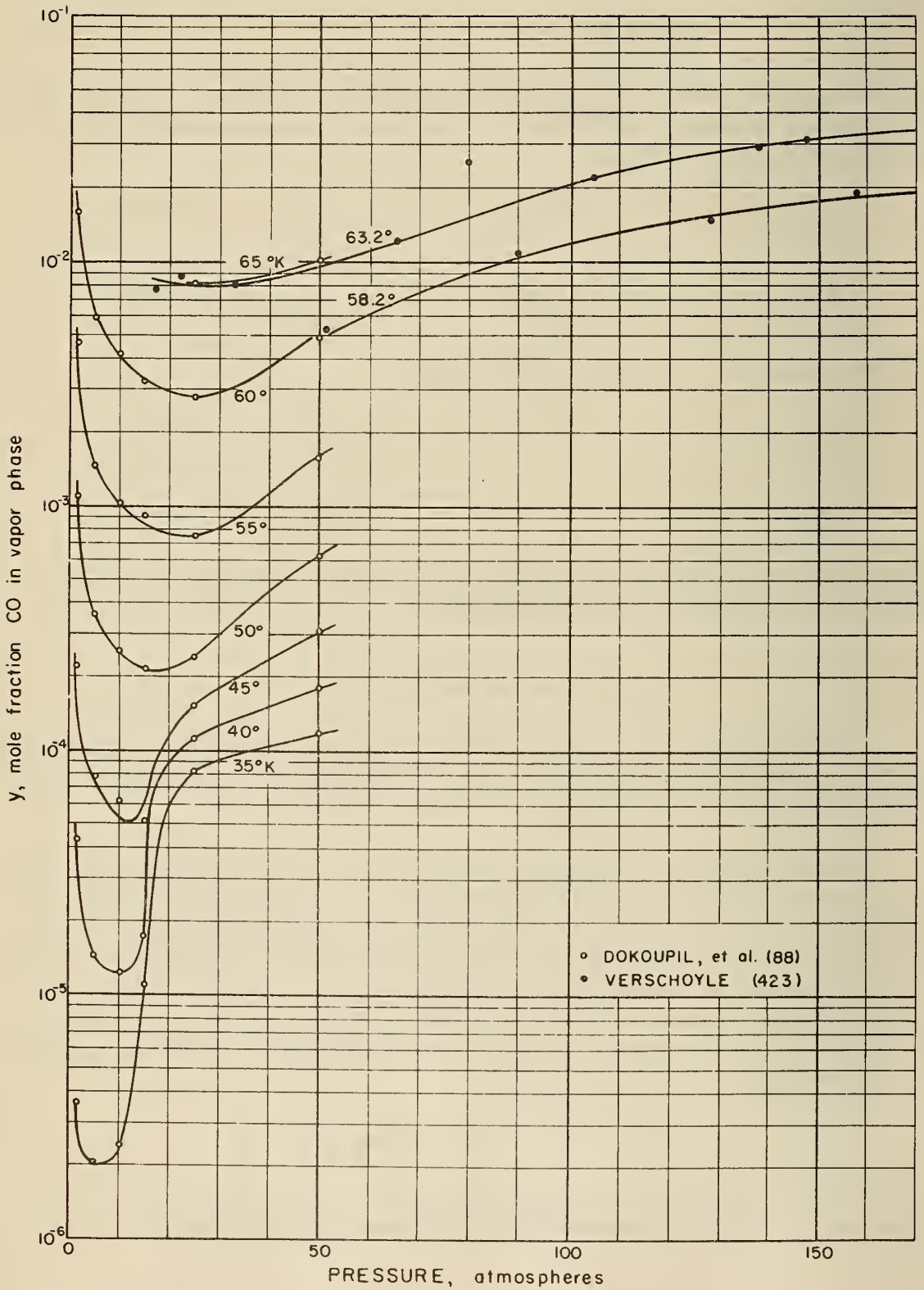


Figure 5. Solid-Vapor Equilibria. Concentration of Carbon Monoxide in the Vapor Phase.

Phenomena Index





Phenomena

MAJOR COMPONENT  
HYDROGEN

| Category         | Other Components                            | References   |
|------------------|---|--|
| Adsorption       |   | 8, 11, 84, 87, 107,<br>119, 176, 183, 187,<br>208, 209, 211, 212,<br>249, 250, 266, 296,<br>318, 332, 333, 351,<br>395, 414, 419 |
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|                  | Nitrogen                                    | 188, 419   |
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|                  | Carbon Dioxide                              | 141  |
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|                  | Helium                                      | 387  |
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## Phenomena

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| Category         | Other Components                     | References                            |
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|                  | Hydrogen-Nitrogen                    | 4, 88, 96, 368, 423                   |
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|                  | Hydrogen-Nitrogen                    | 450                                   |

Phenomena

## MAJOR COMPONENT

## GENERAL

| Category         | Other Components | References   |
|------------------|------------------|--|
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Processes Index



## Processes

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Processes

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GENERAL

| Category   | Other Components | References                                      |
|------------|------------------|---|
| Analytical |                  | 38, 69, 142, 196,<br>286, 384, 403,<br>404, 425 |



10.0

Bibliography of References

1. van Agt, F. The behavior of hydrogen relative to the law of corresponding states  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 176c, 7pp. (1925)
2. van Agt, F. and Kamerlingh Onnes, H. Isotherms of monatomic substances and of their binary mixtures. XXI. The compressibility of hydrogen and helium between 90° and 14°K (in Dutch)  
Verslag Gewone Vergader. Afd. Natuurk. Ned. Akad. Wetenschap. 34, 625-37 (1925)
3. van Agt, F. and Kamerlingh Onnes, H. The compressibility of hydrogen and helium between 90° and 14°K  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 176b, 15 pp. (1925)
4. Akers, W. W. and Eubanks, L. S. Vapor-liquid equilibrium in the system hydrogen-nitrogen-carbon monoxide  
Advances in Cryogenic Eng. 3, 275-93 (1960)
5. Almquist, J. A. and Dodge, R. L. Ultra-purification of gas mixtures  
Chem. & Met. Eng. 33, 89-92 (1926)
6. Anon. Bibliography of gas properties  
Trans. Am. Soc. Mech. Engrs. 71, 894-5, 901-2 (1949)
7. Anon. Hydrogen processing; hydrogen reference data  
Petrol. Processing 11, 136-8 (1956)
8. Armbruster, M. H. and Austin, J. E. The adsorption of gases on smooth surfaces of steel: argon, neon, hydrogen, nitrogen, carbon monoxide and carbon dioxide  
J. Am. Chem. Soc. 66, 159-71 (1944)
9. Arnold, R. D. and Hoge, H. J. A test of the ideal solution laws for hydrogen, hydrogen-deuteride and deuterium. Vapor pressures and critical constants of the individual components  
J. Chem. Phys. 18, 1295 (1950)
10. Augustin, H. Density of liquid hydrogen, index of refraction and dispersion of liquid hydrogen in liquid nitrogen (in German)  
Ann. Physik [4], 46, 419-45 (1915)

11. Barrer, R. M. Interaction of hydrogen with micro-crystalline charcoal. II. Activated sorption of hydrogen and methane by carbon  
Proc. Roy. Soc. (London) A149, 231-69 (1935)
12. Barrer, R. M. and Robins, A. B. Sorption of mixtures. II. Equilibria between binary gas mixtures and some zeolites  
Trans. Faraday Soc. 49, 929-39 (1953)
13. Bartell, F. E. and Almy, E. G. Activated silica gel  
J. Phys. Chem. 36, 475-89 (1932)
14. Bartlett, E. P. Compressibility isotherms of hydrogen, nitrogen and mixtures of these gases at 0° and pressures to 1000 atmospheres  
J. Am. Chem. Soc. 49, 687-701 (1927)
15. Bartlett, E. P., Cupples, H. L. and Tremearne, T. H. Compressibility isotherms of hydrogen, nitrogen and a 3:1 mixture of these gases at temperatures between 0° and 400° and at pressures to 1000 atmospheres  
J. Am. Chem. Soc. 50, 1275-88 (1928)
16. Bartlett, E. P., Hetherington, H. C., Kvalnes, H. M. and Tremearne, T. H. Compressibility isotherms of carbon monoxide at temperatures from -70° to 200° and at pressures to 1000 atmospheres  
J. Am. Chem. Soc. 52, 1374-82 (1930)
17. Bartlett, E. P., Hetherington, H. C., Kvalnes, H. M. and Tremearne, T. H. The compressibility isotherms of hydrogen, nitrogen and a 3:1 mixture of these gases at temperatures of -70°, -50°, -25° and -20°C and at pressures to 1000 atmospheres  
J. Am. Chem. Soc. 52, 1363-74 (1930)
18. Batuecas, T. Compressibility of certain gases at low pressures (in French)  
J. chim. phys. 31, 65-75 (1934)

19. Batuecas, T., Schlatter, C. and Maverick, G. Compressibility of gases at 0° and below one atmosphere and their divergence from Avogadro's law. IV. Carbon monoxide and nitrogen (in French)  
J. chim. phys. 26, 548-55 (1929)
20. Beattie, J. A. and Bridgeman, O. C. A new equation of state for fluids  
Proc. Am. Acad. Arts Sci. 63, 229-308 (1928)
21. Beattie, J. A. and Bridgeman, O. C. A new equation of state for fluids. II. Application to helium, neon, hydrogen, nitrogen, oxygen, air and methane. III. The normal densities and compressibilities of several gases at 0°C  
J. Am. Chem. Soc. 50, 3133-8 (1928)
22. Beattie, J. A. and Ikehara, S. An equation of state for gas mixtures. II. A study of the methods of combination of the constants of the Beattie-Bridgeman equation of state  
Proc. Am. Acad. Arts Sci. 64, 127-76 (1930)
23. Becker, E. W. and Stehl, O. The viscosity difference between ortho and para hydrogen at low temperatures (in German)  
Z. Physik 133, 615-28 (1952)
24. Beenakker, J. J. M. and Varekamp, F. H. Equation of state of hydrogen and its isotopes below 20°K  
Bull. inst. intern. froid Annexe 1956, No. 2, 189-94 (1956)
25. Beenakker, J. J. M., Varekamp, F. H. and van Itterbeek, A. The isotherms of the hydrogen isotopes and their mixtures with helium at the boiling point of hydrogen  
Physica 25, 9-24 (1959)
26. Benham, A. L. Vapor-liquid equilibria of light hydrocarbon systems containing hydrogen at low temperatures  
Ph.D. Thesis, Univ. of Mich., Ann Arbor (1956)
27. Benham, A. L. and Katz, D. L. Vapor-liquid equilibria for hydrogen-light hydrocarbon systems at low temperatures  
A. I. Ch. E. Journal 3, 33-6 (1957)

28. Benham, A. L., Katz, D. L. and Williams, R. B. Phase behavior of hydrogen-light hydrocarbon systems  
A. I. Ch. E. Journal 3, 236-41 (1957)
29. Benson, S. W. Critical densities and related properties of liquids  
J. Phys. & Colloid Chem. 52, 1060-74 (1948)
30. Berg, C., Fairfield, R. G., Imhoff, D. H. and Multer, H. J. Hypersorption-Process for separating gases  
Oil Gas J. 47, 95, 97, 130, 132, 135 (1949)
31. Bergeon, R. The solubility of solids and liquids in compressed gases (in French)  
Genie chim. 79, 139-51 (1958)
32. Bergholm, A. Vapor-liquid equilibria at high pressure (in Swedish)  
Svensk Kem. Tedskr. 63, 233-49 (1951)
33. Bjerrum, N. The specific heat of gases. II. Oxygen, hydrogen, argon, nitrogen and water vapor (in German)  
Z. Elektrochem. 18, 101-4 (1912)
34. Blacet, F. E. and MacDonald, G. D. Microanalysis of gases. III. Hydrogen, carbon monoxide, hydrogen chloride and ammonia  
Ind. Eng. Chem. Anal. Ed. 6, 334-6 (1934)
35. Blacet, F. E., MacDonald, G. D. and Leighton, P. A. Micro-analysis of gases. II. Carbon monoxide, ethylene and acetylene  
Ind. Eng. Chem. Anal. Ed. 5, 272-4 (1933)
36. Black, C. Phase equilibria in binary and multicomponent systems. Modified van Laar-type equation  
Ind. Eng. Chem. 50, 403-12 (1958)
37. Black, C. Vapor phase imperfections in vapor-liquid equilibria  
Ind. Eng. Chem. 50, 391-402 (1958)

38. Blondel, A. Microanalyzer for small gas samples (in French)  
Fonderie, No. 144, 19-24 (1958)
39. Bol'shakov, P. E. Partial molal volume, fugacity and activity coefficients of nitrogen and hydrogen in their mixtures at high pressure (in Russian)  
Acta Physicochim. U. R. S. S. 20, 259-67 (1945)
40. Bol'shakov, P. E., Gamburg, D. Yu., Efremova, G. D., Khazanova, N. E. and Tsiklis, D. S. Entropy-temperature diagrams for hydrogen, nitrogen, carbon monoxide, ethane and ethylene (in Russian)  
Trudy Gosudarst. Nauch. -Issledovatel. i Proekt. Inst. Azot. Prom. 1952, No. 1, 67-71
41. Botella, S. G. Compressibility of carbon monoxide at 0°, at surrounding temperatures and at pressure between 50 and 130 atmospheres (in Spanish)  
Anales soc. espan. fis y quim. 27, 315-50 (1929)
42. Bratu, E. M. A general equation for calculating the pressure of saturated vapors (in Romanian)  
Bul. inst. natl. cercitari technol. 2, 36-49 (1947)
43. Bridgman, P. W. Compressibility of five gases to high pressures  
Proc. Am. Acad. Arts Sci. 59, 173-211 (1923)
44. Briggs, H. Adsorption of gases by charcoal, silica and other substances  
Proc. Roy. Soc. (London) A100, 88-102 (1921)
45. Briggs, H. and Cooper, W. The adsorption of gas under pressure  
Proc. Roy. Soc. (Edinburgh) 41, 119-27 (1920)
46. Brodski, A. B. Calculation of the composition of equilibrium gas mixtures at high pressures (in Russian)  
Acta Physicochim. U. R. S. S. 17, 228-9 (1942)
47. Brunot, A. W. Properties of hydrogen mixtures  
Trans. Am. Soc. Mech. Engrs. 62, 613-9 (1940)



