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PHYSICAL PROPERTIES AND THERMODYNAMIC FUNCTIONS OF FUELS, OXIDIZERS, AND PRODUCTS OF COMBUSTION

II OXIDIZERS

CHEMICAL RESEARCH DIVISION STAFF
BATTELLE MEMORIAL INSTITUTE • COLUMBUS, OHIO

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PHYSICAL PROPERTIES AND THERMODYNAMIC FUNCTIONS OF FUELS, OXIDIZERS, AND PRODUCTS OF COMBUSTION

II OXIDIZERS

INTRODUCTION

This report is one of a series of technical survey reports which have been prepared by Battelle Memorial Institute on a subcontract under Prime Contract No.W33-038 ac-14105, Project RAND, between The RAND Corporation and the United States Air Force.

This collection of the physical and thermodynamic properties of a diverse variety of elements and compounds which may be of interest as the oxidizers in rocket propellant mixtures was compiled in the course of Battelle's exploratory work for Project RAND. In many instances, the data were not readily obtainable but were scattered throughout the physical and chemical literature. To make these data available to others working in the rocket propulsion field, they are being published as RAND reports.

This is the second volume of three related compendia of physical properties and thermodynamic functions of rocket and ramjet propellant substances. The three volumes are entitled: I, Fuels; II, Oxidizers; and III, Products of Combustion.

The information contained in this report was compiled during the period October 1, 1947 to November 15, 1948.

REG. NO.
LOG NO.
WDSOT 274159

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PROJECT RAND

PHYSICAL PROPERTIES AND THERMODYNAMIC FUNCTIONS OF FUELS, OXIDIZERS, AND PRODUCTS OF COMBUSTION

II OXIDIZERS

CHEMICAL RESEARCH DIVISION STAFF

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ELEMENTS AND COMPOUNDS ARE TABULATED

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SUMMARY

A compilation of the physical properties and thermodynamic functions of thirteen chemical elements and compounds which may be of interest as oxidizer components for rocket propellant mixtures has been prepared. All available sources of information were consulted, and this report presents what are believed to be the most reliable values.

All the data pertaining to each oxidizer have been grouped together and are arranged in the following order:

1. Molecular formula.
2. Molecular weight.
3. Melting or freezing point.
4. Boiling point and/or sublimation temperature.
5. Density (vapor; liquid; solid).
6. Vapor pressure.
7. Triple point.
8. Viscosity (vapor; liquid).
9. Surface tension.
10. Coefficient of thermal expansion.
11. Coefficient of thermal conductivity.
12. Dipole moment.
13. Heat of fusion.
14. Heat of vaporization and/or sublimation.
15. Heat of formation.
16. Heat of combustion.
17. Critical data.
18. Equation of state.
19. Compressibility.
20. Heat capacity of vapor, C_p and C_v.
21. Ratio of specific heats.
22. Heat capacity of liquid and solid.
23. Free energy of formation.
24. Free-energy function.
25. Heat-content function.
26. Entropy.

In some cases there are gaps in the available data. Where this is true, the entry "no information" has been made under the appropriate heading in the data sheets.

For convenience of reference, the sources of the data cited have been included as a part of each data sheet. In addition, a detailed bibliography of all sources consulted, whether the reported results were used or not, is appended to the report. These bibliographies will serve as guides for further research on specific compounds and will also indicate the degree of exhaustiveness of search for data made in any given case.

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PHYSICAL PROPERTIES AND THERMODYNAMIC FUNCTIONS OF FUELS, OXIDIZERS, AND PRODUCTS OF COMBUSTION

II OXIDIZERS

INTRODUCTION

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BORON TRIFLUORIDE

MOLECULAR FORMULA

BF_3

MOLECULAR WEIGHT

67.82

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = 144.46°K

Ref. Eucken, A., and Schröder, E., *Z. physik. Chem.*, B, Vol.41 (1938), pp.307-19.

BOILING POINT

Boiling point = 172.2°K

This value critically selected from the literature.

Ref. K.K. Kelley, *U.S. Bur. Mines Bull.383* (1935).

DENSITY

Gas

Temperature (°C)	Density (gm/cc)
-183	0.7365
-95.0	0.6495
-91.8	0.6452
-87.6	0.6379
-83.4	0.6314
-80.5	0.6276
-78.3	0.6255
-77.7	0.6235

Ref. Biltz, Le Boucher, and Fischer, *Z. anorg. Chem.*, Vol.207 (1932), p.67.

Liquid

d = 1.58 gm/ml at −101°C

d = 1.68 gm/ml at −128°C

Ref. Biltz, Le Boucher, and Fischer, *Z. anorg. Chem.*, Vol.207 (1932), p.67.

Solid

d = 1.98 gm/cc at −188°C

Ref. Biltz, Le Boucher, and Fischer, *Z. anorg. Chem.*, Vol.207 (1932), p.67.

VAPOR PRESSURE

Temperature (°C)	Pressure (atm)
−12.25	49.0
−14.60	45.5
−20.12	38.5
−29.96	27.9
−35.00	23.8
−39.20	20.5
−49.25	13.8

Ref. Booth and Carter, *J. Phys. Chem.*, Vol.36 (1932), pp.1359-63.

Temperature (°K)	Pressure (mm Hg)	State
127.8	5.0	Solid
131.4	9.5	"
138.9	29.0	"
143.4	54.7	"
145.9	70.1	Liquid
155.4	177.9	"
163.2	355.1	"
170.3	615.1	"
173.1	760 (Extrapolated)	

Ref. Pohland and Harlos, *Z. anorg. Chem.*, Vol.207 (1932), pp. 242-45.

TRIPLE POINT VISCOSITY SURFACE TENSION COEFFICIENT OF THERMAL EXPANSION COEFFICIENT OF THERMAL CONDUCTIVITY	No information

DIPOLE MOMENT

$\mu = 0$ debye

Ref. Linke and Rohrmann, *Z. physik. Chem.*, B, Vol.35 (1937), pp. 256-60.

HEAT OF FUSION

$\Delta H_f = 480$ cal/mole

This value selected from the literature by Kelley. Calculated from vapor-pressure data.

Ref. Kelley, *U.S. Bur. Mines Bull.393* (1936).

HEAT OF VAPORIZATION

$\Delta H_v = 4.62$ kcal/mole at 172.2°K

Ref. Kelley, *U.S. Bur. Mines Bull.383* (1935).

HEAT OF FORMATION

$$[B]_{amorph} + \frac{3}{2}F_2 = BF_3$$

$\Delta H° = 258.1$ kcal/mole

Ref. von Wartenberg, *Z. anorg. Chem.*, Vol.151 (1926), p.327.

HEAT OF COMBUSTION — No information

CRITICAL DATA

$t_c = -12.25 \pm 0.03°C$

$p_c = 49.2 \pm 0.1$ atm

Ref. Booth and Carter, *J. Phys. Chem.*, Vol.36 (1932), pp.1359-63.

EQUATION OF STATE
COMPRESSIBILITY } No information

HEAT CAPACITY OF GAS, C_p AND C_v

Temperature (°K)	C_p (cal/mole deg)
298.16	12.063
300	12.094
350	12.981
400	13.764
450	14.454
500	15.059
600	16.046
700	16.792
800	17.358
900	17.792
1000	18.128

Above data calculated on Basis of Raman and infrared spectra.

Ref. Spencer, *J. Chem. Phys.*, Vol. 14 (1946), pp.729-32.

RATIO OF SPECIFIC HEATS No information

HEAT CAPACITY OF LIQUID AND SOLID

Liquid

Temperature (°K)	C_p (cal/mole deg)
144.46	Melting point
145	24.53
150	24.64
160	24.84
170	25.05
173	25.10

Ref. Eucken and Schröder, *Z. physik. Chem.*, B, Vol.41 (1938), pp.307-19.

Solid

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
12	1.28	60	9.67
15	1.87	70	10.53
20	2.90	80	11.28
25	3.95	90	12.03
30	5.04	100	12.76
35	6.07	110	13.53
40	7.00	120	14.44
45	7.83	130	15.58
50	8.52	140	16.76
55	9.13		

Ref. Eucken and Schröder, *Z. physik. Chem.*, B, Vol.41 (1938), pp.307-19.

FREE ENERGY OF FORMATION

No information

FREE-ENERGY FUNCTION

Temperature (°K)	$-(F^\circ - H_0^\circ)/T$ (cal/mole deg)
298.16	51.357
300	51.414
350	52.892
400	54.230
450	55.464
500	56.611
600	58.70
700	60.58
800	62.29
900	63.85
1000	65.31

Ref. Spencer, *J. Chem. Phys.*, Vol. 14 (1946), pp.729-32.

HEAT-CONTENT FUNCTION

Temperature (°K)	$(H^\circ - H_0^\circ)/T$ (cal/mole deg)
298.16	9.338
300	9.355
350	9.811
400	10.257
450	10.686
500	11.094
600	11.841
700	12.497
800	13.071
900	13.572
1000	14.012

Ref. Spencer, *J. Chem. Phys.*, Vol.14 (1946), pp.729-32.

ENTROPY

Temperature (°K)	S_t° (cal/mole deg)
298.16	60.695
300	60.770
350	62.702
400	64.488
450	66.150
500	67.704
600	70.54
700	73.07
800	75.36
900	77.42
1000	79.32

Ref. Spencer, *J. Chem. Phys.*, Vol.14 (1946), pp.729-32.

BROMINE

MOLECULAR FORMULA

Br_2

MOLECULAR WEIGHT

159.83

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −7.2°C

Ref. Weber, *Bull. Bur. Standards*, Vol.9 (1913), p.131.

BOILING POINT

Boiling point = 58.80°C at 760 mm Hg

Ref. Bouzat and Liluan, *Compt. rend.*, Vol.178 (1924), p.635.

DENSITY

Vapor No information

Liquid

Temperature (°C)	Density (gm/cc)
0	3.1875
20	3.1193
25	3.1023
30	3.0848

Ref. *International Critical Tables*, Vol.3 (1928), p.20.