48. Burnett, E. S. Compressibility determinations without volume measurements  
J. Appl. Mechanics 3, 136-40 (1936)
49. Burrell, G. A. and Robertson, I. W. Vapor pressures of various compounds at low temperatures  
U. S. Bur. Mines, Tech. Paper 142, 30 pp. (1916)
50. Burshtein, R., Levin, P. and Petrov, S. Activated adsorption of gases on charcoal (in German)  
Physik. Z. Sowjetunion 4, 197-211 (1933)
51. Canjar, L. N., Ford, H. B. and Sebulsky, R. T. Predicting vapor-liquid equilibrium data. II.  
Petrol. Refiner 36, 135-9 (Oct. 1957)
52. Cardoso, E. Critical point (in French)  
J. chim. phys. 10, 470-96 (1913)
53. Cardoso, E. Critical points of nitrogen, oxygen, carbon monoxide and methane (in French)  
J. chim. phys. 13, 312-50 (1916)
54. Cardoso, E. Densities of the coexisting phases of methane and carbon monoxide (in French)  
Arch. sci. phys. et nat. 39, 403-4 (1915)
55. Cath, P. G. and Kamerlingh Onnes, H. The measurement of low temperatures. XXVII. Vapor pressure of hydrogen in the neighborhood of the boiling point and between the boiling point and the critical point  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 152a, 15 pp. (1917)
56. Cawood, W. and Patterson, H. S. Compressibilities of certain gases at low pressures and various temperatures  
J. Chem. Soc. 1933, 619-24 (1933)
57. Chao, K. C. Isobaric vapor-liquid equilibria  
Ind. Eng. Chem. 51, 93-4 (1959)

58. Chester, F. P. and Dugdale, J. S. Melting curves of deuterium and hydrogen  
Phys. Rev. 95, 278-9 (1954)
59. Claude, G. Adsorption of gases by charcoal at low temperatures (in French)  
Compt. rend. 158, 861-4 (1914)
60. Clusius, K. and Teske, W. Vapor pressures and vapor pressure constant of carbon monoxide (in German)  
Z. physik. Chem. B6, 135-51 (1929)
61. Cohen, E. D. G., Offerhaus, J. M., van Leeuwen, J. M. J., Roos, B. W. and DeBoer, J. The transport properties and equation of state of gaseous para- and ortho-hydrogen and their mixtures below 40°K  
Physica 21, 737-9 (1955)
62. Cohen, K. and Urey, H. C. Van der Waals' forces and the vapor pressure of ortho and para hydrogen and ortho and para deuterium  
J. Chem. Phys. 7, 157-63 (1939)
63. Cook, D. and Rowlinson, J. S. Deviations from the principle of corresponding states  
Proc. Roy. Soc. (London) A219, 405-18 (1953)
64. Cook, M. W., Hanson, D. N. and Alder, B. J. Solubility of hydrogen and deuterium in non-polar solvents  
J. Chem. Phys. 26, 748-51 (1957)
65. Cook, M. W. and Hanson, D. N. Accurate measurements of gas solubility  
Rev. Sci. Instr. 28, 370-4 (1957)
66. Cottrell, T. L. Equations of state, physical properties and thermodynamic transformation of intermolecular repulsive forces  
Discussions Faraday Soc. 22, 10-6 (1956)

67. Cottrell, T. L., Hamilton, R. A. and Taubinger, R. P. Second virial coefficients of gases and mixtures. II. Mixtures of carbon dioxide with nitrogen, oxygen, carbon monoxide, argon and hydrogen  
Trans. Faraday Soc. 52, 1310-2 (1956)
68. Cramer, F. An empirical equation of state for extremely high pressures. II. (in German)  
Chem. Tech. (Berlin) 6, 590-5 (1954)
69. Cremer, E. and Prior, F. Application of chromatographic methods to the separation of gases and determination of adsorption energies (in German)  
Z. Elektrochem. 55, 66-70 (1951)
70. Crommelin, C. A., Bijleveld, W. J. and Brown, E. G. Vapour tensions, critical point and triple point of carbon monoxide (in Dutch)  
Proc. Koninkl. Akad. Wetenschap. Amsterdam 34, 1314-7 (1931)
71. Crommelin, C. A. and Swallow, J. C. Isotherms of hydrogen from  $-217^{\circ}$  to  $-240^{\circ}$  at pressures up to 60 atmospheres  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 172a, 7 pp. (1924)
72. Cullen, E. J. and Kobe, K. A. Benedict equation of state: application to vapor-liquid equilibria  
A. I. Ch. E. Journal 1, 452-5 (1955)
73. De Boer, J. Equation of state of gases at low temperature  
Physica 24, S90-7 (1958)
74. Deitz, V. R. Bibliography of solid adsorbents 1900-1942, 1943-1953  
Natl. Bur. Standards (U. S.), Circ. 566, 1528 pp. (1944)
75. Deitz, V. R. and Gleysteen, L. F. Determination of carbon and hydrogen in bone black and chars  
J. Research Natl. Bur. Standards 28, 795-805 (1942)
76. Delaplace, R. Pressures of some permanent gases at low temperatures in the presence of silica gel (in French)  
Compt. rend. 205, 664-5 (1937)

77. Deming, W. E. and Deming, L. S. Some physical properties of compressed gases. IV. The entropies of nitrogen, carbon monoxide and hydrogen  
Phys. Rev. 45, 109-13 (1934)
78. Deming, W. E. and Shupe, L. E. Constants of the Beattie-Bridgeman equation of state with Bartlett's p-v-t data on hydrogen  
J. Am. Chem. Soc. 53, 843-9 (1931)
79. Deming, W. E. and Shupe, L. E. Physical properties of compressed gases. II. Carbon monoxide  
Phys. Rev. 38, 2245-64 (1931)
80. Deming, W. E. and Shupe, L. E. Some physical properties of compressed gases. III. Hydrogen, nitrogen and carbon monoxide  
Phys. Rev. 40, 848-59 (1932)
81. Denton, W. H., Shaw, B., Gayler, R. and Seager, P. Purification of hydrogen for distillation. Part II.  
Trans. Inst. Chem. Engrs. (London) 37, 277-88 (1959)
82. Denton, W. H., Shaw, B. and Ward, D. E. Purification of hydrogen for distillation  
Trans. Inst. Chem. Engrs. (London) 36, 179-200 (1958)
83. DeSorbo, W., Milton, R. M. and Andrews, D. H. New cryogenic methods of using liquid hydrogen  
Chem. Revs. 39, 403-17 (1946)
84. Dewar, J. The adsorption and thermal evolution of gases occluded in charcoal at low temperatures. Adsorption of hydrogen, nitrogen, oxygen, argon, helium, electrolytic gas, carbonic oxide and oxygen and carbonic oxide at 0° and -185°C  
Proc. Roy. Soc. (London) A74, 122-7 (1904)
85. Dewar, J. The densities of solid oxygen, nitrogen, hydrogen, argon, carbon monoxide, etc.  
Proc. Roy. Soc. (London) A73, 251-61 (1904)

86. DiCio, A. Equation of state for carbon monoxide-hydrogen mixtures (in Italian)  
Riv. combustibili 11, 300-7 (1957)
87. van Dingenen, W. and van Itterbeek, A. Measurements of the adsorption of light and heavy hydrogen on charcoal between 90° and 17°K  
Physica 6, 49-58 (1939)
88. Dokoupil, Z., van Soest, G. and Swenker, M. D. P. The equilibrium between the solid phase and the gas phase of the systems hydrogen-nitrogen, hydrogen-carbon monoxide and hydrogen-nitrogen-carbon monoxide  
Appl. Sci. Research A5, 182-241 (1955)
89. Dubinin, M. M. and Zaverina, E. D. Adsorption of gases by active carbons (in Russian)  
Doklady Akad. Nauk S. S. S. R. 72, 319-22 (1950)
90. Dugdale, J. S. and MacDonald, D. K. C. Influence of zero-point energy on the thermodynamic properties of low boiling point elements  
Phil. Mag. [7], 45, 811-7 (1954)
91. Edwards, A. E. and Roseveare, W. E. The second virial coefficient of gaseous mixtures  
J. Am. Chem. Soc. 64, 2816-9 (1942)
92. Ehrett, W. E., Weber, J. H. and Hoffman, D. S. Predicting vapor-liquid equilibrium relations in multicomponent systems  
Ind. Eng. Chem. 51, 711-3 (1959)
93. Ehrlich, G., Hicmott, T. W. and Hudda, F. G. The low-temperature chemisorption of nitrogen and carbon monoxide  
J. Chem. Phys. 28, 506-7 (1958)
94. English, W. N. Continuous purification of hydrogen in a large electron pulse chamber  
Rev. Sci. Instr. 22, 598-600 (1951)
95. Estreicher, T. and Bobotek, J. The behavior of carbon monoxide at low temperatures (in French)  
Bull. intern. acad. sci. Cracovie 1913A, 451-62 (1913)

96. Eubanks, L. S. Vapor-liquid equilibrium in the system hydrogen-nitrogen-carbon monoxide  
Ph. D. Thesis, Rice Inst., Houston (1956)
97. Eucken, E. U. and Lude, K. V. The specific heat of gases at medium and high temperatures. I. The specific heat of the gases air, nitrogen, oxygen, carbon monoxide, carbon dioxide, nitrous oxide and methane between 0° and 200° (in German)  
Z. physik. Chem. B5, 413-41 (1929)
98. Ewald, A. H. Solubility of solids in gases. Part II.  
Trans. Faraday Soc. 49, 1401-5 (1953)
99. Ewald, A. H., Jepson, W. B. and Rowlinson, J. S. The solubility of solids in gases  
Discussions Faraday Soc. 15, 238-43 (1953)
100. Faggiani, D. Energy, enthalpy and entropy of gases according to the most recent determinations (in Italian)  
Termotecnica (Milan) 1, 108-13 (1947)
101. Fales, H. A. and Shapiro, C. S. Thermodynamic properties of substances. III. Vapor volumes as functions of reduced temperature alone  
J. Am. Chem. Soc. 62, 393-406 (1940)
102. Falk, G. and Mann, A. Viscosity of o- and p-hydrogen (in German)  
Z. Physik 142, 277-96 (1955)
103. Farkas, A. Orthohydrogen, parahydrogen and heavy hydrogen  
University Press, Cambridge 215 pp. (1935)
104. Fastovskii, V. G. and Gonikberg, M. G. Solubility of gases in liquids at low temperature and high pressure. III. Solubility of hydrogen in liquid methane (in Russian)  
Acta Physicochim. U. R. S. S. 12, 427-8 (1940)
105. Fedorova, M. F. Binary mixtures of substances melting at low temperatures (in Russian)  
Zhur. Eksp. i Teoret. Fiz. 8, 425-35 (1938)

106. Fenning, R. W. and Whiffin, A. C. The specific heat of gases at high temperatures: carbon monoxide, nitrogen, carbon dioxide, hydrogen, water vapor. Explosion method  
Trans. Roy. Soc. (London) A238, 149-212 (1939)
107. Firth, J. B. Sorption of hydrogen by palladium at low temperatures  
J. Chem. Soc. 117, 171-83 (1920)
108. Fischer, V. Equilibrium isotherms and isobars of carbon monoxide-nitrogen-hydrogen mixtures (in German)  
Ann. Physik [5], 31, 531-9 (1938)
109. Fischer, V. The analysis of a mixture of carbon monoxide, nitrogen and hydrogen (in German)  
Tech. Mech. u. Thermodynam. 1, 268-76 (1930)
110. Foreman, J. K. Microdetermination of carbon dioxide, oxygen, carbon monoxide and hydrogen in gaseous mixtures by the Krogh method (in Austrian)  
Mikrochim. Acta 1956, 1481-7 (1956)
111. Franck, E. U. Solubility of solid substances in compressed gases (in German)  
Z. physik. Chem. (Frankfurt) 6, 345-55 (1956)
112. Franck, E. U. Thermal conduction in highly compressed gases (in German)  
Z. physik. Chem. (Leipzig) 201, 16-31 (1952)
113. Freundlich, H. Adsorption and occlusion (in German)  
Z. physik. Chem. (Leipzig) 61, 249-54 (1907)
114. Friedman, A. S. P-V-T relationships of gaseous hydrogen, nitrogen and hydrogen-nitrogen mixtures  
Ph. D. Thesis, Ohio State Univ., Columbus (1950)
115. Friedman, A. S. and Oppenheim, I. Equation of state of hydrogen isotopes at intermediate densities  
Phys. Rev. 98, 258 (1955)