Solid

$d = 4.107$ gm/cc at −194°C

Ref. Landolt-Börnstein *Physicalisch-Chemische Tabellen*, 3d Suppl. (1935), p.282.

VAPOR PRESSURE

Liquid

Temperature (°C)	Pressure (mm Hg)
−5.05	50
+8.20	100
16.95	150
23.45	200
33.05	300
40.45	400
46.8	500
51.95	600
56.3	700
58.75	760

Ref. Ramsey and Young, *J. Chem. Soc.*, Vol.49 (1886), p.453.

VAPOR PRESSURE (*Cont'd*)

Solid

Temp (°C)	Press. (mm Hg)	Temp (°C)	Press. (mm Hg)
−95	0.0022	−50	1.09
−90	0.0052	−45	1.83
−85	0.0117	−40	2.98
−80	0.0251	−35	4.77
−75	0.0513	−30	7.45
−70	0.102	−25	11.4
−65	0.192	−20	17.1
−60	0.357	−15	25.2
−55	0.628	−10	36.6

Ref. *International Critical Tables*, Vol.3 (1928), p.201.

TRIPLE POINT

Temperature = 266°K

Ref. Furth, *Cambridge Phil. Soc. Proc.*, Vol.37 (1941), p.252.

VISCOSITY

Vapor

Temperature (°C)	$\eta \times 10^7$ (poises)
19	1526
20	1542
21	1535
24	1524
25	1528
138	2097
190	2369
211	2500
242	2626
316	2999
349	3163
410	3476
535	4106
588	4300

Ref. Braune, Basch, and Wentzel, *Z. physik. Chem.*, A, Vol.137 (1928), pp.176, 447.

Liquid

Temperature (°C)	$\eta \times 10^5$ (poises)
−2.6	1287
+7.0	1136
13.6	1056
19.5	995
27.0	925
31.4	901

Ref. *International Critical Tables*, Vol.7 (1930), p.212.

SURFACE TENSION

(Against air)

Temperature (°C)	γ (dynes/cm)
0	45.0
20	41.5
50	36.2

Ref. *International Critical Tables*, Vol.4 (1928), p.447.

COEFFICIENT OF THERMAL EXPANSION (LIQUID)

Temperature (°C)	Volume Relationship
0	100,000
5	100,536
10	101,081
15	101,635
20	102,197
25	102,768
30	103,347
35	103,934
40	104,529
45	105,132
50	105,742
55	106,359
60	106,983

Ref. Thorpe, *J. Chem. Soc.*, Vol.37 (1880), p.141.

COEFFICIENT OF THERMAL CONDUCTIVITY

No information

DIPOLE MOMENT

State	Temperature (°C)	Debye	Reference
Liquid	1-18	0.40	(1)
Gas	19.7-138.8	0.00	(2)

Refs. (1) Anderson, *Proc. Phys. Soc.*, Vol.40 (1928), p.62.

(2) Luft, *Z. Physik*, Vol.84 (1933), p.767.

HEAT OF FUSION

ΔH_f = 2,585 cal/mole

Ref. Regnault, *Ann. chim. et phys.* (3), Vol.26 (1849), p.278.

HEAT OF VAPORIZATION

Temperature (°C)	ΔH_v (kcal/mole)	Reference
10.0	7.47	(1)
25.0	7.685	(2)
56	7.28	(3)
61.6	6.96	(4)

Refs. (1) Smits and Cannegieter, *Z. physik. Chem.*, A, Vol.168 (1934), p.391.

(2) Kelley, *U.S. Bur. Mines Bull.383* (1935).

(3) Andrews, *Quart. J. Chem. Soc. London*, Vol.1 (1849), p.27; *Pogg. Ann.*, Vol.75 (1848), p.501.

(4) Berthelot and Ogier, *Ann. chim. et phys.*, 5, Vol.30 (1883), p.400; 5, Vol.30 (1883), p.411.

HEAT OF FORMATION

Liquid

$$\Delta H^{\circ}_{298.1} = 0, \text{ by definition}$$

HEAT OF COMBUSTION

No information

CRITICAL DATA

$$t_c = 302.2\,^{\circ}C$$
$$d_c = 1.18 \text{ gm/ml}$$

Ref. Nadejdine, *Kiewer Univ. Unters.*, Vol.6 (1885), p.32; Vol.9 (1885), p.721.

EQUATION OF STATE

No information

COMPRESSIBILITY

$$\beta_t = \frac{1}{V_1} \cdot \frac{V_1 - V_2}{P_2 - P_1}$$

Temperature (°C)	Pressure Range (atm)	$\beta \times 10^6$
20	0-100	63.5
20	100-200	58.4
20	200-300	54.6
20	300-400	52.1
20	400-500	49.9

Ref. Landolt-Börnstein *Physicalisch-Chemische Tabellen*, Vol.1 (1923), p.95.

HEAT CAPACITY OF VAPOR, C_p AND C_v

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
200	8.272	850	8.989
250	8.486	900	9.001
298.1	8.618	950	9.011
300	8.622	1000	9.022
350	8.713	1050	9.031
400	8.777	1100	9.041
450	8.824	1150	9.050
500	8.859	1200	9.059
550	8.888	1250	9.068
600	8.911	1300	9.077
650	8.931	1400	9.094
700	8.948	1500	9.113
750	8.963	1600	9.132
800	8.977		

Ref. Gordon and Barnes, *J. Chem. Phys.*, Vol.1 (1933), p.692.

RATIO OF SPECIFIC HEATS

$$\frac{C_p}{C_v} = 1.32 \text{ at } 0.3 \text{ to } 1.5 \text{ atm and } 20 \text{ to } 350°C$$

Ref. *International Critical Tables*, Vol.5 (1929), p.80.

HEAT CAPACITY OF LIQUID AND SOLID No information

FREE ENERGY OF FORMATION

Gas

$$\Delta F^\circ_{298.1} = -754 \text{ cal/mole}$$

Liquid

$$\Delta F^\circ_{298.1} = 0, \text{ by definition}$$

Ref. Kelley, *U.S. Bur. Mines Bull. 383* (1935).

FREE-ENERGY FUNCTION

Temperature (°K)	$-(F^\circ - E_0^\circ)/T$ (cal/mole deg)
200	47.822
250	47.509
298.1	50.868
300	50.918
350	52.130
400	53.196
450	54.146
500	55.006
550	55.789
600	56.509
650	57.176
700	57.797
750	58.377
800	58.922
850	59.437
900	59.923
950	60.384
1000	60.823
1050	61.242
1100	61.643
1150	62.026
1200	62.394
1250	62.747
1300	63.087
1400	63.732
1500	64.334
1600	64.898

Ref. Gordon and Barnes, *J. Chem. Phys.*, Vol. 1 (1933), pp. 692-95.

HEAT-CONTENT FUNCTION

Temperature (°K)	$(H^\circ - H_0^\circ)/T$ (cal/mole deg)
298.16	7.796
300	7.801
400	8.028
500	8.186
600	8.303
700	8.392
800	8.462
900	8.520

HEAT-CONTENT FUNCTION (*Cont'd*)

Temperature (°K)	$(H^\circ - H_0^\circ)/T$ (cal/mole deg)
1000	8.568
1100	8.609
1200	8.644
1300	8.675
1400	8.703
1500	8.728

Ref. *Selected Values of Chemical Thermodynamic Properties*, Nat. Bur. Standards, June 30, 1948.

ENTROPY

Temperature (°K)	S_t° (cal/mole deg)
200	55.291
250	57.162
298.1	58.667
300	58.722
350	60.058
400	61.226
450	62.263
500	63.194
550	64.040
600	64.814
650	65.528
700	66.191
750	66.809
800	67.388
850	67.932
900	68.446
950	68.933
1000	69.396
1050	69.836
1100	70.257
1150	70.659
1200	71.044
1250	71.414
1300	71.770
1400	72.443
1500	73.071
1600	73.660

Ref. Gordon and Barnes, *J. Chem. Phys.*, Vol.1 (1933), pp.692-95.

BROMINE TRIFLUORIDE

MOLECULAR FORMULA BrF_3
MOLECULAR WEIGHT 136.92 Ref. *International Atomic Weights*, 1947.
MELTING POINT Melting point = 8.8°C Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.
BOILING POINT Boiling point = 127.0°C Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.
DENSITY Vapor: No information Liquid: d = 2.843 gm/cc at 8.8°C = 2.51 gm/cc at 127.0°C Solid: d = 3.23 gm/cc at 8.8°C Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)	State
−5	1.2	Solid
0	1.8	"
5	2.6	"
10	3.8	Liquid
20	7.4	"
30	13.7	"
40	23.8	"
60	63.0	"
80	736.0	"
127	760(Extrapolated)	Boiling point

Ref. Ruff and Braida, *Anorg. Chem.*, Vol.214 (1933), p.91.

TRIPLE POINT
VISCOSITY
SURFACE TENSION
COEFFICIENT OF THERMAL EXPANSION
COEFFICIENT OF THERMAL CONDUCTIVITY
DIPOLE MOMENT
HEAT OF FUSION

No information

HEAT OF VAPORIZATION

ΔH_v = approx 10.0 kcal/mole

Ref. Ruff and Braida, *Z. Anorg. Chem.*, Vol.206 (1932), p.63.

HEAT OF FORMATION
HEAT OF COMBUSTION

No information

CRITICAL DATA

t_c = approx 327°C

Ref. Ruff and Braida, *Z. Anorg. Chem.*, Vol.206 (1932), p.63.