116. Friedman, A. S., White, D. and Johnston, H. L. Critical constants, boiling points, triple point constants and vapor pressure of the six isotropic hydrogen molecules based on a simple mass relationship  
J. Chem. Phys. 19, 126-7 (1951)
117. Friedman, H. L. Nonideality of liquid ortho-para hydrogen solutions  
J. Chem. Phys. 27, 220-3 (1957)
118. Frolich, P. K., Tauch, E. J., Hogan, J. J. and Peer, A. A. Solubilities of gases in liquids at high pressures  
Ind. Eng. Chem. 23, 548-50 (1931)
119. Frolich, P. K. and White, A. Adsorption of methane and hydrogen on charcoal at high pressure  
Ind. Eng. Chem. 22, 1058-60 (1930)
120. Ganguli, A. The adsorption of gases by solids  
J. Phys. Chem. 34, 665-8 (1930)
121. Garner, W. E. and Maggs, J. Adsorption of carbon monoxide on zinc oxide  
Trans. Faraday Soc. 32, 1744-8 (1936)
122. Gerf, S. F. and Galkov, G. I. Viscosity of liquefied pure gases and their mixtures. Part III. (in Russian)  
Zhur. Tekh. Fiz. 11, 801-8 (1941)
123. Geyer, E. W. Specific heats and energy charts for gases  
Mech. Eng. 159, 381-3, 423-4 (1945)
124. Giacomini, F. A. The temperature dependency of the molecular heats of gases, especially of ammonia, methane and hydrogen at low temperatures  
Phil. Mag. [6], 50, 146-56 (1925)
125. Giauque, W. F. The entropy of hydrogen and the third law of thermodynamics. The free energy and dissociation of hydrogen  
J. Am. Chem. Soc. 52, 4816-31 (1930)



126. Gibert, R. and Dognin, A. The calculation of the force constants of Lennard-Jones potentials (in French)  
Compt. rend. 246, 2607-9 (1958)
127. Gilliland, E. R. P-V-T relations of gaseous mixtures  
Ind. Eng. Chem. 28, 212-5 (1936)
128. Gilliland, E. R. and Sullivan, T. E. Fugacity of vapor mixtures  
Chem. Eng. Progr. Symposium Ser. No. 2, 48, 18-27 (1952)
129. Godridge, A. M. Some properties of gas mixtures  
Bull. Brit. Coal Utilisation Research Assoc. 18, 1-21 (1954)
130. Goff, J. A. and Gratch, S. Zero-pressure thermodynamic properties of carbon monoxide and nitrogen  
Trans. Am. Soc. Mech. Engrs. 72, 741-9 (1950)
131. Goffredo, L. A review of methods for the determination of small quantities of carbon monoxide (in Italian)  
Riv. combustibili 7, 84-5 (1953)
132. Goig, S. The compressibility of carbon monoxide at 0° and above 50 atmospheres (in French)  
Compt. rend. 189, 246-8 (1929)
133. Goig, S. Compressibility of carbon monoxide at 0° and ordinary temperatures between 50 and 150 atmospheres (in French)  
J. chim. phys. 27, 212-35 (1930)
134. Goldhammer, D. A. Studies in the theory of corresponding states (in German)  
Z. physik. Chem. 71, 577-624 (1910)
135. Gonel, H. W. Gas purification in the chemical industry (in German)  
Chem. Fabrik 6, 479-80 (1933)
136. Gonikberg, M. G. Regular solutions of gases in liquids. I. Regular solutions of hydrogen (in Russian)  
Zhur. Fiz. Khim. 14, 582-8 (1940)

137. Gonikberg, M. G. Regular solutions of gases in liquids. II. More concentrated solutions of hydrogen at high pressures (in Russian)  
Acta Physicochim. U. R. S. S. 12, 921-30 (1940)
138. Gonikberg, M. G., Fastovskii, V. G. and Gurvitsch, J. G. Solubility of gases in liquids at low temperatures and high pressures. I. Solubility of hydrogen in liquid nitrogen at 79°-109°K and at pressures up to 190 atmospheres (in Russian)  
Acta Physicochim. U. R. S. S. 11, 865-82 (1939)
139. Granet, I. Physical properties of hydrogen in convenient graphical form  
Petrol. Refiner 33, 205-6 (1954)
140. Gratch, S. Vapor pressure, specific volume, p-v-t data for hydrogen, nitrogen, oxygen, carbon monoxide, carbon dioxide, air, helium, argon and mercury  
Trans. Am. Soc. Mech. Engrs. 70, 631-40 (1948)
141. Greco, G., Casale, C. and Negri, G. Liquid-vapor equilibria at elevated pressures of one component in the presence of noncondensable components (in Italian)  
Compt. rend. congr. intern. chim. ind. 27<sup>e</sup> Congr., Brussels, 1954.  
Published as Ind. chim. belge. 20, Special No. 251 (1955)
142. Greene, S. A., Moberg, M. L. and Wilson, E. M. Separation of gases by gas adsorption chromatography  
Anal. Chem. 28, 1369-70 (1956)
143. Gregory, H. S. and Archer, C. T. The thermal conductivities of carbon monoxide and nitrous oxide  
Proc. Roy. Soc. (London) A121, 285-93 (1928)
144. Grilly, E. R. Relationships between transport properties of gases  
Am. J. Phys. 20, 447-50 (1952)
145. Grilly, E. R. The vapor pressures of hydrogen, deuterium and tritium up to 3 atmospheres  
J. Am. Chem. Soc. 43, 843-6 (1951)

146. Groth, V. W., Ihle, H. and Murrenhoff, A. Determination of the temperature dependence of the vapor pressure relations (in German)  
Z. Naturforsch. 9a, 895-6 (1954)
147. Guelperine, N. I. and Naiditch, I. M. "I-S" diagrams for hydrogen, carbon monoxide, nitrogen, nitrogen and hydrogen, and carbon monoxide and hydrogen (in French)  
Chim. & ind. (Paris) 34, 1011-20 (1935)
148. Guertler, W. and Prani, M. The melting points of the pure elements (in German)  
Z. Metallk. 11, 1-7 (1919)
149. Guggenheim, E. A. The principle of corresponding states  
J. Chem. Phys. 13, 253-6 (1945)
150. Guggenheim, E. A. The statistical mechanics of regular solutions  
Proc. Roy. Soc. (London) A148, 304-12 (1935)
151. Guggenheim, E. A. Virial coefficients and corresponding states of gases  
Revs. Pure and Appl. Chem. (Australia) 3, 1-24 (1953)
152. Guggenheim, E. A. and McGlashan, M. L. Corresponding states in mixtures of slightly imperfect gases  
Proc. Roy. Soc. (London) A206, 448-63 (1951)
153. van Gulik, W. and Keesom, W. H. The fusion line of hydrogen up to 245 kg/sq cm  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 192b, 3 pp. (1928)
154. Guye, P. A. and Batuecas, T. The compressibility of several gases at 0° and up to one atmosphere and the deviation from Avogadro's law. I. Oxygen, hydrogen and carbon dioxide (in French)  
Helv. Chim. Acta 5, 532-43 (1922)
155. Habada, M. and Hajda, J. Compressibility of hydrogen (in Czech.)  
Chem. průmysl 3, 68-72 (1953)

156. Hala, E., Jiri, P., Vojtech, F. and Otakav, V. Vapor liquid equilibrium  
Pergamon Press, New York, 1958, pp. 299-365
157. Harper, B. G. and Moore, J. C. Vapor-liquid equilibria  
Ind. Eng. Chem. 49, 2010 (1957)
158. Hausen, H. Influence of the Lewis coefficient on the freezing-out of vapors from gas-vapor mixtures (in German)  
Angew. Chem. B20, 177-82 (1948)
159. Havlicek, V. The coefficients of compressibility for gases (in Czech.)  
Strojirenstvi 8, 903-4 (1958)
160. Hawkins, G. A. Brief review of available data on the dynamic viscosity and thermal conductivity for twelve gases  
Trans. Am. Soc. Mech. Engrs. 70, 655-9 (1948)
161. Hempel, W. Determination of hydrogen and methane in gas mixtures (in German)  
Z. angew. Chem. 25, 1841-5 (1912)
162. Henning, F. and Heuse, W. A new determination of the normal boiling points of oxygen, nitrogen and hydrogen (in German)  
Z. Physik 23, 105-16 (1924)
163. Henning, F. and Stock, A. Saturation pressure of some vapors between 10° and -181° (in German)  
Z. Physik 4, 226-44 (1921)
164. Herz, W. On the b of the van der Waals' equation (in German)  
Z. Elektrochem. 29, 527-30 (1923)
165. Hill, R. W. and Ricketson, B. W. A. A lambda-anomaly in the specific heat of solid hydrogen  
Phil. Mag. [ 7 ], 45, 277-82 (1954)
166. Hilsenrath, J. (Editor) Tables of thermal properties of gases  
Natl. Bur. Standards (U. S.) Circ. 564, 201-53 (1955)

167. Himpan, J. A new thermodynamic equation of state for gases and liquids (in Austrian)  
Monatsh. Chem. 84, 787-97 (1953)
168. Hirschfelder, J. O., Bird, R. B. and Spotz, E. L. The transport properties of non-polar gases  
J. Chem. Phys. 16, 968-81 (1948)
169. Hitz, K., Scheller, W. and Treadwell, W. D. The mixed adsorption of hydrogen, oxygen and nitrogen with carbon dioxide on Linden charcoal (in German)  
Helv. Chim. Acta 34, 1783-90 (1951)
170. Hofsass, M. Separation of chemically pure hydrogen from gaseous mixtures (in German)  
Z. kompr. fluss. Gase 30, 13-4 (1933)
171. Hoge, H. J. Heat capacity of a two-phase system with application to vapor correction in calorimetry  
J. Research Natl. Bur. Standards 36, 111-8 (1946)
172. Hoge, H. J. and Arnold, R. D. Vapor pressures of hydrogen, deuterium and hydrogen deuteride and the dew-point pressures of their mixtures  
J. Research Natl. Bur. Standards 47, 63-74 (1951)
173. Hoge, H. J. and Lassiter, J. W. Critical temperatures, pressures and volumes of hydrogen, deuterium and hydrogen deuteride  
J. Research Natl. Bur. Standards 47, 75-9 (1951)
174. Holborn, L. and Otto, J. Isotherms of helium, hydrogen and neon below  $-200^{\circ}$  (in German)  
Z. Physik 38, 359-67 (1926)
175. Holborn, L. and Otto, J. The isotherms of various gases between  $400^{\circ}$  and  $-183^{\circ}$  (in German)  
Z. Physik 33, 1-12 (1925)
176. Hollings, H. and Griffith, R. H. Activated adsorption of hydrogen  
Nature 129, 834 (1932)

177. Homfray, I. F. Adsorption of gases by charcoal  
Proc. Roy. Soc. (London) A84, 99-106 (1910)
178. Homfray, I. F. Adsorption of gases by charcoal (in German)  
Z. physik. Chem. 74, 129-201 (1910)
179. Husing, E. Adsorption of gases and gas mixtures by special  
charcoals (in German)  
Z. tech. Physik 17, 289-301 (1936)
180. van Itterbeek, A. The dependency of  $C_p/C_v$  on pressure for  
hydrogen gas deduced from measurements of the velocity of  
sound at liquid hydrogen temperatures  
Commun. Kamerlingh Onnes Lab. Univ. Leiden, Supp. No. 70b,  
7-12 (1932)
181. van Itterbeek, A. and Borghs, J. The van der Waals adsorption  
of gases (in German)  
Z. physik. Chem. B50, 128-42 (1942)
182. van Itterbeek, A. and van Dingenen, W. Adsorption isotherms  
and heats of adsorption of oxygen and carbon monoxide on  
charcoal in the temperature range of 50° to 90°K  
Physica 4, 1169-80 (1937)
183. van Itterbeek, A. and van Dingenen, W. Determination of  
adsorption isotherms of hydrogen on charcoal between 90°  
and 50°K in connection with desorption experiments  
Physica 4, 389-402 (1937)
184. Jager, G. The theory of the solubility of gases in liquids (in  
German)  
Sitzb. Akad. Wiss., Wien, Abt. IIa, 124, 287-304 (1915)
185. Janak, J., Krejci, R. and Dubdsky, H. E. Zeolites in gas  
chromatography. I. Separation and analysis of mixtures of  
hydrogen, nitrogen, carbon monoxide and methane (in Czech.)  
Chem. listy 52, 1099-107 (1957)
186. Joffe, J. Fugacities in gas mixtures  
Ind. Eng. Chem. 40, 1738-41 (1948)

187. Johnson, M. C. An analysis of hydrogen adsorption phenomena  
Trans. Faraday Soc. 29, 1139-55 (1933)
188. Johnson, V. J. Removal of nitrogen from hydrogen with silica  
gel at low temperatures  
Advances in Cryogenic Eng. 3, 11-8 (1960)
189. Johnson, V. J. (Editor) A compendium of the properties of  
materials at low temperatures - phase I.  
Natl. Bur. Standards Cryogenic Eng. Lab., Boulder, Colorado  
(Dec. 1959)
190. Johnston, H. L., Bezman, I. I. and Hood, C. B. Joule-  
Thomson effects in hydrogen at liquid air and at room tempera-  
tures  
J. Am. Chem. Soc. 68, 2367-73 (1946)
191. Johnston, H. L., Bezman, I. I., Rubin, T., Jensen, L.,  
White, D. and Friedman, A. S. Gaseous data of state for  
hydrogen between 1 and 200 atmospheres from 20° to 300°K  
Phys. Rev. 79, 235 (1950)
192. Johnston, H. L., Keller, W. E. and Friedman, A. S. The  
compressibility of liquid normal hydrogen from the boiling point  
to the critical point at pressures up to 100 atmospheres  
J. Am. Chem. Soc. 76, 1482-6 (1954)
193. Johnston, H. L. and White, D. Pressure-volume-temperature  
relationships of gaseous normal hydrogen from its boiling  
point to room temperature from 0 to 200 atmospheres  
Trans. Am. Soc. Mech. Engrs. 72, 785-7 (1950)
194. Johnston, H. L. and White, D. Summary of experimental  
determinations of the J-T effects in gases  
Trans. Am. Soc. Mech. Engrs. 70, 651-5 (1948)
195. Johnston, H. L., White, D., Wirth, H., Swanson, C., Jensen,  
L. H. and Friedman, A. S. Gaseous data of state. II. The  
p-v-t relationships of gaseous normal hydrogen from the critical  
temperature to room temperature and up to 200 atmospheres  
pressure  
T. R. 264-25, Ohio State Cryogenic Lab. (Nov. 25, 1953)