EQUATION OF STATE COMPRESSIBILITY HEAT CAPACITY OF GAS, C_p AND C_v RATIO OF SPECIFIC HEATS HEAT CAPACITY OF LIQUID AND SOLID FREE ENERGY OF FORMATION FREE-ENERGY FUNCTION HEAT-CONTENT FUNCTION ENTROPY	No information

CHLORINE

MOLECULAR FORMULA Cl_2
MOLECULAR WEIGHT 70.914 Ref. *International Atomic Weights*, 1947.
MELTING POINT Melting point = −100.98°C Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.
BOILING POINT Boiling point = −34.05°C Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

DENSITY

Liquid and Gas (Saturated)

Temperature (°C)	Density (gm/ml) Liquid	Density (gm/ml) Gas
−100	1.717	–
−90	1.694	–
−80	1.673	–
−70	1.646	–
−60	1.622	–
−50	1.598	–
−40	1.574	–
−30	1.550	–
−20	1.524	–
−10	1.496	–
0	1.4678	0.0128
+10	1.438	0.0175
20	1.408	0.0226
30	1.377	0.0300
40	1.344	0.0384
50	1.310	0.0486
60	1.275	0.0600
70	1.240	0.0740
80	1.199	0.0910
90	1.156	0.1125
100	1.109	0.1360
110	1.059	0.1640
120	0.998	0.206
130	0.920	0.258
140	0.750	0.405
144.0	0.573	0.573 (Critical Point)

Ref. Pellaton, *J. chim. et phys.*, Vol.13 (1915), p.426.

Solid — No information

VAPOR PRESSURE

Liquid

Temperature (°C)	Pressure (mm Hg)
−100.98	10.44
−97.66	14.07
−92.72	21.58
−87.64	32.50

Liquid (*Cont'd*)

Temperature (°C)	Pressure (mm Hg)
−82.59	47.74
−77.59	68.31
−72.67	95.07
−67.86	129.49
−63.10	172.74
−57.92	232.51
−53.19	301.24
−48.00	393.96
−43.14	500.42
−38.12	632.73
−33.05	793.85

Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

Solid No information

TRIPLE POINT

Temperature = −100.98°C
Pressure = 10.44 mm Hg

Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

VISCOSITY

Gas

Temperature (°C)	$\eta \times 10^7$ (poises)
20	1327
50	1469
100	1679
150	1875
200	2085
250	2276

Ref. Trautz and Ruf, *Ann. Physik.* (5), Vol.20 (1934), p.127.

VISCOSITY (*Cont'd*)

Gas (*Cont'd*)

Temperature (°C)	$\eta \times 10^7$ (poises)
15.6	1294
225.5	2191
297.0	2480
307.3	2539
333.4	2626
402.7	2870
419.5	2948
474.3	3143
498.8	3209

Ref. Braune and Linke, *Z. physik. Chem.*, A, Vol.148 (1930), p.195.

Liquid

Temperature (°C)	η (poises)
−76.5	0.00729
−74.0	0.00710
−70.5	0.00680
−65.4	0.00646
−60.0	0.00610
−53.0	0.00569
−45.1	0.00530
−33.8	0.00489

Ref. Steacie and Johnson, *J. Am. Chem. Soc.*, Vol.47 (1925), p.754.

SURFACE TENSION

Temperature (°C)	γ (dynes/cm)	Reference
−72	33.65	(1)
−34.5	27	(2)

Refs. (1) Grunmach, *Drud. Ann.*, Vol.4 (1901), p.374.

(2) *International Critical Tables*, Vol.1, p.103.

(In equilibrium with saturated vapor)

Temperature (°C)	γ (dynes/cm)
0.0	21.90
0.7	21.60
11.0	19.85
12.0	19.69
12.7	19.47
17.3	18.56
19.1	18.40
19.4	18.27
28.0	16.99
50.0	13.39

Ref. Marchand, *J. chim. phys.*, Vol.11 (1913), pp.573-76.

COEFFICIENT OF THERMAL EXPANSION

Gas

Change in volume per unit volume per °C = 0.003830 between 0°-100°C at 760 mm Hg

Ref. Hodgman, *Handbook of Chemistry and Physics*, 1947, p.1754.

Liquid

Temperature (°C)	α
−50	0.00151
−25	0.00162
− 0	0.00187
+25	0.00219
50	0.00259
75	0.00314
100	0.00430

Ref. Lange, *Z. angew. Chem.*, Vol.13 (1900), p.683.

COEFFICIENT OF THERMAL CONDUCTIVITY No information

DIPOLE MOMENT

$\mu = 0.23$ debye, for the gas

Ref. Zakrzewski and Doborzynski, *Bull. intern. acad. polon. sci.*, A, 1930, p.300.

HEAT OF FUSION

$\Delta H_f = 1531 \pm 1$ cal/mole at $-100.98°C$

Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

HEAT OF VAPORIZATION

$\Delta H_v = 4878 \pm 4$ cal/mole at 34.05°C and 760 mm Hg

Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

HEAT OF FORMATION

$\Delta H^\circ_{298.1} = 0$, by definition

HEAT OF COMBUSTION No information

CRITICAL DATA

$t_c = 143.9°C$

$p_c = 76$ atm

$d_c = 0.573$ gm/cc

Ref. Pickering, *J. Phys. Chem.*, Vol.28 (1924), p.97.

EQUATION OF STATE

$$\left(P + \frac{n^2 a}{V^2}\right)(1 - nb) = nRT$$

where

P = pressure, atm

V = volume, liters/mole

R = 0.08207 liter atm/mole deg

T = temp, °K

n = number of moles

a = 6.493 liter^2 atm/mole^2

b = 0.05622 liter/mole

Ref. Lange, *Handbook of Chemistry*, 1946, p.1473.

COMPRESSIBILITY

Temperature (°C)	Pressure Range (atm)	$\beta \times 10^6$
20	10-100	118
20	100-200	110
20	200-300	102
20	300-400	90.7
20	400-500	84.5

Ref. Landolt-Börnstein, *Physikalisch-Chemische Tabellen*, Vol.1 (1923), p.95.

HEAT CAPACITY OF GAS, C_p AND C_v

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
100	6.998	800	8.847
150	7.232	873	8.879
200	7.575	973	8.915
243	7.827	1073	8.941
270	7.978	1173	8.964
273.1	7.987	1200	8.969
318	8.176	1273	8.984
373	8.352	1373	9.004
391	8.400	1473	9.019
452	8.526	1600	9.040
473	8.564	1673	9.051
573	8.685	1765	9.060
673	8.770	1892	9.068
773	8.823	2000	9.071

Ref. Trautz and Ader, *Z. Physik*, Vol.89 (1934), p.15.

HEAT CAPACITY OF GAS, C_p AND C_v (*Cont'd*)

Temperature (°K)	C_v (cal/mole deg)
273	5.97
373	6.32
473	6.53
573	6.65
800	6.79
1200	6.9
1600	6.9
2000	7.0
2400	7.0
2800	7.0

Ref. Nernst and Wohl, *Z. tech. Physik.*, Vol.10 (1929), p.608.

RATIO OF SPECIFIC HEATS

Can be calculated from data above

HEAT CAPACITY OF LIQUID AND SOLID

Temp (°K)*	C_p (cal/mole deg)	Temp (°K)*	C_p (cal/mole deg)
14.05	0.810	102.92	10.22
15.21	0.916	108.06	10.38
17.40	1.331	112.99	10.57
19.81	1.842	118.15	10.81
22.93	2.467	123.53	11.00
26.37	3.192	128.67	11.24
29.88	3.946	134.06	11.47
33.94	4.804	139.67	11.72
37.68	5.421	145.19	11.92
42.37	6.018	150.39	12.24
47.14	6.675	155.45	12.41
58.59	7.879	160.31	12.69
65.42	8.382	164.99	12.93
70.50	8.720	172.12	Melting Point
75.25	8.973	178.98	16.01
79.71	9.201	183.75	16.02
84.06	9.427	188.40	15.99
88.66	9.626	193.21	15.99
93.47	9.827	194.08	15.95
98.06	10.03	201.50	15.94

Temp (°K)*	C_p (cal/mole deg)	Temp (°K)*	C_p (cal/mole deg)
208.63	15.92	229.73	15.79
215.90	15.85	236.77	15.73
222.82	15.81	239.05	Boiling Point

*0°C = 273.10°K

Ref. Giauque and Powell, *J. Am. Chem. Soc.*, Vol.61 (1939), p.1970.

FREE ENERGY OF FORMATION

Gas

$\Delta F^{\circ}_{298.1} = 0$, by definition

FREE-ENERGY FUNCTION

(Cl_2 equilibrium mixture)

Temp (°K)	$-(F^{\circ} - E^{\circ}_{0})/T$ (cal/mole deg)	Temp (°K)	$-(F^{\circ} - E^{\circ}_{0})/T$ (cal/mole deg)
250	44.666	1200	56.979
298.1	45.951	1250	57.324
300	45.997	1300	57.656
350	47.141	1400	58.286
400	48.148	1500	58.876
450	49.049	1600	59.430
500	49.865	1700	59.952
550	50.611	1800	60.446
600	51.298	1900	60.916
650	51.936	2000	61.363
700	52.531	2100	61.789
750	53.089	2200	62.196
800	53.614	2300	62.587
850	54.110	2400	62.962
900	54.580	2500	63.324
950	55.027	2600	63.672
1000	55.453	2700	64.009
1050	55.859	2800	64.334
1100	56.248	2900	64.649
1150	56.621	3000	64.956

Ref. Giauque and Overstreet, *J. Am. Soc.*, Vol.54 (1932), p.1731.

HEAT-CONTENT FUNCTION

Temperature (°K)	$(H^\circ - H_0^\circ)/T$ (cal/mole deg)
298.16	7.358
300	7.363
400	7.596
500	7.784
600	7.935
700	8.057
800	8.156
900	8.238
1000	8.309
1100	8.370
1200	8.423
1300	8.469
1400	8.510
1500	8.548

Ref. *Selected Values of Chemical Thermodynamic Properties*, Nat. Bur. Standards, June 30, 1948.

ENTROPY

Temperature (°K)	S° (cal/mole deg)
298.16	53.286
300	53.336
400	55.720
500	57.625
600	59.207
700	60.562
800	61.744
900	62.792
1000	63.735
1100	64.590
1200	65.375
1300	66.096
1400	66.767
1500	67.393

Ref. *Selected Values of Chemical Thermodynamic Properties*, Nat. Bur. Standards, June 30, 1948.

CHLORINE TRIFLUORIDE

MOLECULAR FORMULA

ClF_3

MOLECULAR WEIGHT

92.46

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = -82.6°C

Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.

BOILING POINT

Boiling point = 12.1°C

Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.

DENSITY

Vapor

Temperature (°K)	Pressure (mm Hg)	Density (gm/ml)
294.1	758.1	0.003585
286.0	494.2	0.002437

Ref. Ruff and Krug, *Z. anorg. Chem.*, Vol.190 (1930), p.270.

Liquid

d = 1.77 gm/ml at 12.1°C

Ref. Ruff, *Angew. Chem.*, Vol.46 (1933), p.739.

Solid No information

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)
−71.9	10
0	495
11.3*	760

*This value later determined by Ruff, *Angew. Chem.*, Vol.46 (1933), p.739, to be 12.1°C.

Ref. Ruff and Krug, *Z. anorg. Chem.*, Vol.190 (1930), p.270.

TRIPLE POINT
VISCOSITY
SURFACE TENSION
COEFFICIENT OF THERMAL EXPANSION
COEFFICIENT OF THERMAL CONDUCTIVITY
DIPOLE MOMENT
HEAT OF FUSION

No information

HEAT OF VAPORIZATION

ΔH_v = 5900 cal/mole at 760 mm Hg

Ref. Ruff and Braida, *Z. anorg. Chem.*, Vol.214 (1933), p.91.

HEAT OF FORMATION
HEAT OF COMBUSTION

No information

CRITICAL DATA

t_c = 153.5°C (calculated)

Ref. Ruff and Krug, *Z. anorg. Chem.*, Vol.190 (1930), p.270.

EQUATION OF STATE COMPRESSIBILITY HEAT CAPACITY OF GAS, C_p AND C_v RATIO OF SPECIFIC HEATS HEAT CAPACITY OF LIQUID AND SOLID FREE ENERGY OF FORMATION FREE-ENERGY FUNCTION HEAT-CONTENT FUNCTION ENTROPY	No information

FLUORINE

MOLECULAR FORMULA F_2
MOLECULAR WEIGHT 38.00 Ref. *International Atomic Weights*, 1947.
MELTING POINT Melting point = 217.9°C Ref. Kanda, *Bull. Chem. Soc. Japan*, Vol.12 (1937), p.511.
BOILING POINT Boiling point = −187.95 ± 0.1°C at 760 mm Hg Ref. Claussen, *J. Am. Chem. Soc.*, Vol.56 (1934), p.614.

DENSITY

Gas

d = 1.695 gm/liters at 0°C and 760 mm Hg

Ref. *International Critical Tables*, Vol.1 (1927), p.102.

Liquid

Temperature (°C)	Density (gm/cc)
−200	1.14
−187	1.108

Ref. Moissan and Dewar, *Bull. soc. chim.* (3), Vol.17 (1897), p.931.

Solid

d = 1.3 at −204.1°C

Ref. *International Critical Tables*, Vol.1 (1926), p.104.

VAPOR PRESSURE

Temperature (°K)	Pressure (mm Hg)
59.60	10.1
63.61	26.3
65.00	35.5
68.70	65.2
69.99	92.05
72.85	143.35
75.01	209.1
77.51	289.5
79.35	381.5
79.98	402.35
83.43	608.1
84.52	712.75
85.00	740.1
86.21	845.2

Ref. Kanda, *Bull. Chem. Soc. Japan*, Vol.12 (1937), p.416.

TRIPLE POINT No information

VISCOSITY

Gas

Temperature (°K)	Pressure (mm Hg)	$\eta \times 10^5$ (poises)
273.2	763	2093
248.9	763	1727
229.6	763	1611
213.1	765	1492
192.3	765	1379
167.9	765	1201
148.8	758	1080
118.9	758	875
86.8	758	555

Ref. Kanda, *Bull. Chem. Soc. Japan*, Vol.12 (1937), p.463.

Liquid No information

SURFACE TENSION

Temperature (°K)	γ (dynes/cm)
61.41	13.85
65.30	13.17
71.00	12.20
81.50	10.41

Ref. Kanda, *J. Chem. Soc. Japan*, Vol.58 (1937), p.706.

COEFFICIENT OF THERMAL EXPANSION
COEFFICIENT OF THERMAL CONDUCTIVITY
DIPOLE MOMENT
} No information

HEAT OF FUSION

ΔH_f = 372 cal/mole at 55.2°K

Ref. Kanda, *Bull. Chem. Soc. Japan*, Vol.12 (1937), p.463.

HEAT OF VAPORIZATION

ΔH_v = 1560 cal/mole at −187.95°C

Ref. Claussen, *J. Am. Chem. Soc.*, Vol.56 (1934), p.614.

HEAT OF FORMATION

$\Delta H^\circ_{298.1} = 0$ for the gas

HEAT OF COMBUSTION No information

CRITICAL DATA

t_c = 144°K

p_c = 55 atm

Ref. Cady and Hildebrand, *J. Am. Chem. Soc.*, Vol.52 (1930), p.3842.

EQUATION OF STATE

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

where

P = pressure, atm

V = volume, liters/mole

R = 0.08207 liter atm/mole deg

T = temp., °K

n = number of moles

a = 1.1793 liter^2 atm/mole^2

b = 0.02608 liter/mole

Ref. Dodge, *Chemical Engineering Thermodynamics* (1944), p.662.

COMPRESSIBILITY No information

HEAT CAPACITY OF GAS, C_p AND C_v

Temperature (°K)	C_p (cal/mole deg)
298.1	7.522
300	7.530
400	7.912
500	8.186
600	8.373
800	8.594
1000	8.710
1200	8.777
1400	8.819
1600	8.847
1800	8.866
2000	8.880

Ref. Murphy and Vance, *J. Chem. Physics*, Vol.7 (1939), p.806.

C_v = 5.535 cal/mole at 298.1°K

Ref. Landau and Rosen, Manhattan District Declassified Report No.154, 1-b, U.S. Atomic Energy Comm., Oak Ridge, Tennessee, 1946.

RATIO OF SPECIFIC HEATS

$$\frac{C_p}{C_v} = 1.360 \text{ at } 298.1°K$$

Ref. Landau and Rosen, Manhattan District Declassified Report No.154, 1-b, U.S. Atomic Energy Comm., Oak Ridge, Tennessee, 1946.

HEAT CAPACITY OF LIQUID AND SOLID No information

FREE ENERGY OF FORMATION

Gas

$$\Delta F^{\circ}_{298.1} = 0, \text{ by definition}$$

FREE-ENERGY FUNCTION

Temperature (°K)	$-(F^\circ - H_o^\circ)/T$ (cal/mole deg)
298.1	41.488
300	41.533
400	43.594
500	43.230
600	46.594
800	48.802
1000	50.561
1200	52.024
1400	53.281
1600	54.380
1800	55.354
2000	56.243

Ref. Murphy and Vance, *J. Chem. Physics*, Vol.7 (1939), p.806.

HEAT-CONTENT FUNCTION

May be calculated from the following data:

$$H^\circ_{298.1} - H^\circ_o = 2111 \text{ cal/mole deg}$$

Temp (°K)	$H^\circ - H^\circ_{298.1}$ (cal/mole deg)	Temp (°K)	$H^\circ - H^\circ_{298.1}$ (cal/mole deg)
298.1	0	3200	25,342
400	786	3400	27,126
600	2,416	3600	28,906
800	4,112	3800	30,694
1000	5,843	4000	32,481
1200	7,591	4200	34,265
1400	9,352	4400	36,046
1600	11,114	4600	37,835
1800	12,886	4800	39,620
2000	14,661	5000	41,409
2200	16,440	5200	43,197
2400	18,215	5400	44,983
2600	19,994	5600	46,765
2800	21,776	5800	48,552
3000	23,560	6000	50,341

Ref. Goodrich, Sachsel, and Mantis, Unpublished Calculations, Battelle Memorial Institute, 1947.

ENTROPY

Temp (°K)	S_t° (cal/mole deg)	Temp (°K)	S_t° (cal/mole deg)
298.1	48.576	1000	58.580
300	48.623	1200	60.119
400	50.844	1400	61.476
500	52.642	1600	62.659
600	54.141	1800	63.694
800	56.594	2000	64.637

Ref. Murphy and Vanco, *J. Chem. Physics*, Vol.7 (1939), p.806.

Temp (°K)	S_t° (cal/mole deg)	Temp (°K)	S_t° (cal/mole deg)
2200	65.483	4200	71.245
2400	66.253	4400	71.657
2600	66.965	4600	72.057
2800	67.625	4800	72.439
3000	68.242	5000	72.801
3200	68.817	5200	73.154
3400	69.358	5400	73.489
3600	69.865	5600	73.818
3800	70.350	5800	74.126
4000	70.813	6000	74.430

Ref. Goodrich, Sachsel, and Mantis, Unpublished Calculations, Battelle Memorial Institute, 1947.

HYDROGEN PEROXIDE

MOLECULAR FORMULA

H_2O_2

MOLECULAR WEIGHT

34.016

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −0.89°C

Ref. Cuthbertson Matheson, and Maass, *J. Am. Chem. Soc.*, Vol.50 (1928), pp.1120-21.

BOILING POINT

Boiling point 150.5°C

Ref. Giguere and Maass, *Can. J. Research*, Vol.18, B (1940), p.181.

DENSITY

Vapor No information

Liquid

Temperature (°C)	Density (gm/cc)
−12.13	1.4774
−9.80	1.4751
−8.38	1.4733
−6.23	1.4705
−2.85	1.4674
−0.53	1.4638
+0.10	1.4631
1.20	1.4617
3.00	1.4597
5.55	1.4570
8.30	1.4541
12.60	1.4490
15.30	1.4465
19.90	1.4419

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

Solid

Temperature (°C)	Density (gm/cc)
−4.45	1.6434
−7.45	1.6437

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)
20	1.5
25	2.0
30	2.75
35	4.0
40	5.7
45	7.8
50	10.4
55	13.8
60	18.1
65	23.3
70	29.65
75	37.6
80	47.4
85	59.1
90	71.5

Ref. Maass and Hiebert, *J. Am. Chem. Soc.*, Vol.46 (1924), pp.2693-2700.