196. Joyner, L. G., Weimberger, E. B. and Montgomery, C. W. Surface area measurements of activated carbon, silica gel and other adsorbents  
J. Am. Chem. Soc. 67, 2182-8 (1945)
197. Justi, E. Thermodynamics of real gas mixtures (in German)  
Forsch. Gebiete Ingenieurw. 15, 18-21 (1944)
198. Kamerlingh Onnes, H. An apparatus for the purification of gaseous hydrogen by liquid hydrogen (in Dutch)  
Koninkl. Akad. Wetenschap. Amsterdam 11, 883-6 (1910)
199. Kamerlingh Onnes, H. Expression of the equation of state of gases and liquids by means of a series  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 71, 3-25 (1901)
200. Kamerlingh Onnes, H. and Braak, C. Isotherms of hydrogen between  $-104^{\circ}\text{C}$  and  $217^{\circ}\text{C}$   
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 97a, 28 pp. (1906) and Nos. 99a, 3 pp., 100a, 9 pp. (1907)
201. Kamerlingh Onnes, H. and Crommelin, C. A. Isotherms of diatomic substances and their binary mixtures. XIII. Liquid densities of hydrogen between the boiling point and the triple point; contraction of hydrogen on freezing  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 137a, 3 pp. (1913)
202. Kamerlingh Onnes, H. and Weber, S. Vapor pressure of substances of low critical temperature at low temperatures  
Verslag. Akad. Wetenschap. Amsterdam 22, 226-39 (1914)
203. Kast, H. and Selle, H. Detection and colorimetric determination of carbon monoxide (in German)  
Gas-u Wasserfach 69, 812-5 (1926)
204. Kawakita, K. and Itiyaniagi, B. Elimination of a small amount of carbon monoxide in hydrogen (in Japanese)  
J. Soc. Chem. Ind. Japan 43, Suppl. Binding 121 (1940)



205. Kazavchinskii, Ya. A. A method of determining the constants for the virial form of the equation of state for a real gas (in Russian)  
Doklady Akad. Nauk S. S. S. R. 95, 1005-8 (1954)
206. Keesom, W. H. Second virial coefficient for diatomic gases (in Dutch)  
Koninkl. Ned. Akad. Wetenschap. Proc. 15, 417-31 (1913)
207. Keesom, W. H. Thermodynamic investigations including triple point and critical magnitudes of oxygen, argon, nitrogen, neon, hydrogen and helium (in German)  
Onnes-Festschrift 1922, 89-163 (1922)
208. Keier, N. P. and Roginskii, S. Z. The kinetics of desorption of activated adsorbed hydrogen (in Russian)  
Zhur. Fiz. Khim. 23, 897-916 (1949)
209. Keier, N. P. and Roginskii, S. Z. The properties of broadly heterogeneous surfaces as shown by the study of the adsorption of oxygen and hydrogen on activated charcoal (in Russian)  
Problemy Kinetiki i Kalaliza, Akad. Nauk S. S. S. R. No. 7, 410-35 (1949)
210. Kihara, T. Virial coefficients and intermolecular potential of small, non-spherical molecules  
J. Phys. Soc. Japan 11, 362-6 (1956)
211. Kingman, F. E. T. Adsorption of hydrogen on charcoal  
Nature 127, 742 (1931)
212. Kingman, F. E. T. Adsorption of hydrogen on charcoal  
Trans. Faraday Soc. 28, 269-72 (1932)
213. Kinoshita, M. and Oisi, J. Expansion and pressure coefficients of nitrogen, hydrogen, helium and neon and the absolute temperature of 0°C  
Phil. Mag. [7], 24, 52-62 (1937)
214. Koeppe, W. The integral J-T effect for hydrogen at low temperatures and pressures up to 120 atmospheres (in German)  
Kaltetechnik 8, 275 (1956)

215. Kogan, V. B. and Fridman, V. M. Computation methods for phase equilibrium for binary liquid-vapor systems (in Russian) *Zhur. Fiz. Khim.* 28, 1889-95 (1954)
216. Kogan, V. B., Lazarev, B. G. and Bulatova, R. B. State diagram of the hydrogen-deuterium system (in Russian) *Zhur. Eksptl. i Teoret. Fiz.* 34, 238-40 (1958)
217. Kohl, A. L. and Riesenfeld, F. C. Today's processes for gas purification  
*Chem. Eng.* 66, 127-78 (June 15, 1959)
218. Kolsky, R. G., Gilmer, R. M. and Gilles, P. W. Free-energy functions for 54 gaseous elements  
*J. Chem. Phys.* 27, 494-5 (1957)
219. Komarov, P., Likhter, A. and Ruhemann, M. The diagrams of state of mixtures fusing at low temperatures: systems nitrogen-oxygen and nitrogen-carbon monoxide (in Russian) *Zhur. Tekh. Fiz.* 5, 1723-8 (1935)
220. Kordes, E. General equation of state for saturated vapors (in German)  
*Naturwissenschaften* 40, 359-60 (1953)
221. Kordes, E. The heterogeneous equilibrium liquid-vapor (in German)  
*Z. Elektrochem.* 58, 424-31 (1954)
222. Korsching, H. Diffusion-separator for gases (in German)  
*Z. Naturforsch.* 6a, 213-7 (1951)
223. Kortum, G., Freier, H. J. and Woerner, F. The dynamic method for the determination of vapor-liquid equilibria (in German)  
*Chem.-Ing.-Tech.* 25, 125-33 (1953)
224. Kritscheveskii, I. R. and Kazarnovskii, Ya. S. An equation of state for gaseous mixtures (in Russian)  
*Acta Physicochim. U. R. S. S.* 10, 217-44 (1939)

225. Kritscheveskii, I. R. and Levchenko, G. T. Compressibility of gas mixtures. II. P-V-T data for binary and ternary mixtures of methane, nitrogen and hydrogen (in Russian) *Acta Physicochim. U. R. S. S.* 14, 271-8 (1941)
226. Kritscheveskii, I. R. and Markov, V. P. The compressibility of gas mixtures. I. The p-v-t data for binary and ternary mixtures of hydrogen, nitrogen and carbon dioxide (in Russian) *Acta Physicochim. U. R. S. S.* 12, 59-66 (1940)
227. Kyryacos, G. and Boord, C. E. Separation of hydrogen, oxygen, nitrogen, methane and carbon monoxide by gas adsorption chromatography  
*Anal. Chem.* 29, 787-8 (1957)
228. van Laar, J. J. The critical density of hydrogen, helium and neon (in Dutch)  
*Chem. Weekblad* 16, 1557-64 (1919)
229. Lachmann, W. Process and apparatus for separating mixtures of gases or vapors by adsorption or chemical combination (in German)  
*Z. Sauerstoff-Stickstoff-Ind.* 16, 5-11 (1924)
230. Lachowicz, S. K. Solubility of gases in liquids at high pressures  
*J. Imp. Coll. Chem. Eng. Soc.* 8, 51-68 (1954)
231. Lachowicz, S. K. The relative solubility of hydrogen and deuterium in liquids at low temperatures  
*Research Correspondence* 8, No. 6, S 27-8 (1955)
232. Lambert, B. and Heaven, H. S. Gas-solid equilibria. VI. Adsorption from binary gas mixtures by silica gel  
*Proc. Roy. Soc. (London)* A153, 584-600 (1936)
233. Langmuir, J. Theory of adsorption  
*Phys. Rev.* 6, 79-80 (1915)
234. Leduc, A. Expansion coefficients in gases (in French)  
*Compt. rend.* 148, 1173-6 (1909)

235. Lee, J. F. Specific heat of gases at the critical point (in German)  
Z. angew. Math. u. Phys. 4, 401-4 (1953)
236. Lennard-Jones, J. E. The molecule fields of hydrogen, nitrogen and neon  
Proc. Roy. Soc. (London) A112, 214-29 (1926)
237. Lennard-Jones, J. E. and Cook, W. R. The equation of state of a gaseous mixture  
Proc. Roy. Soc. (London) A115, 334-48 (1927)
238. Lenoir, J. M. and Hipkin, H. G. Equilibrium ratios of hydrogen and the critical locus of hydrogen-paraffin mixtures  
A. I. Ch. E. Journal 3, 318-20 (1957)
239. Lepointe, R. Heat of adsorption of gases by charcoal at  $-183^{\circ}\text{C}$  (in French)  
J. phys. radium 7, 469-72 (1936)
240. Lewis, W. K., Gilliland, E. R., Chertow, B. and Cadogan, W. P. Adsorption equilibria. Pure gas isotherms  
Ind. Eng. Chem. 42, 1326-32 (1950)
241. Liang, S. C. Low vapor pressure measurements and thermal transpiration  
J. Phys. Chem. 56, 660-2 (1952)
242. Livingston, M. K. The cross-sectional areas of molecules adsorbed on solid surfaces  
J. Colloid Sci. 4, 447-58 (1949)
243. Lorenz, R. and Magnus, A. The separation of gas mixtures by diffusion (in German)  
Z. anorg. u. allgem. Chem. 136, 97-113 (1924)
244. Lorenz, R. and Wiedbrauck, E. Adsorption equilibria of mixtures of two gases (in German)  
Z. anorg. u. allgem. Chem. 143, 268-76 (1925)
245. Lowry, H. H. and Morgan, S. O. The adsorption of gases by graphic carbon  
J. Phys. Chem. 29, 1105-15 (1925)

246. Lu, B. C. Y., Li, J. C. M. and Ting, T. W. Cluster theory of vapor-liquid equilibria  
Ind. Eng. Chem. 51, 219-22 (1959)
247. Lydersen, A. L. and Hammer, E. Vapor-liquid equilibrium still for low pressures  
Chem. Eng. Sci. 7, 241-5 (1958)
248. Magnus, A. and Roth, N. Adsorption. VII. The adsorption of carbon dioxide-hydrogen mixtures on wood charcoal (in German)  
Z. anorg. u. allgem. Chem. 150, 311-25 (1926)
249. Maidanovskaya, L. G. Adsorption of hydrogen on silica gel and glass (in Russian)  
Zhur. Fiz. Khim. 6, 1111-6 (1935)
250. Maidanovskaya, L. G., Panfilov, I. A. and Zakharova, R. O. Adsorption of hydrogen and some electrolytes on iron oxide (in Russian)  
Uchenye Zapiski Tomsk. Gosudarst. Univ. im V. V. Kuibysheva No. 26, 93-102 (1955)
251. Malanchuk, M. and Stuart, E. B. Effect of heat treatment on silica gel  
Ind. Eng. Chem. 50, 1207-10 (1958)
252. Margenau, H. The second virial coefficient for gases: a critical comparison between theoretical and experimental results  
Phys. Rev. 36, 1782-90 (1930)
253. Markiv, V. P. Compressibility of gaseous mixtures. II. Verification of the equation of state for gaseous mixtures (in Russian)  
Zhur. Fiz. Khim. 15, 410-5 (1941)
254. Maron, S. H. and Turnbull, D. Equation of state for gases at high pressures involving only critical constants  
J. Am. Chem. Soc. 64, 2195-8 (1942)

255. Marshak, R. E., Morse, P. M. and York, H. Equation of state of hydrogen, helium and Russell mixtures at high pressures and temperatures  
*Astrophys. J.* 111, 214-20 (1950)
256. Martin, J. J. and Hou, Y. C. Development of an equation of state for gases  
*A. I. Ch. E. Journal* 1, 142-51 (1955)
257. Martin, J. J., Kapoor, R. M. and DeNevers, N. An improved equation of state for gases  
*A. I. Ch. E. Journal* 5, 159-60 (1959)
258. Maslan, F. D. and Aberth, E. R. Equation of state for liquids  
*J. Chem. Phys.* 19, 658-9 (1951)
259. Maslan, F. D., Altman, M. and Aberth, E. R. Prediction of gas-adsorbent equilibria  
*J. Phys. Chem.* 57, 106-9 (1953)
260. Maslan, F. D. and Littman, T. M. Compressibility chart for hydrogen and inert gases  
*Ind. Eng. Chem.* 45, 1566-8 (1953)
261. Mathias, E. Study of density curves at low temperatures (in German)  
*Physik. Ber.* 4, 701-2 (1923)
262. Mathias, E. and Crommelin, C. A. Carbon monoxide and helium (in French)  
*Ann. phys.* 5, 137-66 (1936)
263. Mathias, E. and Crommelin, C. A. Work done in the Leiden cryogenic lab. concerning the equation of state of argon, neon and hydrogen between the 3rd and 4th intern. Congr. of refrig. Proc. Intern. Congr. Refrig. 4th Congr., London, 1, 89-106 (1924)
264. Mathot, V., Stavely, L. A. K., Young, J. A. and Parsonage, N. G. Thermodynamic properties of the system methane-carbon monoxide at 90.67°K  
*Trans. Faraday Soc.* 52, 1488-1500 (1956)

265. Maverick, S. and Schlatter, C. Compressibility at 0° and below 1 atmosphere and the deviation from the law of Avogadro of several gases (in French)  
J. chim. phys. 27, 36-43, 44-53 (1930)
266. McBain, J. W. The mechanism of the adsorption of hydrogen by carbon  
Phil. Mag. [ 6 ], 18, 916-35 (1909)
267. McBain, J. W. and Britton, G. T. The nature of the sorption by charcoal of gases and vapors under great pressure  
J. Am. Chem. Soc. 52, 2198-222 (1930)
268. McLellan, A. G. A new function in the theory of fluids and an equation of state for liquids and gases  
Phil. Mag. [ 8 ], 3, 707-14 (1958)
269. Megaw, H. D. The density and compressibility of solid hydrogen and deuterium at 4.2°K  
Phil. Mag. [ 7 ], 28, 129-47 (1939)
270. Medek, J. Gas adsorption on the surface of solids (in Czech.)  
Paliva 34, 292-8 (1954)
271. Melkonian, G. A. and Reys, B. Isotope displacement by adsorption and desorption on silica gels at low temperatures and pressures (in German)  
Z. Elektrochem. 58, 616-9 (1954)
272. Meyer, G. and Slooff, A. Determination of carbon monoxide in admixture with hydrogen and methane  
Rec. trav. chim. 54, 800-3 (1935)
273. Meyers, C. H. An equation for the isotherms of pure substances at their critical temperatures  
J. Research Natl. Bur. Standards 29, 157-76 (1942)
274. Michels, A. An experiment on the interaction of dissimilar molecules (in Italian)  
Nuovo cimento, Suppl. 4, 358-64 (1958)