TRIPLE POINT No information

VISCOSITY

Vapor No information

Liquid

Temperature (°C)	η (poise)
0.04	0.01828
11.90	0.01456
12.20	0.01447
19.60	0.01272

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

SURFACE TENSION

Temperature (°C)	γ (dynes/cm)
0.2	78.73
6.2	77.79
11.0	77.51
13.9	76.47
18.2	75.94

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

COEFFICIENT OF THERMAL EXPANSION

Change in liquid density per degree temperature change (°C) = 0.001075 (Range, −10° to 20°C)

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

COEFFICIENT OF THERMAL CONDUCTIVITY No information

DIPOLE MOMENT

$\mu = 2.1$ debye

Ref. Linton and Maass, *Can. J. Research*, Vol.7 (1932), p.81.

HEAT OF FUSION

$\Delta H_f = 74.$ cal/gm

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

HEAT OF VAPORIZATION

$\Delta H_v = 326$ cal/gm

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol.42 (1920), pp.2548-69.

HEAT OF FORMATION

$$H_2 + O_2 = H_2O_2(l)$$

$$\Delta H = 45{,}320 \text{ cal/mole}$$

Ref. Landolt-Börnstein, *Physikalisch-Chemische Tabellen*, II (1923), p.1490.

HEAT OF COMBUSTION No information

CRITICAL DATA

t_c = 459.°C

Ref. Maass and Hiebert, *J. Am. Chem. Soc.*, Vol. 46 (1924), pp. 2693-2700.

EQUATION OF STATE
COMPRESSIBILITY
HEAT CAPACITY OF GAS, C_p AND C_v
RATIO OF SPECIFIC HEATS

No information

HEAT CAPACITY OF LIQUID AND SOLID

C_p = 0.579 cal/gm at 0 to 18.5°C ± 4%

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol. 42 (1920), pp. 2548-69.

C_p = 0.470 cal/gm at −9.0°C to melting point ± 4%

Ref. Maass and Hatcher, *J. Am. Chem. Soc.*, Vol. 42 (1920), pp. 2548-69.

FREE ENERGY OF FORMATION

State	F°_{298} (cal/mole)
Gas	−24,730
Liquid	−28,230
Solid	−27,980

Ref. Lewis and Randall, *Thermodynamics and the Free Energy of Chemical Substances*, 1st ed., 1923, p. 495.

FREE-ENERGY FUNCTION
HEAT-CONTENT FUNCTION
ENTROPY

No information

NITRIC ACID

MOLECULAR FORMULA

HNO_3

MOLECULAR WEIGHT

63.016

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −41.59°C

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

BOILING POINT

Boiling point = 86.°C at 760 mm Hg

Ref. Landolt-Börnstein, *Physikalisch-Chemische Tabellen*, Vol.2 (1923), p.1477.

DENSITY

Vapor (Air = 1)

Temperature (°C)	Specific Gravity
86	2.05
100	2.02
130	1.92
160	1.79
190	1.59
220	1.42
250	1.29
256	1.25
265	1.24
312	1.23

The acid decomposes with temperature according to the equation $4HNO_3 = 4NO_2 + 2H_2O + O_2$ until decomposition is complete at 256°C.

Ref. Carius, *Ber.*, Vol.4 (1871), p.828.

Liquid

Temperature (°C)	Density (gm/cc)
0	1.5472
12.5	1.5245
25	1.5018

Ref. Klemenc and Rupp, *Z. anorg. Chem.*, Vol.194 (1930), p.51.

Solid

d = 1.883 gm/cc at −195°C

Ref. Biltz and Hülsmann, *Z. anorg. u. allgem. Chem.*, Vol.207 (1932), p.377.

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)	References
0	14.7	(1)
5	20.1	"
10	27.1	"
15	36.2	"
20	48.0	"
25	61.0	(2)
30	77.4	"
35	102.	(3)
40	133.	"
45	170.	"
50	215	"
55	262.	"
60	320.	"
65	385.	"
70	460	"
75	540	"
80	625	"
85	720	"
90	820	"

Refs. (1) Wilson and Miles, *Trans. Faraday. Soc.*, Vol.36 (1940), p.356.

(2) Berl and Saenger, *Monatsh.*, Vols.53-54 (1929), p.1036.

(3) Taylor, *Ind. Eng. Chem.*, Vol.17 (1925), p.633.

TRIPLE POINT No information

VISCOSITY

Vapor No information

Liquid

Temperature (°C)	η (poises)
10	0.0107
20	0.00913
40	0.00698

Ref. Bingham and Stone, *J. Phys. Chem.*, Vol.27 (1923), p.701.

SURFACE TENSION (99.8% HNO_3)

Temperature (°C)	γ (dynes/cm)
11.6	42.7
46.2	37.2
78.2	32.6

Ref. *International Critical Tables*, Vol.4 (1928), p.464.

COEFFICIENT OF THERMAL EXPANSION

Temperature Range (°C)	α
4-14.2	0.001274
14.2-24.2	0.001240

Ref. Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, Vol.8, p.566.

COEFFICIENT OF THERMAL CONDUCTIVITY
DIPOLE MOMENT } No information

HEAT OF FUSION

ΔH_f = 2503 ± 2 cal/mole at −41.59°C

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

HEAT OF VAPORIZATION

ΔH_v = 7.25 kcal/mole at 86°C

Ref. Landolt-Börnstein, *Physikalisch-Chemische Tabellen*, Vol. 2 (1923), p.1477.

HEAT OF FORMATION

Vapor

$\Delta H^\circ_{298.1}$ = −3199 cal/mole

Liquid

$\Delta H^\circ_{298.1}$ = −41,349 cal/mole

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

HEAT OF COMBUSTION
CRITICAL DATA
EQUATION OF STATE
COMPRESSIBILITY

No information

HEAT CAPACITY OF GAS, C_p AND C_v

$C_p = 6.57 + 18.75 \times 10^{-3}\ T$ (from 273°-500°K)

(Equation derived from heat-content data of Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1942), p.2479.)

Ref. Egan, *Ind. Eng. Chem.*, Vol.37 (1945), p.303.

RATIO OF SPECIFIC HEAT No information

HEAT CAPACITY OF LIQUID AND SOLID

Liquid (data from smoothed experimental curve)

Temperature (°K)	C_p (cal/mole deg)
240	26.70
250	26.65
260	26.59
270	26.51
280	26.42
290	26.33
300	26.24

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

Solid (data from smoothed experimental curve)

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
15	0.677	95	9.794
20	1.238	100	10.06
25	1.934	110	10.56
30	2.740	120	11.09
35	3.609	130	11.47
40	4.468	140	11.92
45	5.193	150	12.37
50	5.855	160	12.81
55	6.463	170	13.27
60	7.012	180	13.72
65	7.522	190	14.20
70	7.988	200	14.70
75	8.419	210	15.25
80	8.825	220	15.82
85	9.187	230	16.46
90	9.510		

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

FREE ENERGY OF FORMATION

Gas $\Delta F^{\circ}_{298.1} = -17,554$

Liquid $\Delta F_{298.1} = -19,030$

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

FREE-ENERGY FUNCTION

(HNO_3 gas)

Temperature (°K)	$(F^\circ - H_0^\circ)/T$ (cal/mole deg)
275	54.08
298.1	54.25
300	54.31
325	55.05
350	55.78
375	56.45
400	57.13
425	57.75
450	58.35
475	58.98
500	59.53

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61; Vol.65 (1943), p.2479.

HEAT-CONTENT FUNCTION

Gas

Temperature (°K)	$(H^\circ - H_0^\circ)/T$ (cal/mole deg)
275	9.16
298.1	9.37
300	9.39
325	9.62
350	9.84
375	10.07
400	10.31
425	10.54
450	10.79
475	11.02
500	11.25

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61, Vol.65 (1943), p.2479.

ENTROPY

Vapor

Temperature (°K)	S_f° (cal/mole deg)
275	63.24
298.1	63.62
300	63.70
325	64.67
350	65.62
375	66.52
400	67.44
425	68.29
450	69.14
475	70.00
500	70.78

Liquid

$S^\circ_{298.1}$ = 37.19 cal/mole deg

Ref. Forsythe and Giauque, *J. Am. Chem. Soc.*, Vol.64 (1942), pp.48-61, Vol.65(1943), p.2479.

NITROGEN DIOXIDE
(Nitrogen Tetroxide)

MOLECULAR FORMULA

NO_2; N_2O_4

MOLECULAR WEIGHT

NO_2 = 46.008

N_2O_4 = 92.016

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −11.20°C (equilibrium mixture of NO_2 and N_2O_4)

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

BOILING POINT

Boiling point = 21.15°C at 760 mm Hg (equilibrium mixture of NO_2 and N_2O_4)

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40

DENSITY

Vapor (specific gravity, compared with air as unity)

Temp (°C)	Specific Gravity	Temp (°C)	Specific Gravity
4.2	2.588	79.	1.84
11.3	2.645	80.6	1.80
24.5	2.520	97.5	1.783
32.	2.65	100.1	1.68
35.4	2.53	111.3	1.65
39.8	2.46	121.5	1.63
52.	2.26	135.	1.60
60.2	2.08	154.	1.58
70.	1.95	183.2	1.57

Ref. Friend, *A Textbook of Inorganic Chemistry*, Vol.6, Part I (1928), p.168.

Above values refer to a mixture of NO_2 and N_2O_4 at equilibrium at observed temperature.

Liquid (NO_2-N_2O_4 equilibrium mixture)

Temperature (°C)	Density (gm/ml)
−5	1.5035
−4	1.5030
−2	1.5020
−1	1.5000
0	1.4935
+5	1.4880
10	1.4770
15	1.4740
21.6	1.4398

Ref. Guether, *Annalen*, Vol.245 (1888), p.96; Thorpe, *Trans. Chem. Soc.*, Vol.37 (1880), p.141.

DENSITY (*Cont'd*)

Solid (NO_2-N_2O_4 equilibrium)

Temperature (°C)	Density (gm/cc)
−195.	1.979
−79.	1.899

Ref. Biltz, Fischer, and Wünnenberg, *Z. anorg. Chem.*, Vol.193 (1930), pp.351-66.

VAPOR PRESSURE

Liquid (0°C = 273.10°K)

Temperature (°K)	Pressure (mm Hg)
240.296	19.97
240.322	20.11
248.476	43.58
255.62	82.46
258.78	108.21
261.90	139.78
264.05	158.25
268.04	198.72
271.94	246.66
275.93	305.63
279.32	364.93
284.21	467.85
288.21	569.45
292.14	688.07
294.89	783.29

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

Temperature (°C)	Pressure (mm Hg)
19.9	721
29.95	1133.5
39.85	1737
48.95	2522

Ref. Mittasch, Kuss, and Schlueter, *Z. anorg. Chem.*, Vol.159 (1927), p.29.

Solid (equilibrium mixture of NO_2 and N_2O_4)

Temperature (°C)	Pressure (mm Hg)
−100	0.0023
−90	0.0093
−80	0.0360
−70	0.1510
−60	0.605
−50	2.440
−40	9.770
−30	39.240

Ref. Egerton, *Trans. Chem. Soc.*, Vol.105 (1914), p.647.

TRIPLE POINT

Temperature = −11.20°C at 139.78 mm Hg

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

VISCOSITY

Vapor No information

Liquid (equilibrium mixture of NO_2 and N_2O_4)

Temperature (°C)	η (centipoises)
0.72	0.5220
5.09	0.4954
9.15	0.4720
11.87	0.4578
15.36	0.4401

Ref. Thorpe and Rodger, *Phil. Trans.*, Vol.185 (1895), p.397.

SURFACE TENSION

(Equilibrium mixture of NO_2 and N_2O_4)

Temperature (°C)	γ (dynes/cm)
1.6	30.6 ± 1.0
19.8	27.5 ± 1.0

Ref. *International Critical Tables*, Vol.4 (1928), p.447.

COEFFICIENT OF THERMAL EXPANSION

Gas (equilibrium mixture of NO_2 and N_2O_4)

Temperature (°C)	Volume
0	1.00000
5	1.00789
10	1.01573
15	1.02370
20	1.03196
21.64	1.02523

Ref. Thorpe, *J. Chem. Soc.*, Vol.37 (1880), p.244.

COEFFICIENT OF THERMAL CONDUCTIVITY

Gas (equilibrium mixture of NO_2 and N_2O_4)

9.6×10^{-5} cal/cm sec deg at 55°C

Ref. *International Critical Tables*, Vol.5 (1929), p.214.

DIPOLE MOMENT

0.39 debye for NO_2 gas

0.55 debye for N_2O_4 gas

Ref. Zahn, *Physik. Z.*, Vol.34 (1933), p.461.

HEAT OF FUSION

(Equilibrium mixture of NO_2 and N_2O_4)

ΔH_f = 3.502 kcal/mole at −11.20°C

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

HEAT OF VAPORIZATION

(Equilibrium mixture of NO_2 and N_2O_4)

ΔH_v = 9.110 kcal/mole at 21.15°C

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

HEAT OF FORMATION

$\Delta H^{\circ}_{298.1}$ = 7964 cal/mole for NO_2 gas

$\Delta H^{\circ}_{298.1}$ = 2239 cal/mole for N_2O_4 gas

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

HEAT OF COMBUSTION No information

CRITICAL DATA

t_c = 158.2°C

d_c = 0.507 gm/ml

Ref. Bennewitz and Windisch, *Z. physik. Chem.*, A, Vol.166 (1933), p.401.

p_c = 100 atm

Ref. Scheffer and Treub, *Z. physik. Chem.*, Vol.81 (1912), pp.308-32.

EQUATION OF STATE

(Equilibrium mixture of NO_2 and N_2O_4)

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

where

P = pressure, atm

V = volume, liters/mole

R = 0.08207 liter atm/mole deg

T = temp, °K

n = number of moles

a = 5.284 liter^2 atm/mole^2

b = 0.04424 liter

Ref. Lange, *Handbook of Chemistry*, 6th ed., 1946, p.1472.

COMPRESSIBILITY No information

HEAT CAPACITY OF GAS, C_p AND C_v

(Experimental Values for N_2O_4)

Temperature (°C)	C_p (cal/mole deg)
33.73	11.4
41.00	12.0
44.00	12.0
55.03	15.2
60.90	14.7
63.33	16.6
70.70	14.9
80.89	16.1
97.51	17.5

(Calculated Values for N_2O_4)

Temperature (°C)	C_p (cal/mole deg)
100	18.8
110	18.9
120	19.0
130	19.1
140	19.2
150	19.4
160	19.5

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

C_v = 6.67 cal/mole deg for NO_2 gas at 15°C and 1 atm

Ref. Leduc, *Chem. Revs.*, Vol.6 (1929), p.13.

RATIO OF SPECIFIC HEATS

γ = 1.303 at 15°C and 1 atm for NO_2

Ref. Leduc, *Chem. Revs.*, Vol.6 (1929), p.13.

HEAT CAPACITY OF LIQUID AND SOLID (N_2O_4)

Liquid

Temperature (°K)	C_p (cal/mole deg)
265.44	32.79
269.91	32.92
275.38	33.10
281.19	33.34
286.86	33.60
291.28	33.74

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

Solid

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
16.80	1.315	128.86	16.82
19.10	1.833	133.97	17.19
21.46	2.370	140.15	17.58
24.11	3.000	144.09	17.95
26.95	3.718	148.89	18.26
30.18	4.539	153.87	18.65
33.70	5.442	158.93	19.01
38.51	6.544	163.83	19.35
44.08	7.652	168.69	19.66
49.10	8.546	173.79	20.03
54.09	9.345	178.90	20.39
58.84	10.02	184.06	20.72
62.23	10.52	189.40	21.12
63.66	10.76	194.62	21.53
67.31	11.16	199.98	21.93
72.44	11.68	205.60	22.32
77.66	12.32	210.97	22.73
82.52	12.77	216.37	23.10
87.50	13.35	221.53	23.50
93.03	13.88	226.30	23.83
98.69	14.41	232.37	24.31
103.99	14.87	238.12	24.78
109.02	15.26	243.65	25.19
113.77	15.66	249.27	25.60
118.69	15.99	254.65	25.94
123.82	16.40	258.26	26.23

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

FREE ENERGY OF FORMATION

$\Delta F^{\circ}_{298.1}$ = 12,275 cal/mole for NO_2 gas

$\Delta F_{298.1}$ = 23,440 cal/mole for N_2O_4 gas

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

FREE-ENERGY FUNCTION

Temperature (°K)	$-(F^{\circ} - H^{\circ})/T$ (cal/mole deg)	
	NO_2	N_2O_4
275	48.536	58.021
298.1	49.202	59.106
300	49.252	59.192
325	49.918	60.302
350	50.538	61.365
375	51.122	62.377
400	51.670	63.363
425	52.195	64.301
450	52.676	
500	53.617	
550	54.471	
600	55.266	
650	56.010	
700	56.709	
750	57.373	
800	57.992	
850	58.583	
900	59.152	

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

HEAT-CONTENT FUNCTION No information

ENTROPY

	$S^{\circ}_{298.1}$ (cal/mole deg)	$\Delta S_{298.1}$ (cal/mole deg)
NO_2 gas	57.47	−14.46
N_2O_4 gas	72.73	−71.12

Ref. Giauque and Kemp, *J. Chem. Phys.*, Vol.6 (1938), p.40.

NITROGEN TRIFLUORIDE

MOLECULAR FORMULA

NF_3

MOLECULAR WEIGHT

71.01

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −208.5°C

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.217 (1934), p.93.

BOILING POINT

Boiling point = −129.0°C at 760 mm Hg

Ref. Menzel and Mohry, *Z. anorg. Chem.*, Vol.210 (1933), p.257.

DENSITY

Gas

d = 3.16 gm/liter at 0°C and 760 mm Hg

Ref. Ruff, Fischer, and Luft, *Z. anorg. Chem.*, Vol.172 (1928), p.427.

Liquid

Temperature (°C)	Density (gm/cc)
−120.	1.504
−123.	1.514
−125.5	1.525
−127.5	1.536
−129.	1.537
−131.5	1.548
−192.	1.812

Ref. Ruff, *Z. anorg. Chem.*, Vol.197 (1931), p.277.

Solid No information

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)
−192.5	0.2
−167.5	17.0
−140.58	311.5
−137.71	394.2
−135.68	464.3
−134.94	490.7
−133.95	530.1
−133.25	558.7
−132.60	586.1
−131.69	626.9
−130.85	667.3
−130.55	680.8
−129.76	722.2
−129.19	751.0
−129.07	756.5
−128.28	773.1

Ref. Menzel and Mohry, *Z. anorg. Chem.*, Vol.210 (1933), p.257.

TRIPLE POINT
VISCOSITY (Gas and Liquid)
SURFACE TENSION
COEFFICIENT OF THERMAL EXPANSION
COEFFICIENT OF THERMAL CONDUCTIVITY

No information

DIPOLE MOMENT

μ = 0.25 debye at −80° to 25°C
0.21 debye at 25° to 95°C
0.24 debye at −80° to 95°C

Ref. Watson, Kane, and Ramaswamy, *Proc. Roy. Soc.*, A, Vol.156 (1936), p.130.

HEAT OF FUSION No information

HEAT OF VAPORIZATION

ΔH_v = 2880 cal/mole at −129.0°C

Ref. Menzel and Mohry, *Z. anorg. Chem.*, Vol.210 (1933), p.257.

HEAT OF FORMATION

ΔH = −26 ± 2 kcal/mole, at room temperature and at constant volume

Ref. Ruff and Wallauer, *Z. anorg. Chem.*, Vol.196 (1931), p.428.

HEAT OF COMBUSTION
CRITICAL DATA
EQUATION OF STATE
COMPRESSIBILITY
HEAT CAPACITY OF GAS, C_p AND C_v
RATIO OF SPECIFIC HEATS
HEAT CAPACITY OF LIQUID AND SOLID
FREE ENERGY OF FORMATION
FREE-ENERGY FUNCTION
HEAT-CONTENT FUNCTION
ENTROPY

No information

OXYGEN

MOLECULAR FORMULA

O_2

MOLECULAR WEIGHT

32.000

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting point = −218.71°C

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.2300.