275. Michels, A., de Graaff, W., Wassenaar, T., Levelt, J. M. H. and Louwse, P. Compressibility isotherms of hydrogen and deuterium between  $-175^{\circ}\text{C}$  and  $150^{\circ}\text{C}$   
*Physica* 25, 25-42 (1959)
276. Michels, A. and Gerver, A. J. J. A recalculation of the isothermal measurements of Kohnstamm and Walstra (in German)  
*Ann. Physik* [5], 16, 745-50 (1933)
277. Michels, A. and Goudekot, M. Compressibility of hydrogen between  $0^{\circ}$  and  $150^{\circ}$  up to 3000 atmospheres  
*Physica* 8, 353-9 (1941)
278. Michels, A. and Goudekot, M. Thermodynamic properties of hydrogen and deuterium up to 700 amagats between  $0^{\circ}$  and  $150^{\circ}$   
*Physica* 8, 387-97 (1941)
279. Michels, A., Lunbeck, R. J. and Wolkers, G. J. Thermodynamic properties of carbon monoxide at temperatures between  $0^{\circ}\text{C}$  and  $150^{\circ}\text{C}$  and at densities up to 600 amagat  
*Physica* 18, 128-34 (1952)
280. Michels, A., Nijhoff, G. P. and Gerver, A. J. J. Isothermal measurements on hydrogen between  $0^{\circ}$  and  $100^{\circ}$  and up to 1000 atmospheres (in German)  
*Ann. Physik* [5], 12, 562-8 (1932)
281. Michels, A., Wassenaar, T. and Swietering, T. N. The vapor pressure of carbon monoxide  
*Physica* 18, 160-2 (1952)
282. Millar, R. W. Specific heats of polyatomic gases at low temperatures  
*J. Am. Chem. Soc.* 45, 874-81 (1923)
283. Mills, R. L. and Grilly, E. R. Melting curves of helium 3, helium 4, hydrogen, deuterium, neon, nitrogen and oxygen up to 3500 kg/sq cm  
*Phys. Rev.* 99, 480-6 (1955)
284. Mills, R. L. and Grilly, E. R. Melting curves of hydrogen, deuterium and tritium up to 3500 kg/sq cm  
*Phys. Rev.* 101, 1246-7 (1956)



285. Miyako, R. Viscosity and second virial coefficients of gaseous hydrogen at low temperatures (in Japanese)  
Proc. Phys. Math. Soc. Japan [3], 24, 852-63 (1942)
286. Mizuike, A. Gas microanalysis. Absorption and explosion method (in Japanese)  
Japan Analyst 3, 17-21 (1954)
287. Mizushima, M. Theory of intermolecular potential and the second virial coefficient of hydrogen at low temperatures  
J. Chem. Phys. 21, 2107-14 (1953)
288. Moles, E. and Salazer, Y. M. T. A revision of the density of the normal liter of carbon monoxide. The atomic weight of carbon (in Spanish)  
Anales soc. espan. fis. y quim. 30, 182-99 (1932)
289. Mori, Y. The perfect gas and the equation of state of real gases  
J. Sic. Research Inst. (Tokyo) 48, 272-9 (1954)
290. Morrison, T. J. and Billett, F. Measurement of gas solubilities  
J. Chem. Soc. 1948, 2033-5 (1948)
291. Nelson, L. C. and Obert, E. F. Generalized p-v-t properties of gases  
Trans. Am. Soc. Mech. Engrs. 76, 1057-66 (1954)
292. Nelson, L. C. and Obert, E. F. Laws of corresponding states  
A. I. Ch. E. Journal 1, 74-7 (1955)
293. van Ness, H. C. Use of the Redlich and Kwong equation of state in calculating thermodynamic properties of gases from experimental compressibility data  
A. I. Ch. E. Journal 1, 100-4 (1955)
294. van Ness, H. C. and Mrazek, R. V. Treatment of thermodynamic data for homogeneous binary systems  
A. I. Ch. E. Journal 5, 209-12 (1959)

295. Neusser, E. The van der Waals' equation for rare gases (in German)  
Physik. Z. 33, 76-81 (1932)
296. Neven, P. and van Tiggelen, A. Quantitative adsorption of hydrogen  
Bull. soc. chim. Belges 61, 328-9 (1952)
297. Nijhoff, G. P. and Keesom, W. H. Isotherms of hydrogen at temperatures of 0° and 100°C  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 188d, 4 pp. (1927)
298. Nijhoff, G. P. and Keesom, W. H. Isotherms of hydrogen at temperatures from -225.5° to -248.3°C and pressures from 1.6 to 4.2 atmospheres  
Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 188e, 2 pp. (1928)
299. Nosanow, L. H. and Mayer, J. E. The virial coefficients for a Lennard-Jones gas  
J. Chem. Phys. 28, 874-7 (1958)
300. Oiski, J. 0° and 100° isotherms of helium, hydrogen, neon, argon, air and carbon dioxide at pressures below 2 atmospheres and absolute temperature of 0°C  
J. Sci. Research Inst. (Tokyo) 43,
301. Oliphant, M. L. E. Selective adsorption from gaseous mixtures by a mercury surface formed in the mixture  
Phil. Mag. [7], 6, 422-33 (1928)
302. Opfell, J. B., Sage, B. H. and Pitzer, K. S. Application of the Benedict equation to the theorem of corresponding states  
Ind. Eng. Chem. 48, 2069-76 (1956)
303. Organick, E. I. and Hollingsworth, B. J. Computing convergence pressure  
Petrol. Refiner 38, 172-3 (1959)

304. Othmer, D. F., Kowalski, R. C. and Naphtali, L. M. Correlating heats of solution and vapor-liquid equilibria. Construction of Ponchon diagrams  
Ind. Eng. Chem. 51, 89-92 (1959)
305. Paal, C. and Hartman, W. Gaseometric determination of hydrogen by catalytic absorption (in German)  
Ber. 43, 243-58 (1910)
306. Palazzo, D. F., Schreiner, W. C. and Skaperdas, G. T. Low temperature recovery of hydrogen from refinery gases  
Ind. Eng. Chem. 49, 685-8 (1957)
307. Pamfilov, A. V. and Kagan, S. L. Determination of small concentrations. VIII. Carbon monoxide (in Russian)  
Zhur. Obsheei Khim. 4, 1390-3 (1934)
308. Paoluzi, G. A new equation of state (in Italian)  
Ricerca sci. 25, 567-75 (1955)
309. Paoluzi, G. New isothermal constant for gases (in Italian)  
Ann. geofis. (Rome) 10, 241-5 (1957)
310. Paoluzi, G. The equation of state for gaseous mixtures (in Italian)  
Chim. e ind. (Milan) 39, 350-3 (1957)
311. Patrick, W. A., Frazer, J. C. W. and Rush, R. I. A study of the structural changes in amorphous materials. Silica gel  
J. Phys. Chem. 31, 1511-20 (1927)
312. Peter, S. and Weinert, M. Solubility of hydrogen, carbon monoxide, carbon dioxide and water vapor in liquid hydrocarbons (in German)  
Z. physik. Chem. (Frankfurt) 5, 114-21 (1955)
313. Peters, K. and Proksch, E. The kinetics of adsorption of gases near their critical temperature (in German)  
Z. Elektrochem. 61, 1241-6 (1957)
314. Petit, P. Solubility of nitrogen in hydrogen below the critical temperature of nitrogen (in French)  
Compt. rend. 246, 1171-2 (1957)

315. Petit, P. and Weil, L. Solubility of oxygen, nitrogen and argon in liquid hydrogen  
Bull. inst. intern. froid Annexe 1958-1, Suppl., 271-4, Delft (1958)
316. Pfefferle, W. C., Jr., Goff, J. A. and Miller, J. G. Compressibility of gases. I. The Burnett method. An improved method of treatment of data. Extension of the method to gas mixtures  
J. Chem. Phys. 23, 509-13 (1955)
317. Pfundt, O. Detection and recording of small amounts of carbon monoxide, particularly in purified contact hydrogen (in German)  
Chem. Fabrik 6, 69-71 (1933)
318. Phillips, T. D. Adsorption of hydrogen  
Phys. Rev. 45, 215 (1934)
319. Pickering, S. F. A review of the critical constants of various gases  
J. Phys. Chem. 28, 97-124 (1924)
320. Pickering, S. F. A review of the literature relating to the critical constants of various gases  
Natl. Bur. Standards (U. S.), Sci. Paper No. 541, 597-629 (1926)
321. Pickering, S. F. Compressibilities of gases  
Natl. Bur. Standards (U. S.), Misc. Publ. No. 71, 14 pp. (1925)
322. Picon, M. The extreme sensitivity of the determination of carbon monoxide, ethylene and acetylene by iodic anhydride (in French)  
Bull. soc. chim. France 1956, 370-1 (1956)
323. Pier, M. Specific heat and gaseous equilibria by explosion studies, carbon dioxide, sulfur dioxide and carbon monoxide (in German)  
Z. Elektrochem. 16, 897-903 (1910)

324. Pierotti, G. J., Deal, C. H. and Derr, E. L. Activity coefficients and molecular structure  
Ind. Eng. Chem. 51, 95-102 (1959)
325. Pietsch, H. Determination of very small amounts of oxygen, carbon monoxide, methane and nitrogen in purest ethylene by adsorption chromatography (in German)  
Erdol u. Kohle 11, 157-9 (1958)
326. Pings, C. J., Jr. and Sage, B. H. Equations of state  
Ind. Eng. Chem. 49, 1315-28 (1957)
327. Pitzer, K. S. Corresponding states for perfect liquids  
J. Chem. Phys. 7, 583-90 (1939)
328. Pitzer, K. S. Volumetric and thermodynamic properties of fluids. I. Theoretical basis and virial coefficients  
J. Am. Chem. Soc. 77, 3427-33 (1955)
329. Pitzer, K. S. and Curl, R. F., Jr. Volumetric and thermodynamic properties of fluids. III. Empirical equation for the second virial coefficient  
J. Am. Chem. Soc. 79, 2369-70 (1957)
330. Pitzer, K. S., Lipman, D. F., Curl, R. F., Jr., Huggens, C. M. and Petersen, D. E. Volumetric and thermodynamic properties of fluids. II. Compressibility factor, vapor pressure and entropy of vaporization  
J. Am. Chem. Soc. 77, 3433-40 (1955)
331. Piutti, A. Adsorption of carbon monoxide (in Italian)  
Ciorn. chim. ind. ed appl. 5, 70-3 (1923)
332. Podgurski, H. H. and Emmett, P. H. The adsorption of hydrogen and carbon monoxide on iron surfaces  
J. Phys. Chem. 57, 159-64 (1953)
333. Pollard, F. H. The adsorption of carbon monoxide and hydrogen by platinized asbestos  
J. Phys. Chem. 27, 356-75 (1923)

334. Powers, R. W., Mattox, R. W. and Johnston, H. L.  
Thermal conductivity of liquid normal and para-hydrogen from  
15° to 27°K  
J. Am. Chem. Soc. 76, 5792-3 (1954)
335. Prausnitz, J. M. Fugacities in high-pressure equilibria and  
in rate processes  
A. I. Ch. E. Journal 5, 3-9 (1959)
336. Prausnitz, J. M. Fugacities in simple gas mixtures  
Chem. Eng. Sic. 6, 112-5 (1957)
337. Prausnitz, J. M. Regular solution theory for gas-liquid  
solutions  
A. I. Ch. E. Journal 4, 269-72 (1958)
338. Prausnitz, J. M. and Benson, P. R. Effective collision  
diameters and correlation of some thermodynamic properties  
of solutions  
A. I. Ch. E. Journal 5, 301-3 (1959)
339. Prausnitz, J. M. and Benson, P. R. Solubility of liquids in  
compressed hydrogen, nitrogen and carbon dioxide  
A. I. Ch. E. Journal 5, 161-4 (1959)
340. Prausnitz, J. M. and Gunn, R. D. Pseudocritical constants  
from volumetric data for gas mixtures  
A. I. Ch. E. Journal 4, 494 (1958)
341. Prausnitz, J. M. and Gunn, R. D. Volumetric properties of  
non-polar gaseous mixtures  
A. I. Ch. E. Journal 4, 430-5 (1958)
342. Prausnitz, J. M. and Snider, G. D. Thermodynamic  
consistency test for multicomponent solutions  
A. I. Ch. E. Journal 5, 7 S - 8 S (1959)
343. Ray, G. C. and Box, E. O., Jr. Adsorption of gases on  
activated charcoal  
Ind. Eng. Chem. 42, 1315-8 (1950)