BOILING POINT

Boiling point = −182.97°C at 760 mm Hg

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.2300.

DENSITY

Gas (Saturated)

Temperature (°C)	Density (gm/ml)
−210.4	0.0001
−182.0	0.0051
−154.51	0.0385
−140.2	0.0805
−129.9	0.1320
−123.3	0.2022
−120.4	0.2701

Ref. Mathias and Onnes, *Communs. Phys. Lab. Univ. Leiden*, No.117 (1917).

Liquid

Temperature (°C)	Density (gm/ml)
−120.4	0.6032
−123.3	0.6779
−129.9	0.7781
−140.2	0.8742
−154.51	0.9758
−182.0	1.1415

Ref. Mathias and Onnes, *Communs. Phys. Lab. Univ. Leiden*, No.117 (1917).

Liquid (*Cont'd*)

Temperature (°C)	Density (gm/ml)
184.0	1.1479
186.0	1.1575
188.0	1.1671
190.0	1.1767
192.0	1.1863
194.0	1.1959
196.0	1.2056
198.0	1.2152
200.0	1.2248
202.0	1.2344
204.0	1.2441
205.0	1.2489

Ref. Baly and Donnan, *J. Chem. Soc.*, Vol.81 (1902), p.907.

Solid

d = 1.4256 gm/cc at −252.5°C

Ref. Dewar, *Proc. Roy. Soc.*, Vol.73 (1904), p.251.

VAPOR PRESSURE

Liquid

Temperature (°K)	Pressure (mm Hg)
62.37	9.59
68.57	36.11
71.71	64.01
77.59	162.15
81.08	263.2
86.18	493.3
89.18	687.8
89.87	738.8
90.13	760.0
90.47	786.6

Ref. Cath, *Communs. Phys. Lab. Univ. Leiden*, No.152d.

VAPOR PRESSURE (*Cont'd*)

Liquid (*Cont'd*)

Temperature (°K)	Pressure (atm)
118.22	9.096
123.84	12.506
134.14	21.328
142.45	30.914
147.81	38.571
151.76	45.142
154.27	49.713 (Critical Point)

Ref. Onnes, Dorsman, and Holst, *Communs. Phys. Lab. Univ. Leiden*, No.145b (1914).

Solid

Temperature (°K)	Pressure (mm Hg)
37.3	0.0008
39.0	0.0044
43.1	0.010
44.1	0.022
46.0	0.045
50.7	0.291
54.3	1.20

Ref. Aoyama and Kanda, *Science Repts. Tohoku Imp. Univ.* (1), Vol.24 (1935), p.107.

TRIPLE POINT

Temperature = −218.4°C

Ref. *International Critical Tables*, Vol.3 (1928), p.203.

VISCOSITY

Gas

Temperature (°K)	$\eta \times 10^7$ (poises)
90	691
100	768
110	843
120	917
130	999
140	1061
150	1132
160	1202
170	1272
180	1341
190	1409
200	1476
210	1541
220	1604
230	1666
240	1728
250	1786
260	1845
270	1902
280	1958
290	2015
296.1	2049
300	2071

Above values taken from smoothed experimental curve.

Ref. Johnston and McCloskey, *J. Phys. Chem.*, Vol.44 (1940), p.1038.

Liquid

Temperature (°K)	η (poises)
65	0.445
70	0.356
75	0.297
80	0.252
85	0.218
90	0.191
95	0.168
100	0.149
105	0.136

VISCOSITY (*Cont'd*)

Liquid (*Cont'd*)

Temperature (°K)	η(poises)
110	0.126
115	0.119
120	0.113
125	0.109
130	0.105
135	0.102
140	0.099
145	0.096
150	0.094
155	0.091

Above values obtained from smooth curve of data obtained from listed references.

Refs. Rudenko, *J. Exp. Theoret. Phys. (U.S.S.R.)*, Vol.9 (1939), p.1078.
Rudenko and Schubrikow, *Physik. Z. Sowjetunion (U.S.S.R.)*, Vol.6 (1934), p.470.
Itterbeek and Paemel, *Physica*, Vol.8 (1941), p.133.
Verschaffelt and Nicaise, *Communs. Phys. Lab. Univ. Leiden*, No.149b (1916).

SURFACE TENSION

Temperature (°K)	γ (dynes/cm)
70	18.3
75	17.0
80	15.7
85	14.5
90	13.2

Ref. Baly and Donnan, *J. Chem. Soc.*, Vol.81 (1902), p.907.

COEFFICIENT OF THERMAL EXPANSION

Gas

$$\alpha = \frac{V - V_0}{V_0\, t}$$

Pressure (mm Hg)	100 α 0°-50°C	100 α 0°-100°C
0	0.3660	0.3660
1	0.3679	0.3676
5	0.3752	0.3739
10	0.3842	0.3817
15	0.3932	0.3894
20	0.4019	0.3971
25	0.4107	0.4047
30	0.4193	0.4123
35	0.4729	0.4199
40	0.4364	0.4274
45	0.4446	0.4347
50	0.4530	0.4420
55	0.4614	0.4492
60	0.4696	0.4563
65	0.4777	0.4632
70	0.4856	0.4701
75	0.4935	0.4768

Ref. Halborn and Otto, *Z. Physik*, Vol.10 (1922), p.367; *International Critical Tables*, Vol.3 (1928), p.9.

COEFFICIENT OF THERMAL CONDUCTIVITY

Temp (°K)	$k \times 10^5$ (cal/cm sec deg)	Temp (°K)	$k \times 10^5$ (cal/cm sec deg)
80	1.701	150	3.287
90	1.930	160	3.508
100	2.159	170	3.728
110	2.387	180	3.946
120	2.614	190	4.162
130	2.840	200	4.375
140	3.064	210	4.584

COEFFICIENT OF THERMAL CONDUCTIVITY (*Cont'd*)

Temp (°K)	$k \times 10^5$ (cal/cm sec deg)	Temp (°K)	$k \times 10^5$ (cal/cm sec deg)
220	4.790	298.1	6.314
230	4.993	300	6.350
240	5.194	310	6.547
250	5.392	320	6.748
260	5.586	330	6.954
270	5.780	340	7.164
273.1	5.839	350	7.378
280	5.970	360	7.594
290	6.159	370	7.812
293.1	6.218	380	8.033

Ref. Johnston and Grilly, *J. Chem. Phys.*, Vol.14 (1946), p.233.

DIPOLE MOMENT No information

HEAT OF FUSION

ΔH_f = 106.3 ± 0.3 cal/mole at −218.71°C

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.300.

HEAT OF VAPORIZATION

ΔH_v = 1628.8 ± 1.6 cal/mole at −182.97°C and 760 mm Hg

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.300.

HEAT OF FORMATION

$\Delta H^\circ_{298.1}$ = 0, for the gas

HEAT OF COMBUSTION No information

CRITICAL DATA

$t_c = -118.8°C$

$p_c = 49.7$ atm

Ref. Onnes, Doroman, and Holst, *Communs. Phys. Lab. Univ. Leiden*, No.145b (1914).

$d_c = 0.4299$ gm/cc

Ref. Mathias and Onnes, *Proc. K. Akad. Wetensch. Amsterdam*, Vol.13 (1911), p.939.

EQUATION OF STATE

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

where

P = pressure, atm

V = volume, liters/mole

T = temp, °K

R = 0.08207 liter atm/mole deg

n = number of moles

a = 1.360 liter^2 atm/mole^2

b = 0.03183 liter/mole

Ref. Lange, *Handbook of Chemistry* (1946), p.1474.

COMPRESSIBILITY

Gas

Pressure (atm)	PV 0°C	15.65°C	100°C	200°C
1	1.000	–	–	–
100	0.9265	1.0045	1.3750	–
200	0.9140	0.9945	1.4000	1.8190
300	0.9625	1.0420	1.4530	1.8850
400	1.0515	1.1250	1.5320	1.9610
500	1.1560	1.2270	1.6220	2.0500
600	1.2690	1.3370	1.7200	2.1420
700	1.3855	1.4515	1.8270	2.2415
800	1.5030	1.5660	1.9340	2.3430
900	1.6200	1.6820	2.0415	2.4465
1000	1.7355	1.7980	2.1510	–

Ref. Amagat, *Ann. chim. et phys.*, Vol.29 (1893), p.68.

HEAT CAPACITY OF GAS, C_p AND C_v

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
0	0	1100	8.440
50	6.963	1200	8.530
100	6.963	1300	8.608
200	6.962	1400	8.676
250	6.970	1500	8.739
298.16	7.017	1750	8.885
300	7.019	2000	9.024
400	7.194	2250	9.166
500	7.429	2500	9.305
600	7.670	2750	9.418
700	7.885	3000	9.518
800	8.064	3500	9.711
900	8.212	4000	9.879
1000	8.335	–	–

Ref. American Petroleum Institute, Research Project No.44 (1947), Table 1-v.

RATIO OF SPECIFIC HEATS

Temperature (°K)	$C_p/C_v = \gamma$*
1000	1.3130
1500	1.2942
1750	1.2881
2000	1.2824
2250	1.2768
2500	1.2715
2750	1.2674
3000	1.2638
3500	1.2573
4000	1.2518

*Calculated for ideal gas from C_p data in above references

Ref. American Petroleum Institute, Research Project No.44 (1947), Table 1-v.

HEAT CAPACITY OF LIQUID AND SOLID

Liquid

Temp (°K)	C_p (cal/mole deg)	Temp (°K)	C_p (cal/mole deg)
56.95	12.76	75.86	12.80
57.95	12.72	77.58	12.84
60.97	12.71	78.68	12.83
61.48	12.71	81.13	12.88
65.57	12.71	82.31	12.86
65.92	12.71	82.96	12.88
68.77	12.73	84.79	12.93
69.12	12.75	86.43	12.91
70.67	12.77	86.61	12.95
71.38	12.78	86.97	12.92
73.31	12.81	87.32	12.91
74.95	12.85	90.33	12.99

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.300.

HEAT CAPACITY OF LIQUID AND SOLID (*Cont'd*)

Solid

Temperature (°K)	C_p (cal/mole deg)	Temperature (°K)	C_p (cal/mole deg)
12.97	1.10	29.88	6.61
14.14	1.52	30.63	6.94
15.12	1.60	31.08	6.93
15.57	1.79	33.05	7.52
16.66	2.33	33.33	7.73
16.80	2.18	34.41	8.08
16.94	2.25	35.57	8.26
18.13	2.67	35.77	8.49
18.32	2.71	37.59	9.08
18.45	2.79	37.85	9.12
19.34	3.07	38.47	9.80
20.26	3.50	39.99	9.80
20.85	3.60	40.18	9.92
21.84	4.20	40.67	10.16
22.24	4.27	42.21	10.73
Transition at	23.66	Transition at	43.76
25.02	5.42	45.90	11.02
25.61	5.57	47.76	11.07
26.75	5.75	48.11	11.01
28.00	6.05	48.97	10.99
28.08	6.42	50.55	11.01
–	–	51.68	11.03
–	–	52.12	11.06

Ref. Giauque and Johnston, *J. Am. Chem. Soc.*, Vol.51 (1929), p.300.

FREE ENERGY OF FORMATION

$\Delta F_{298.1} = 0$, by definition

FREE-ENERGY FUNCTION

Temp (°K)	$-(F^\circ - H_o^\circ)/T$ (cal/mole deg)	Temp (°K)	$-(F^\circ - H_o^\circ)/T$ (cal/mole deg)
0	0	1100	51.415
200	39.294	1200	52.077
250	40.835	1300	52.695
298.16	42.061	1400	53.272
300	42.106	1500	53.808
400	44.112	1750	55.027
500	45.675	2000	56.103
600	46.968	2250	57.059
700	48.071	2500	57.930
800	49.044	2750	58.730
900	49.911	3000	59.468
1000	50.697	3500	60.798
–	–	4000	61.958

Ref. American Petroleum Institute, Research Project No.44 (1947), Table O-s, p.192.

HEAT-CONTENT FUNCTION

Temp (°K)	$(H^\circ - H_o^\circ)/T$ (cal/mole deg)	Temp (°K)	$(H^\circ - H_o^\circ)/T$ (cal/mole deg)
0	0	1200	7.6533
200	6.9220	1300	7.7238
250	6.9307	1400	7.7893
298.16	6.9418	1500	7.8509
300	6.9424	1750	7.9885
400	6.9811	2000	8.1094
500	7.0484	2250	8.2195
600	7.1320	2500	8.3196
700	7.2248	2750	8.4133
800	7.3176	3000	8.500
900	7.4107	3500	8.6595
1000	7.4970	4000	8.8038
1100	7.5775		

Ref. American Petroleum Institute, Research Project No.44 (1947), Table O-r, p.174.

ENTROPY

Temp (°K)	S_t (cal/mole deg)	Temp (°K)	S_t (cal/mole deg)
0	0	1100	58.992
50	36.567	1200	59.730
200	46.216	1300	60.419
250	47.766	1400	61.061
298.16	49.003	1500	61.659
300	49.048	1750	63.015
400	51.093	2000	64.212
500	52.723	2250	65.278
600	54.100	2500	66.250
700	55.296	2750	67.143
800	56.362	3000	67.968
900	57.322	3500	69.458
1000	58.194	4000	70.762

Ref. American Petroleum Institute, Research Project No.44 (1947), Table O-t, p.210.

OXYGEN FLUORIDE

MOLECULAR FORMULA

OF_2

MOLECULAR WEIGHT

54.00

Ref. International Atomic Weights, 1947.

MELTING POINT

Melting point = −223.8°C

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.190 (1930), p.257.

BOILING POINT

Boiling point = −144.8°C at 760 mm Hg

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.198 (1930), p.39.

DENSITY

Gas

Specific Gravity = 1.836 at −167 °C (air = 1)

Ref. Lebeau and Damiens, *Compt. rend.*, Vol.188 (1929), p.1253.

Liquid

d = 1.90 gm/cc at −223.8 °C

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.198 (1931), p.39.

Solid No information

VAPOR PRESSURE

Temperature (°C)	Pressure (mm Hg)
−191.5	3.2
−183.5	12.4
−168	93.2
−163	169.7
−161	211.9
−157	289.4
−150.5	546.0
−148	692.6

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.190 (1930), p.257.

TRIPLE POINT
VISCOSITY
SURFACE TENSION
COEFFICIENT OF THERMAL EXPANSION
COEFFICIENT OF THERMAL CONDUCTIVITY
DIPOLE MOMENT
HEAT OF FUSION

No information

HEAT OF VAPORIZATION

ΔH_v = 2508 cal/mole (calculated)

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.190 (1930), p.257.

HEAT OF FORMATION

$\Delta H^\circ_{298.1}$ = 5500 cal/mole

Ref. Bichowsky and Rossini, *Thermochemistry*, 1936, p.21.

HEAT OF COMBUSTION No information

CRITICAL DATA

t_c = approx −83°C (calculated)

Ref. Ruff and Menzel, *Z. anorg. Chem.*, Vol.190 (1930), p.257.

EQUATION OF STATE
COMPRESSIBILITY
HEAT CAPACITY OF GAS, C_p AND C_v
RATIO OF SPECIFIC HEATS
HEAT CAPACITY OF LIQUID AND SOLID

No information

FREE ENERGY OF FORMATION

$\Delta F^\circ_{298.1}$ = 9.5 kcal/mole

Ref. Latimer, *Oxidation States of the Elements and Their Potentials in Aqueous Solutions*, 1938, p.46.

FREE-ENERGY FUNCTION HEAT-CONTENT FUNCTION	No information

ENTROPY

$\Delta S^{\circ}_{298.1}$ = approx 59 cal/mole deg

Ref. Latimer, *Oxidation States of the Elements and Their Potentials in Aqueous Solutions*, 1938, p.46.

OZONE

MOLECULAR FORMULA

O_3

MOLECULAR WEIGHT

48.000

Ref. *International Atomic Weights*, 1947.

MELTING POINT

Melting Point = −251.4°C

Ref. Riesenfeld and Schwab, *Ber.*, Vol.55 (1922), p.2095.
Riesenfeld, *Z. Elektrochem.*, Vol.29 (1922), p.119.

BOILING POINT

Boiling point = −111.5° ± 0.2°C at 760 mm Hg
−112.5° ± 0.2°C at 730 mm Hg

Ref. Briner and Biedermann, *Helv. Chim. Acta*, Vol.16 (1933), p.207.

DENSITY

Gas

d = 2.1445 gm/liter at 0°C and 760 mm Hg

Ref. Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, Vol.1 (1927), p.894.

Liquid

d = 1.71 ± 0.05 gm/ml at −111°C

Ref. *International Critical Tables*, Vol.3 (1928), p.21

VAPOR PRESSURE

Temperature (°K)	Pressure (mm Hg)
81.36	0.00686
83.24	0.01519
86.01	0.04211
89.94	0.08890

Ref. Spangenberg, *Z. physik. Chem.*, Vol.119 (1926), p.419.

Temperature (°K)	Pressure (mm Hg)
104.2	4.8
111.3	12.1
120.0	33.8
131.7	101.7
142.7	237.3
154.6	500.2
162.5*	760.0
164.7	840.8

* Interpolated.

Ref. Riesenfeld and Beja, *Z. anorg. u. allgem. Chem.*, Vol.132 (1923), p.179.

TRIPLE POINT VISCOSITY SURFACE TENSION COEFFICIENT OF THERMAL EXPANSION COEFFICIENT OF THERMAL CONDUCTIVITY DIPOLE MOMENT HEAT OF FUSION	No information

HEAT OF VAPORIZATION

ΔH_v = 2880 cal/mole at −111°C

Ref. Kelley, *U.S. Bur. Mines Bull.* *383* (1935).

HEAT OF FORMATION

ΔH_{298} = −33.93 ± 0.24 kcal/mole at constant pressure

Ref. Gunther, Wassmuth, and Schryver, *Z. physik. Chem.*, A, Vol.158 (1932), p.297.

HEAT OF COMBUSTION No information

CRITICAL DATA

t_c = −5°C
p_c = 67 atm
d_c = 0.537 gm/cc

Ref. Riesenfeld and Schwab, *Z. Physik*, Vol.11 (1922), p.12.

EQUATION OF STATE COMPRESSIBILITY	No information

HEAT CAPACITY OF GAS, C_p AND C_v

C_p = 10.94 cal/mole deg at 300°-476°K
(Calorimetric determination)

Ref. Lewis and von Elbe, *J. Chem. Phys.*, Vol. 2 (1934), p. 294.

RATIO OF SPECIFIC HEATS
HEAT CAPACITY OF LIQUID AND SOLID } No information

FREE ENERGY OF FORMATION

$\Delta F^\circ_{298.16}$ = 39.06 kcal/mole

Ref. Nat. Bur. Standards, *Selected Values of Chemical Thermodynamic Properties*, March 31, 1947.

FREE-ENERGY FUNCTION

Temperature (°K)	$-(F^\circ - E_0^\circ)/T$ (cal/mole deg)
298.1	48.545
500	52.966
1000	59.646
1500	64.041
2000	67.352
2500	70.024
3000	72.255

Ref. Shand and Spuer, *J. Am. Chem. Soc.*, Vol. 65 (1943), pp. 179, 2481.

HEAT-CONTENT FUNCTION No information

ENTROPY

$S^\circ_{298.1}$ = 56.80 ± 0.1 cal/mole deg

Ref. Shand and Spuer, *J. Am. Chem. Soc.*, Vol. 65 (1943), pp. 179, 2481.

REFERENCES

Arrangement

The bibliographical references are grouped under the various oxidizers considered, except for references to books, which often cover several materials and are grouped separately. References to the literature from which values have been taken for inclusion in these data sheets are denoted by an asterisk; others usually contain physical or thermodynamic data which have been included in later summary publications, or which have been superseded by values judged to be more reliable. Many of the less readily accessible references were consulted only in abstract form when the abstract showed that it was probably not worth while to have recourse to the original.

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