344. Redlich, O., Kister, A. T. and Turnquist, C. E. Thermodynamics of solutions-analysis of vapor-liquid equilibria  
Chem. Eng. Progr. Symposium Ser. 48, No. 2, 49-61 (1952)
345. Redlich, O. and Kwong, J. N. S. On the thermodynamics of solutions. V. An equation of state. Fugacities of gaseous solutions  
Chem. Revs. 44, 233-44 (1949)
346. Regak, N. Ya. and Smirnov, N. I. A study of adsorption processes. II. Adsorption of unsaturated gases by activated charcoal (in Russian)  
Zhur. Priklad. Khim. 28, 433-6 (1955)
347. Reid, R. C. and Sherwood, T. K. The properties of gases and liquids  
McGraw-Hill Book Co., New York, 386 pp. (1958)
348. Reimann, A. L. Clean-up of various gases by magnesium, calcium and barium  
Phil. Mag. [7], 18, 1117-32 (1934)
349. Remy, H. and Hene, W. The adsorption of gases by active charcoal (in German)  
Kolloid-Z. 61, 314-22 (1932)
350. Reuss, J. and Beenakker, J. J. M. Determination of the second virial coefficient  $B_{12}$  for mixtures of gases (in German)  
Physica 22, 869-79 (1956)
351. Reyerson, L. H. The adsorption of hydrogen by silica gel at elevated temperatures  
J. Am. Chem. Soc. 55, 3105-8 (1933)
352. Reyerson, L. H. and Swearingen, L. E. Adsorption of gases by metallized silica gels  
J. Phys. Chem. 31, 88-101 (1927)
353. Ribkin, L. L. Tables of the thermodynamic properties of gases (in Russian)  
Izvest. Vsesoyuz. Teplotekh. Inst. im. Feliksa Dzerzhinskogo 21, 81-111 (1952)

354. Risenfeld, W. B. and Watson, K. N. Equation of state of liquids and gases at low temperatures  
Phys. Rev. 108, 518-36 (1957)
355. Rische, E. A. Freezing-out vapors from gas-vapor mixtures by forced purging streams (in German)  
Chem. -Ing. -Tech. 29, 603-14 (1957)
356. Robin, S. Solution in compressed gases (in French)  
J. phys. radium 14, 330-44 (1953)
357. Robin, S. and Vodar, B. Interpretations of some measurements of solubility in compressed gases (in French)  
J. phys. radium 13, 264-70 (1952)
358. Robin, S. and Vodar, B. Solubility in compressed gases  
Discussions Faraday Soc. No. 13, 233-8 (1953)
359. Rowe, H. The adsorption of gases by activated charcoal at very low pressures. I. At air temperatures  
Phil. Mag. [7], 1, 109-31 (1926)
360. Rowe, H. The adsorption of gases by activated charcoal at very low pressures. II. At  $-183^{\circ}\text{C}$   
Phil. Mag. [7], 1, 1042-54 (1926)
361. Rowlinson, J. S. Reduced equation of state  
Trans. Faraday Soc. 51, 1317-26 (1955)
362. Rowlinson, J. S. and Richardson, M. J. The solubility of solids in compressed gases  
Advances in Chemical Physics, Interscience Publishers, Inc., New York, Vol. II, 85-118 (1959)
363. Rowlinson, J. S. and Sutton, J. R. The statistical thermodynamics of solutions of non-spherical molecules. II. Liquid-vapor equilibrium and the formation of azeotropes  
Proc. Roy. Soc. (London) A229, 396-404 (1955)
364. Rozen, A. M. The calculations of thermodynamic quantities from experimental p-v-t data (in Russian)  
Zhur. Fiz. Khim. 27, 178-93 (1953)



365. Rozen, A. M. Method of deviation coefficients in the technical thermodynamics of high pressure (in Russian)  
Zhur. Fiz. Khim. 19, 469-84 (1945)
366. Rudenko, N. S. Molecular weight, density and viscosity of liquefied gases (in Russian)  
Zhur. Tekh. Fiz. 18, 1123-6 (1948)
367. Ruhemann, M. and Fedoritenko, A. Physical bases for separation of helium and nitrogen (in Russian)  
Zhur. Tekh. Fiz. 7, 35-42 (1937)
368. Ruhemann, M. and Zinn, N. The system hydrogen-nitrogen-carbon monoxide and the scrubbing out of carbon monoxide (in German)  
Physik. Z. Sowjetunion 12, 389-403 (1937)
369. Sage, B. H. and Lacey, W. N. The partial volume and its significance  
Calif. Oil World 34, No. 22, 31-2, 34-5; No. 23, 16-7, 32 (1941)
370. Sage, B. H., Olds, R. H. and Lacey, W. N. Two gaseous mixtures containing hydrogen and nitrogen. Thermodynamic properties  
Ind. Eng. Chem. 40, 1453-9 (1948)
371. Sage, B. H. and Reamer, H. H. Some methods of experimental study of vapor-liquid equilibria  
Chem. Eng. Progr. Symposium Ser. 48, No. 2, 3-17 (1952)
372. Saurel, J. R. Equations of state and the thermodynamic properties of compressed gases (in French)  
Genie chim. 79, 12-22, 44-51 (1958)
373. Schaefer, C. A. and Thodos, G. Reduced density correlation for hydrogen: liquid and gaseous states  
A. I. Ch. E. Journal 5, 155-8 (1959)
374. Schaefer, C. A. and Thodos, G. Thermal conductivity of diatomic gases. Liquid and gaseous states  
A. I. Ch. E. Journal 5, 367-72 (1959)

375. Schafer, K. The second virial coefficient of the different modifications of light and heavy hydrogen. I. Experimental determination (in German)  
Z. physik. Chem. B36, 85-104 (1937)
376. Schafer, K. The second virial coefficient of the different modifications of light and heavy hydrogen. II. Theoretical calculations (in German)  
Z. physik. Chem. B38, 187-208 (1937)
377. Schames, L. Direct relationship of equation of state and internal friction of nitrogen, helium, neon, hydrogen, air, argon and oxygen (in German)  
Physik. Z. 32, 16-20 (1931)
378. Schiller, F. C. and Canjar, L. N. An equation of state for carbon monoxide vapor-liquid equilibria for the nitrogen-carbon monoxide system  
Chem. Eng. Progr. Symposium Ser. No. 7, 49, 67-72 (1953)
379. Schroder, W. Measuring vapor-liquid equilibria at elevated pressures (in German)  
Chem. -Ing. -Tech. 30, 523-5 (1958)
380. Schuftan, P. Determination of carbon monoxide in hydrogen (in German)  
Z. angew. Chem. 39, 276-8 (1926)
381. Scott, G. A. Isotherms of hydrogen, carbon monoxide and their mixtures  
Proc. Roy. Soc. (London) A125, 330-44 (1929)
382. Scott, R. B. and Brickwedde, F. G. Molecular volumes and expansivities of liquid normal hydrogen and parahydrogen  
J. Chem. Phys. 5, 736-44 (1937)
383. Scott, R. B., Brickwedde, F. G., Urey, H. C. and Wahl, M. H. The vapor pressures and derived thermal properties of hydrogen and deuterium  
J. Chem. Phys. 2, 454-64 (1934)

384. Sekera, A. and Stranik, J. Apparatus for the determination of the solubility of solids in liquids (in Czech.)  
Chem. listy 50, 1864-5 (1956)
385. Simon, F., Ruhemann, M. and Edwards, W. A. M. Melting point curves of hydrogen, neon, nitrogen and argon (in German)  
Z. physik. Chem. B6, 331-42 (1929)
386. Smith, A. L., Hallett, N. C. and Johnston, H. L. Condensed gas calorimetry. VI. The heat capacity of liquid para-hydrogen from the boiling point to the critical point  
J. Am. Chem. Soc. 76, 1486-8 (1954)
387. Smith, S. R. I. Gas-liquid phase equilibria in the system helium-hydrogen. II. Development of mass spectrometer techniques for analysis of helium-hydrogen and their isotopes  
Ph. D. Thesis, Ohio State Univ., Columbus (1952)
388. Stage, H. and Baumgarten, I. S. The determination of vapor-liquid equilibrium (in German)  
Oel u. Kohle 40, 126-31 (1944)
389. Steckel, F. Dew and boiling points for mixtures of nitrogen with carbon monoxide at pressures up to 17 atmospheres (in Russian)  
Zhur. Tekh. Fiz. 6, 137-40 (1936)
390. Steckel, F. Dew and boiling point curves of nitrogen-carbon monoxide mixtures up to 17 atmospheres (in German)  
Physik. Z. Sowjetunion 8, 337-41 (1935)
391. Steckel, F. and Zinn, N. Determination of diagram of state of the liquid-vapor system methane-nitrogen-hydrogen (in Russian)  
Zhur. Khim. Prom. 16, 24-8 (1939)
392. Stevenson, R. Compressions and solid phases of carbon dioxide, carbon disulfide, carbonyl sulfide, oxygen and carbon monoxide at low temperatures  
J. Chem. Phys. 27, 673-5 (1957)

393. Stewart, J. W. Compressibilities of some solidified gases at low temperatures  
Phys. Rev. 97, 578-82 (1955)
394. Stock, A., Henning, F. and Kuss, E. Vapor pressure tables for determinations between 25° and -185° (in German)  
Ber. 54B, 1119-29 (1921)
395. Storfer, E. Heterogeneous catalysis. I. Activated adsorption of hydrogen on charcoal (in German)  
Z. Elektrochem. 41, 198-204 (1935)
396. Strehlow, R. A. Method of extrapolating equation-of-state data to higher temperatures  
J. Chem. Phys. 23, 1562 (1955)
397. Su, G. J. and Chang, C. H. Generalized Beattie-Bridgeman equation of state for real gases  
J. Am. Chem. Soc. 68, 1080-3 (1946)
398. Su, G. J. and Chang, C. H. Generalized equation of state of real gases  
Ind. Eng. Chem. 38, 800-2 (1946)
399. Su, G. J., Huang, P. H. and Chang, Y. M. The compressibilities of gas mixtures  
J. Am. Chem. Soc. 68, 1403-4 (1946)
400. Swenson, C. A. The catalysis of the ortho-para conversion in liquid hydrogen  
J. Chem. Phys. 18, 520-2 (1950)
401. Szuba, J., Gajewski, Z. and Laskowska, H. An apparatus for the determination of the solubility of solids in liquids by the weighing method (in Polish)  
Koks, Smola, Gaz 2, 75-7 (1957)
402. Tanner, C. C. and Masson, I. The pressure of gaseous mixtures. III.  
Proc. Roy. Soc. (London) A126, 268-88 (1930)

403. Tickner, A. W. and Lossing, F. P. Mass spectrometer measurements of low vapor pressures  
J. Chem. Phys. 18, 148 (1950)
404. Tickner, A. W. and Lossing, F. P. Measurements of low vapor pressure by means of a mass spectrometer  
J. Phys. & Colloid Chem. 55, 733-40 (1951)
405. Tierney, J. W. Correlation of vapor-liquid equilibrium data  
Ind. Eng. Chem. 50, 707-10 (1958)
406. Titov, A. The adsorption of gases on charcoal (in German)  
Z. physik. Chem. 74, 641-78 (1910)
407. Torocheshnikov, N. S. Isotherms and isobars of the nitrogen-carbon monoxide system (in Russian)  
Tech. Phys. U. S. S. R. 4, 365-9 (1937)
408. Torocheshnikov, N. S. and Sernenova, V. A. Equilibrium liquid-vapor in the system hydrogen-methane-nitrogen-carbon monoxide (in Russian)  
Trudy Moskov, Khim. Tekhnol. Inst. im. D. I. Mendeleeva No. 18, 115-7 (1954)
409. Townend, D. T. A. and Bhatt, L. A. Isotherms of hydrogen, carbon monoxide and their mixture  
Proc. Roy. Soc. (London) A134, 502-12 (1931)
410. Trautz, M. and Badstubner, W. Calculation of the specific heats of gases from vapor-pressure curves (in German)  
Ann. Physik [5], 8, 185-202 (1931)
411. Trzeciak, M. P-V-T relationships of gaseous normal deuterium and three hydrogen-nitrogen mixtures  
Ph. D. Thesis, Ohio State Univ., Columbus (1954)
412. Tsiklis, D. S. Heterogeneous equilibria in binary systems (in Russian)  
Zhur. Fiz. Khim. 20, 181-8 (1946)

413. Turvizumi, A. Porous structure of active carbons. IV. Adsorption of nitrogen, methane, carbon dioxide and ethylene (in Japanese)  
Nippon Kagaku Zasshi 80, 221-4 (1959)
414. Ubbelohde, A. R. Kinetics of adsorption processes. III. Influence of nuclear spin on sorption of hydrogen on charcoal  
Trans. Faraday Soc. 28, 291-9 (1932)
415. Ubbelohde, A. R. and Egerton, A. The kinetics of adsorption processes  
Proc. Roy. Soc. (London) A134, 512-23 (1931)
416. Updegraff, N. C. Gas prepurification for low-temperature processing  
Chem. Eng. Progr. 53, 268-71 (1957)
417. Urry, W. D. Adsorption with silica gel at low temperatures  
J. Phys. Chem. 36, 1831-45 (1932)
418. Vagin, E. Y. and Zhukhovitskii, A. A. Theory of thermal separation of gas mixtures by the adsorption method (in Russian)  
Doklady Akad. Nauk S. S. S. R. 94, 273-6 (1954)
419. Van Der Waarden, M. and Scheffer, F. E. C. Adsorption of nitrogen, hydrogen and their mixtures on silica gel  
Rec. trav. chim. 71, 689-98 (1952)
420. Vasil'ev, B. N., Bering, B. P., Dubinin, M. M. and Serpinskii, V. V. Adsorption at high pressures (in Russian)  
Doklady Akad. Nauk S. S. S. R. 114, 131-4 (1957)
421. Verschaffelt, J. E. Contributions to the knowledge of the surface  $\psi$  of Van der Waals (in Dutch)  
Arch. neerl. sci. 11, 358-444 (1906)
422. Verschoyle, T. T. H. Isotherms of hydrogen, nitrogen and hydrogen-nitrogen mixtures at 0° and 20° up to a pressure of 200 atmospheres  
Proc. Roy. Soc. (London) A111, 552-76 (1926)

423. Verschoyle, T. T. H. The ternary system: carbon monoxide-nitrogen-hydrogen and the component binary systems between temperatures of  $-185^{\circ}$  and  $-215^{\circ}$  and between pressures of 0 and 225 atmospheres  
Trans. Roy. Soc. (London) A230, 189-220 (1931)
424. Verth, H. and Schroder, E. Melting diagrams of several binary systems of condensed gases (in German)  
Z. physik. Chem. A179, 16-22 (1937)
425. Vyakhirev, D. A., Bruk, A. I. and Guglina, S. A. Volumetric-chromatographic method of gas analysis (in Russian)  
Doklady Akad. Nauk S. S. S. R. 90, 577-9 (1953)
426. Vykoukal, J. and Linhart, K. Polarographic determination of carbon monoxide traces (in Czech.)  
Paliva 33, 236-41 (1953)
427. Waclawik, J. Apparatus for the continuous determination of traces of carbon monoxide in gases by conductimetry (in French)  
Chim. anal. 40, 247-9 (1958)
428. Wagener, S. Adsorption measurements at very low pressures. II.  
J. Phys. Chem. 61, 267-71 (1957)
429. Wagner, G. The various methods of gas purification in industry (in Austrian)  
Osterr. Chemiker-Zt. 42, 313-5 (1939)
430. Waitman, A. and Macoveanu, L. Conductometric determination of carbon monoxide (in Rumanian)  
Rev. chim. (Bucharest) 7, 468-72 (1956)
431. Weiss, P. Equation of state of fluids. Negative internal pressures at high temperature (in French)  
Compt. rend. 200, 1700-2 (1935)
432. Weizel, W. Apparatus for purification of inert gases and hydrogen (in German)  
Z. tech. Physik 19, 146-8 (1938)

433. Wenzel, L. A. Low-temperature distillation  
Chem. Eng. Progr. 53, 272-7 (1957)
434. White, D., Friedman, A. S. and Johnston, H. L. Direct  
determination of the critical temperature and critical  
pressure of normal hydrogen  
J. Am. Chem. Soc. 72, 3565-70 (1950)
435. White, D., Friedman, A. S. and Johnston, H. L. Low  
pressure p-v-t data of gaseous hydrogen from the boiling point  
to room temperature  
Ohio State Univ. Cryogenic Lab., Columbus, T. R. 264-12  
(1951)
436. White, D., Friedman, A. S. and Johnston, H. L. The vapor  
pressure of normal hydrogen from the boiling point to the  
critical point  
J. Am. Chem. Soc. 72, 3927-30 (1950)
437. Widdoes, L. C. and Katz, D. L. Vapor-liquid equilibrium  
constants for carbon monoxide  
Ind. Eng. Chem. 40, 1742-6 (1948)
438. Wiebe, R. and Gaddy, V. L. Compressibilities of hydrogen  
and of four mixtures of hydrogen and nitrogen at 0°, 25°, 50°,  
100°, 200°, and 300° and to 1000 atmospheres  
J. Am. Chem. Soc. 60, 2300-3 (1938)
439. Wilkins, F. J. Adsorption of gaseous mixtures at solid  
surfaces  
Nature 141, 1054-5 (1938)
440. Winkler, O. Adsorption of gases at low pressures by active  
carbon and silica gel (in German)  
Z. tech. Physik 14, 319-32 (1933)
441. Wirth, H. Separation of gases by sorption processes. II.  
(in Austrian)  
Monatsh. Chem. 84, 741-50 (1953)
442. Wohl, K. Thermodynamic evaluations of binary and ternary  
liquid systems  
Trans. Am. Inst. Chem. Engrs. 42, 215-49 (1946)



443. Woodhead, M. and Whytlaw-Gray, R. A comparison of the densities of carbon monoxide and oxygen and the atomic weight of carbon  
J. Chem. Soc. 1933, 846-54 (1933)
444. Woolley, H. W. Effect of dissociation on the thermodynamic properties of pure diatomic gases  
Nat. Advisory Comm. Aeronaut. Tech. Note No. 3270, 19 pp. (1955)
445. Woolley, H. W. High rotational levels and the partition function for hydrogen  
J. Chem. Phys. 9, 470-2 (1941)
446. Woolley, H. W., Scott, R. B. and Brickwedde, F. G. Compilation of thermal properties of hydrogen in its various isotopic and ortho-para modifications  
J. Research Natl. Bur. Standards 41, 379-475 (1948)
447. Wylie, L. M. The vapor pressure of solid argon, carbon monoxide, methane, nitrogen and oxygen from their triple points to the boiling point of hydrogen  
M. S. Thesis, Georgia Inst. of Tech., Atlanta (1958)
448. Young, J. A. Some thermodynamic studies of binary liquid mixtures of carbon monoxide and methane  
B. Sc. Thesis, New College, Oxford (1954)
449. Yu, K. T. and Coull, J. Development of isothermal and isobaric equations-vapor-liquid equilibrium in non-ideal systems  
Chem. Eng. Progr. Symposium Ser. No. 2, 48, 38-45 (1952)
450. Yushkevich, N. F. and Zhavoronkov, N. M. The purification of hydrogen and hydrogen-nitrogen mixtures from carbon monoxide in the synthetic ammonia industry (in Russian)  
Zhur. Khim. Prom. 11, 18-24 (1934)
451. Zickermann, C. Adsorption of gases on solid surfaces at low temperatures (in German)  
Z. Physik 88, 43-54 (1934)

452. Zlunitsyn, S. A. and Rudenko, N. S. Compressibility of hydrogen at low temperatures (in Russian)  
Zhur. Eksptl. i Teoret. Fiz. 16, 776-9 (1946)
453. Zwanzig, R. W., Kirkwood, J. G., Stripp, K. F. and Oppenheim, I. Errata: radial distribution functions and the equation of state of monatomic fluids  
J. Chem. Phys. 22, 1625 (1954)

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Appendix



TABLE I

CO-H<sub>2</sub> PRESSURE-CONCENTRATION DATA

Reference: Verschoyle (423)

| Temperature |      | Pressure<br>Atm | Liquid                |           | Vapor                 |           | K              |                |
|-------------|------|-----------------|-----------------------|-----------|-----------------------|-----------|----------------|----------------|
| °C          | °K   |                 | Mole % H <sub>2</sub> | Mole % CO | Mole % H <sub>2</sub> | Mole % CO | H <sub>2</sub> | N <sub>2</sub> |
| -183        | 88.2 | 181.3           | 45.4                  | 54.6      | 70.4                  | 29.6      | 1.55           | 0.542          |
| "           | "    | 166.7           | 41.0                  | 59.0      | 77.1                  | 22.9      | 1.88           | 0.388          |
| "           | "    | 128.2           | 30.3                  | 69.7      | 84.8                  | 15.2      | 2.80           | 0.218          |
| "           | "    | 89.6            | 21.7                  | 78.3      | 88.7                  | 11.3      | 4.09           | 0.144          |
| "           | "    | 89.3            | 20.3                  | 79.7      | 88.8                  | 11.2      | 4.37           | 0.141          |
| "           | "    | 55.9            | 13.4                  | 86.6      | 90.2                  | 9.8       | 6.73           | 0.113          |
| "           | "    | 55.8            | 12.9                  | 87.1      | 89.3                  | 10.7      | 6.92           | 0.123          |
| "           | "    | 31.4            | 7.1                   | 92.9      | 88.8                  | 11.2      | 12.5           | 0.121          |
| "           | "    | 22.1            | 5.2                   | 94.8      | 86.6                  | 13.4      | 16.6           | 0.141          |
| "           | "    | 17.2            | 3.6                   | 96.4      | 84.0                  | 16.0      | 23.3           | 0.166          |
| -190        | 83.2 | 224.8           | 54.1                  | 45.9      | 66.3                  | 33.7      | 1.23           | 0.734          |
| "           | "    | 220.9           | 48.6                  | 51.4      | 69.4                  | 30.6      | 1.43           | 0.595          |
| "           | "    | 215.1           | 47.0                  | 53.0      | 73.7                  | 26.3      | 1.57           | 0.496          |
| "           | "    | 210.4           | 44.8                  | 55.2      | 75.9                  | 24.1      | 1.69           | 0.437          |
| "           | "    | 205.4           | 43.5                  | 56.5      | 76.6                  | 23.4      | 1.76           | 0.414          |
| "           | "    | 200.6           | 41.1                  | 58.9      | 76.7                  | 23.3      | 1.87           | 0.396          |
| "           | "    | 200.6           | 41.5                  | 58.5      | 77.7                  | 22.3      | 1.87           | 0.381          |
| "           | "    | 195.8           | 40.1                  | 59.9      | 79.5                  | 20.5      | 1.98           | 0.342          |
| "           | "    | 190.9           | 38.1                  | 61.9      | 80.5                  | 19.5      | 2.11           | 0.315          |
| "           | "    | 186.1           | 36.8                  | 63.2      | 80.8                  | 19.2      | 2.20           | 0.304          |
| "           | "    | 176.4           | 31.4                  | 65.6      | 83.1                  | 16.9      | 2.42           | 0.258          |
| "           | "    | 166.8           | 32.9                  | 67.1      | 84.3                  | 15.7      | 2.56           | 0.234          |
| "           | "    | 128.1           | 24.9                  | 75.1      | 88.9                  | 11.1      | 3.57           | 0.148          |
| "           | "    | 128.1           | 25.4                  | 74.6      | 88.8                  | 11.2      | 3.50           | 0.150          |
| "           | "    | 109.8           | 22.8                  | 77.2      | 90.4                  | 9.6       | 3.96           | 0.124          |
| "           | "    | 109.8           | 21.0                  | 79.0      | 90.7                  | 9.3       | 4.32           | 0.118          |
| "           | "    | 109.6           | 20.6                  | 79.4      | 90.6                  | 9.4       | 4.40           | 0.118          |
| "           | "    | 89.5            | 19.5                  | 80.5      | 91.8                  | 8.2       | 4.71           | 0.102          |
| "           | "    | 89.3            | 17.0                  | 83.0      | 92.0                  | 8.0       | 5.41           | 0.0964         |
| "           | "    | 51.2            | 12.5                  | 87.5      | 93.2                  | 6.8       | 7.46           | 0.0777         |
| "           | "    | 51.2            | 10.2                  | 89.8      | 93.1                  | 6.9       | 9.13           | 0.0768         |
| "           | "    | 17.2            | 2.7                   | 97.3      | 89.9                  | 10.1      | 33.3           | 0.104          |
| -200        | 73.2 | 224.9           | 27.5                  | 72.5      | 89.0                  | 11.0      | 3.24           | 0.152          |
| "           | "    | 224.8           | 26.5                  | 73.5      | 89.3                  | 10.7      | 3.37           | 0.146          |
| "           | "    | 205.6           | 25.0                  | 75.0      | 91.2                  | 8.8       | 3.65           | 0.117          |
| "           | "    | 205.4           | 25.7                  | 74.3      | 90.2                  | 9.8       | 3.51           | 0.132          |
| "           | "    | 186.2           | 22.9                  | 77.1      | 91.6                  | 8.4       | 4.00           | 0.109          |
| "           | "    | 186.2           | 23.6                  | 76.4      | 91.4                  | 8.6       | 3.87           | 0.113          |
| "           | "    | 176.4           | 23.0                  | 77.0      | 92.0                  | 8.0       | 4.00           | 0.104          |
| "           | "    | 176.4           | 21.8                  | 78.2      | 91.7                  | 8.3       | 4.21           | 0.106          |
| "           | "    | 152.4           | 20.6                  | 79.4      | 93.0                  | 7.0       | 4.51           | 0.0882         |
| "           | "    | 113.9           | 16.6                  | 83.4      | 95.1                  | 4.9       | 5.73           | 0.0588         |
| "           | "    | 113.8           | 15.4                  | 84.6      | 95.5                  | 4.5       | 6.20           | 0.0532         |
| "           | "    | 113.7           | 16.5                  | 83.5      | 94.8                  | 5.2       | 5.75           | 0.0623         |
| "           | "    | 80.2            | 12.7                  | 87.3      | 95.9                  | 4.1       | 7.55           | 0.0470         |
| "           | "    | 80.1            | 12.0                  | 88.0      | 96.4                  | 3.6       | 8.03           | 0.0409         |
| "           | "    | 51.0            | 8.4                   | 91.6      | 96.7                  | 3.3       | 11.5           | 0.0360         |
| "           | "    | 31.8            | 5.6                   | 94.4      | 97.5                  | 2.5       | 17.4           | 0.0265         |
| "           | "    | 17.3            | 3.3                   | 96.7      | 96.7                  | 3.3       | 29.3           | 0.0341         |
| -205        | 68.2 | 215.2           | 20.2                  | 79.8      | 93.4                  | 6.6       | 4.62           | 0.0827         |
| "           | "    | 200.0           | 18.8                  | 81.2      | 93.9                  | 6.1       | 4.99           | 0.0751         |
| "           | "    | 152.3           | 16.3                  | 83.7      | 94.6                  | 5.4       | 5.80           | 0.0645         |
| "           | "    | 118.4           | 13.8                  | 86.2      | 96.5                  | 3.5       | 6.99           | 0.0406         |
| "           | "    | 79.9            | 10.2                  | 89.8      | 97.7                  | 2.3       | 9.58           | 0.0256         |
| "           | "    | 41.4            | 6.3                   | 93.7      | 97.5                  | 2.5       | 15.5           | 0.0267         |
| "           | "    | 41.4            | 6.2                   | 93.8      | 98.5                  | 1.5       | 15.9           | 0.0160         |
| "           | "    | 31.7            | 4.9                   | 95.1      | 98.6                  | 1.4       | 20.1           | 0.0147         |
| "           | "    | 26.6            | 4.2                   | 95.8      | 97.6                  | 2.4       | 23.2           | 0.0251         |
| "           | "    | 21.7            | 3.3                   | 96.7      | 98.2                  | 1.8       | 29.8           | 0.0156         |
| "           | "    | 17.0            | 3.0                   | 97.0      | 97.9                  | 2.1       | 32.6           | 0.0216         |

TABLE II

CO-H<sub>2</sub> CRITICAL CONSTANTS

Reference: Verschoyle (423)

|             |      | Plait-Point     |                       | Critical Point of Contact |                       |
|-------------|------|-----------------|-----------------------|---------------------------|-----------------------|
| Temperature |      | Pressure<br>Atm | Mole % H <sub>2</sub> | Pressure<br>Atm           | Mole % H <sub>2</sub> |
| °C          | °K   |                 |                       |                           |                       |
| -185        | 88.2 | 187             | 58                    | 54                        | 90                    |
| -190        | 83.2 | 228             | 60                    | 48                        | 93                    |
| -200        | 73.2 | (325)           | (64)                  | 34                        | 97.5                  |
| -205        | 68.2 | (380)           | (66)                  | 30                        | 99.5                  |

TABLE III

CO-H<sub>2</sub> PRESSURE-CONCENTRATION DATA

Reference: Ruhemann and Zinn (368)

| Temperature<br>°K | Pressure<br>Atm | Liquid                |           | Vapor                 |           | K              |                |
|-------------------|-----------------|-----------------------|-----------|-----------------------|-----------|----------------|----------------|
|                   |                 | Mole % H <sub>2</sub> | Mole % CO | Mole % H <sub>2</sub> | Mole % CO | H <sub>2</sub> | N <sub>2</sub> |
| 90                | 50              | 11.2                  | 88.8      | 87.2                  | 12.8      | 7.79           | 0.144          |
| "                 | 35              | 9.5                   | 90.5      | 85.9                  | 14.1      | 9.04           | 0.156          |
| "                 | 25.8            | 6.5                   | 93.5      | 84.5                  | 15.5      | 13.0           | 0.166          |
| "                 | 20              | 4.6                   | 95.4      | 81.9                  | 18.1      | 17.8           | 0.190          |
| "                 | 11.7            | 2.9                   | 97.1      | 74.5                  | 25.5      | 25.7           | 0.263          |
| "                 | 6.9             | 1.2                   | 98.8      | 61.6                  | 38.4      | 51.3           | 0.389          |
| 83                | 49.7            | 10.3                  | 89.7      | 92.1                  | 7.9       | 8.94           | 0.0881         |
| "                 | 34.5            | 8.1                   | 91.9      | 91.5                  | 8.5       | 11.3           | 0.0925         |
| "                 | 19.5            | 3.1                   | 96.9      | 89.5                  | 10.5      | 28.9           | 0.108          |
| "                 | 12.0            | 1.6                   | 98.4      | 85.4                  | 14.6      | 53.4           | 0.148          |
| 78                | 50              | 9.3                   | 90.7      | 94.1                  | 5.9       | 10.1           | 0.0650         |
| "                 | 35              | 6.9                   | 93.1      | 93.8                  | 6.2       | 13.6           | 0.0666         |
| "                 | 25.8            | 5.0                   | 95.0      | 92.1                  | 7.9       | 18.4           | 0.0832         |
| "                 | 20              | 3.8                   | 96.2      | 91.5                  | 8.5       | 24.1           | 0.0884         |
| "                 | 11.7            | 1.9                   | 98.1      | 88.1                  | 11.9      | 46.4           | 0.121          |

TABLE IV

CO-H<sub>2</sub> PRESSURE-CONCENTRATION DATA

Reference: Akers and Eubanks (4)

| Temperature |       | Pressure<br>Atm | Liquid                |           | Vapor                 |           | K              |        |
|-------------|-------|-----------------|-----------------------|-----------|-----------------------|-----------|----------------|--------|
| °F          | °K    |                 | Mole % H <sub>2</sub> | Mole % CO | Mole % H <sub>2</sub> | Mole % CO | H <sub>2</sub> | CO     |
| -240        | 122.2 | 64.1            | 30.0                  | 70.0      | 30.0                  | 70.0      | 1.0            | 1.0    |
| "           | "     | 54.1            | 13.4                  | 86.6      | 33.4                  | 66.6      | 2.49           | 0.769  |
| "           | "     | 34.0            | 4.1                   | 95.9      | 22.1                  | 77.9      | 5.36           | 0.812  |
| -280        | 100   | 136.1           | 41.2                  | 58.8      | 61.1                  | 38.9      | 1.48           | 0.662  |
| "           | "     | 115.5           | 32.2                  | 67.8      | 73.5                  | 26.5      | 2.28           | 0.391  |
| "           | "     | 95.7            | 24.1                  | 75.9      | 77.5                  | 22.5      | 3.22           | 0.296  |
| "           | "     | 75.0            | 16.5                  | 83.5      | 78.2                  | 21.8      | 4.74           | 0.261  |
| "           | "     | 53.8            | 11.4                  | 88.6      | 77.8                  | 22.2      | 6.82           | 0.251  |
| "           | "     | 34.0            | 6.5                   | 93.5      | 76.5                  | 23.5      | 11.8           | 0.251  |
| "           | "     | 21.4            | 3.5                   | 96.5      | 67.4                  | 32.6      | 19.3           | 0.338  |
| -310        | 83.3  | 238.1           | 66.3                  | 33.7      | 74.7                  | 25.3      | 1.13           | 0.751  |
| "           | "     | 217.1           | 45.4                  | 54.6      | 80.3                  | 19.7      | 1.77           | 0.361  |
| "           | "     | 175.9           | 31.3                  | 68.7      | 83.1                  | 16.9      | 2.65           | 0.246  |
| "           | "     | 154.3           | 27.3                  | 72.7      | 85.5                  | 14.5      | 3.13           | 0.199  |
| "           | "     | 136.1           | 24.2                  | 75.8      | 88.4                  | 11.6      | 3.65           | 0.153  |
| "           | "     | 115.5           | 21.0                  | 79.0      | 89.5                  | 10.5      | 4.26           | 0.133  |
| "           | "     | 95.7            | 15.6                  | 84.4      | 91.0                  | 9.0       | 5.83           | 0.107  |
| "           | "     | 75.0            | 13.3                  | 86.7      | 93.4                  | 6.6       | 7.02           | 0.0761 |
| "           | "     | 53.7            | 9.4                   | 90.6      | 93.0                  | 7.0       | 9.91           | 0.0772 |
| "           | "     | 34.0            | 6.2                   | 93.8      | 92.4                  | 7.6       | 14.9           | 0.0810 |
| "           | "     | 21.4            | 4.1                   | 95.9      | 90.3                  | 9.7       | 21.9           | 0.101  |



TABLE V

## SOLID-VAPOR EQUILIBRIA

Reference: Verschoyle (423)

| Temperature |      | Pressure<br>Atm | Vapor Phase           |           |
|-------------|------|-----------------|-----------------------|-----------|
| °C          | °K   |                 | Mole % H <sub>2</sub> | Mole % CO |
| -210        | 63.2 | 195.75          | 96.31                 | 3.69      |
| "           | "    | 176.41          | 96.53                 | 3.47      |
| "           | "    | 147.39          | 96.88                 | 3.12      |
| "           | "    | 137.76          | 97.03                 | 2.97      |
| "           | "    | 104.01          | 97.80                 | 2.20      |
| "           | "    | 79.80           | 97.42                 | 2.58      |
| "           | "    | 65.74           | 98.76                 | 1.24      |
| "           | "    | 32.03           | 99.18                 | 0.82      |
| "           | "    | 21.85           | 99.12                 | 0.88      |
| "           | "    | 16.81           | 99.22                 | 0.78      |
| -215        | 58.2 | 176.37          | 98.18                 | 1.82      |
| "           | "    | 157.03          | 98.08                 | 1.92      |
| "           | "    | 128.05          | 98.50                 | 1.50      |
| "           | "    | 89.52           | 98.90                 | 1.10      |
| "           | "    | 51.37           | 99.47                 | 0.53      |

TABLE VI

## SOLID-VAPOR EQUILIBRIA

Reference: Dokoupil, Van Soest and Swenker (88)

| Pressure<br>Atm | Temperature<br>°K | Vapor Phase<br>Mole % CO | Pressure<br>Atm | Temperature<br>°K | Vapor Phase<br>Mole % CO |
|-----------------|-------------------|--------------------------|-----------------|-------------------|--------------------------|
| 50              | 69.9              | 1.86                     | 10              | 63.0              | 0.763                    |
| "               | 65.7              | 1.03                     | "               | 56.2              | 0.152                    |
| "               | 60.8              | 0.569                    | "               | 54.2              | 0.0784                   |
| "               | 57.9              | 0.330                    | "               | 51.4              | 0.0427                   |
| "               | 55.4              | 0.171                    | "               | 51.4              | 0.0430                   |
| "               | 49.7              | 0.0623                   | "               | 45.8              | 0.00605                  |
| "               | 45.6              | 0.0329                   | "               | 42.1              | 0.00314                  |
| "               | 35.6              | 0.0124                   | "               | 37.0              | 0.000522                 |
| 25              | 67.7              | 1.36                     | "               | 36.0              | 0.000356                 |
| "               | 66.5              | 1.038                    | "               | 33.9              | 0.000172                 |
| "               | 62.8              | 0.515                    | "               | 31.9              | 0.0000873                |
| "               | 60.0              | 0.284                    |                 |                   |                          |
| "               | 56.0              | 0.0983                   | 5               | 62.6              | 1.22                     |
| "               | 50.4              | 0.0234                   | "               | 56.4              | 0.234                    |
| "               | 41.7              | 0.0126                   | "               | 54.7              | 0.120                    |
| "               | 35.5              | 0.00850                  | "               | 51.4              | 0.0549                   |
| 15              | 60.7              | 0.400                    | "               | 46.2              | 0.00765                  |
| "               | 59.4              | 0.266                    | "               | 42.2              | 0.00320                  |
| "               | 55.6              | 0.104                    | "               | 37.6              | 0.000552                 |
| "               | 54.6              | 0.0834                   | "               | 35.8              | 0.000362                 |
| "               | 51.4              | 0.0328                   | "               | 33.4              | 0.0000925                |
| "               | 46.1              | 0.00624                  | 1.3             | 58.8              | 1.25                     |
| "               | 44.9              | 0.00480                  | "               | 55.3              | 0.527                    |
| "               | 42.5              | 0.00374                  | "               | 50.5              | 0.103                    |
| "               | 42.5              | 0.00358                  | "               | 47.2              | 0.0445                   |
| "               | 42.1              | 0.00320                  | "               | 44.2              | 0.0167                   |
| "               | 38.1              | 0.00139                  | "               | 39.8              | 0.00361                  |
| "               | 35.0              | 0.00112                  | "               | 38.2              | 0.00145                  |
| "               | 34.1              | 0.00102                  | "               | 36.4              | 0.000620                 |
| "               | 34.1              | 0.00103                  | "               | 34.4              | 0.000288                 |
|                 |                   |                          | "               | 32.3              | 0.000158                 |

TABLE VII  
SOLID-VAPOR EQUILIBRIA

Reference: Dokoupil, Van Soest and Swenker (88)

Table VI, This Report

| Temperature,<br>°K | Pressure,<br>Atm. | $y$ ,<br>Mole Fraction CO<br>in Vapor Phase |
|--------------------|-------------------|---|
| 35                 | 1.3               | 0.0000355                                   |
| "                  | 5                 | 0.0000205                                   |
| "                  | 10                | 0.0000240                                   |
| "                  | 15                | 0.0000110                                   |
| "                  | 25                | 0.000083                                    |
| "                  | 50                | 0.000119                                    |
| 40                 | 1.3               | 0.000044                                    |
| "                  | 5                 | 0.0000145                                   |
| "                  | 10                | 0.0000125                                   |
| "                  | 15                | 0.0000175                                   |
| "                  | 25                | 0.000112                                    |
| "                  | 50                | 0.000180                                    |
| 45                 | 1.3               | 0.000223                                    |
| "                  | 5                 | 0.0000780                                   |
| "                  | 10                | 0.0000620                                   |
| "                  | 15                | 0.0000510                                   |
| "                  | 25                | 0.000153                                    |
| "                  | 50                | 0.000310                                    |
| 50                 | 1.3               | 0.00110                                     |
| "                  | 5                 | 0.000361                                    |
| "                  | 10                | 0.000253                                    |
| "                  | 15                | 0.000212                                    |
| "                  | 25                | 0.000241                                    |
| "                  | 50                | 0.000630                                    |
| 55                 | 1.3               | 0.00470                                     |
| "                  | 5                 | 0.00148                                     |
| "                  | 10                | 0.00103                                     |
| "                  | 15                | 0.000910                                    |
| "                  | 25                | 0.000750                                    |
| "                  | 50                | 0.00160                                     |
| 60                 | 1.3               | 0.0160                                      |
| "                  | 5                 | 0.0059                                      |
| "                  | 10                | 0.00420                                     |
| "                  | 15                | 0.00325                                     |
| "                  | 25                | 0.00280                                     |
| "                  | 50                | 0.00480                                     |
| 65                 | 25                | 0.0081                                      |
| "                  | 50                | 0.0100                                      |

TABLE VIII

## THREE-PHASE DATA

Reference: Verschoyle (423)

| Pressure<br>Atm | Temperature |       |
|-----------------|-------------|-------|
|                 | °C          | °K    |
| 55.2            | -206.12     | 67.04 |
| 55.2            | -206.15     | 67.01 |
| 104.1           | -206.54     | 66.62 |
| 104.1           | -206.59     | 66.57 |
| 104.1           | -206.73     | 66.43 |
| 147.4           | -206.48     | 66.68 |
| 147.4           | -206.67     | 66.49 |
| 147.4           | -206.72     | 66.44 |
| 147.4           | -206.87     | 66.29 |
| 205.5           | -206.34     | 66.82 |
| 205.5           | -206.38     | 66.78 |
| 205.5           | -206.39     | 66.77 |







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