VI. PROPERTIES OF NITROGEN

CONTENTS

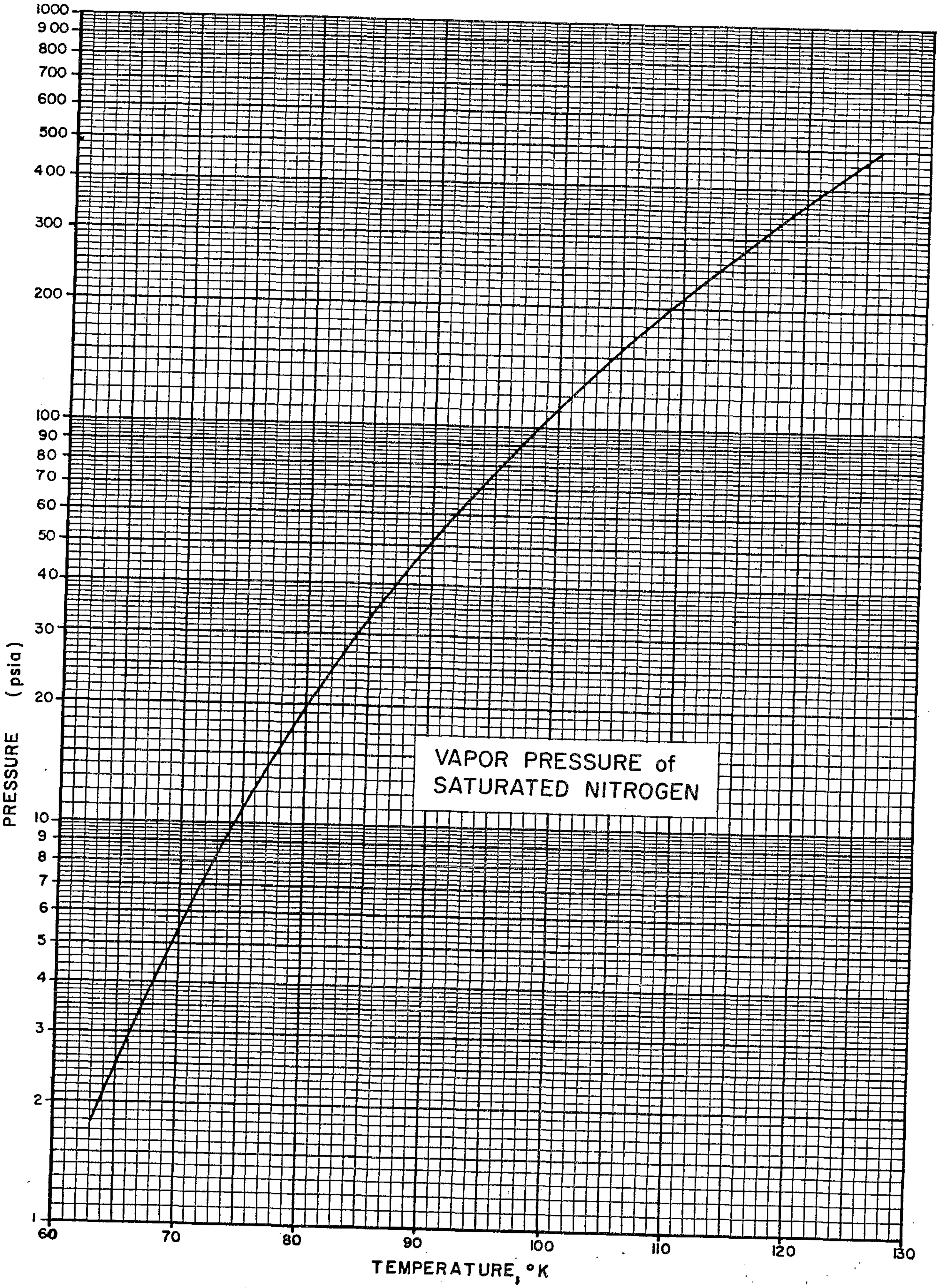
Vapor Pressure of Saturated Nitrogen

Temperature (K)	Pressure (ATM)	Pressure PSIA
63.150	0.123	1.808
64.000	0.144	2.116
65.000	0.172	2.528
66.000	0.203	2.983
67.000	0.240	3.527
68.000	0.281	4.130
69.000	0.328	4.820
70.000	0.380	5.585
71.000	0.439	6.453
72.000	0.505	7.422
73.000	0.579	8.509
74.000	0.660	9.699
75.000	0.750	11.022
76.000	0.849	12.477
77.000	0.958	14.079
77.364	1.000	14.696
78.000	1.077	15.828
79.000	1.207	17.738
80.000	1.349	19.825
81.000	1.503	22.088
82.000	1.670	24.542
83.000	1.850	27.188
84.000	2.045	30.053
85.000	2.254	33.125
86.000	2.480	36.446
87.000	2.721	39.988
88.000	2.980	43.794
89.000	3.256	47.850
90.000	3.551	52.185
91.000	3.864	56.785
92.000	4.198	61.694
93.000	4.553	66.911
94.000	4.929	72.437
95.000	5.327	78.286
96.000	5.748	84.473
97.000	6.192	90.998
98.000	6.662	97.905
99.000	7.156	105.165
100.000	7.676	112.806
101.000	8.223	120.845
102.000	8.798	129.295
103.000	9.401	138.157
104.000	10.032	147.430
105.000	10.694	159.159
106.000	11.387	167.343
107.000	12.111	177.983
108.000	12.867	189.093
109.000	13.657	200.703
110.000	14.480	212.798
111.000	15.339	225.423
112.000	16.233	238.560
113.000	17.164	252.242
114.000	18.133	266.483
115.000	19.140	281.281
116.000	20.188	296.683

Cont.

Temperature (K)	Pressure (ATM)	Pressure PSIA
117.000	21.276	312.672
118.000	22.407	329.293
119.000	23.581	346.546
120.000	24.800	364.461
121.000	26.065	383.051
122.000	27.378	402.347
123.000	28.741	422.378
124.000	30.156	443.173
125.000	31.625	464.761
126.000	33.150	487.172

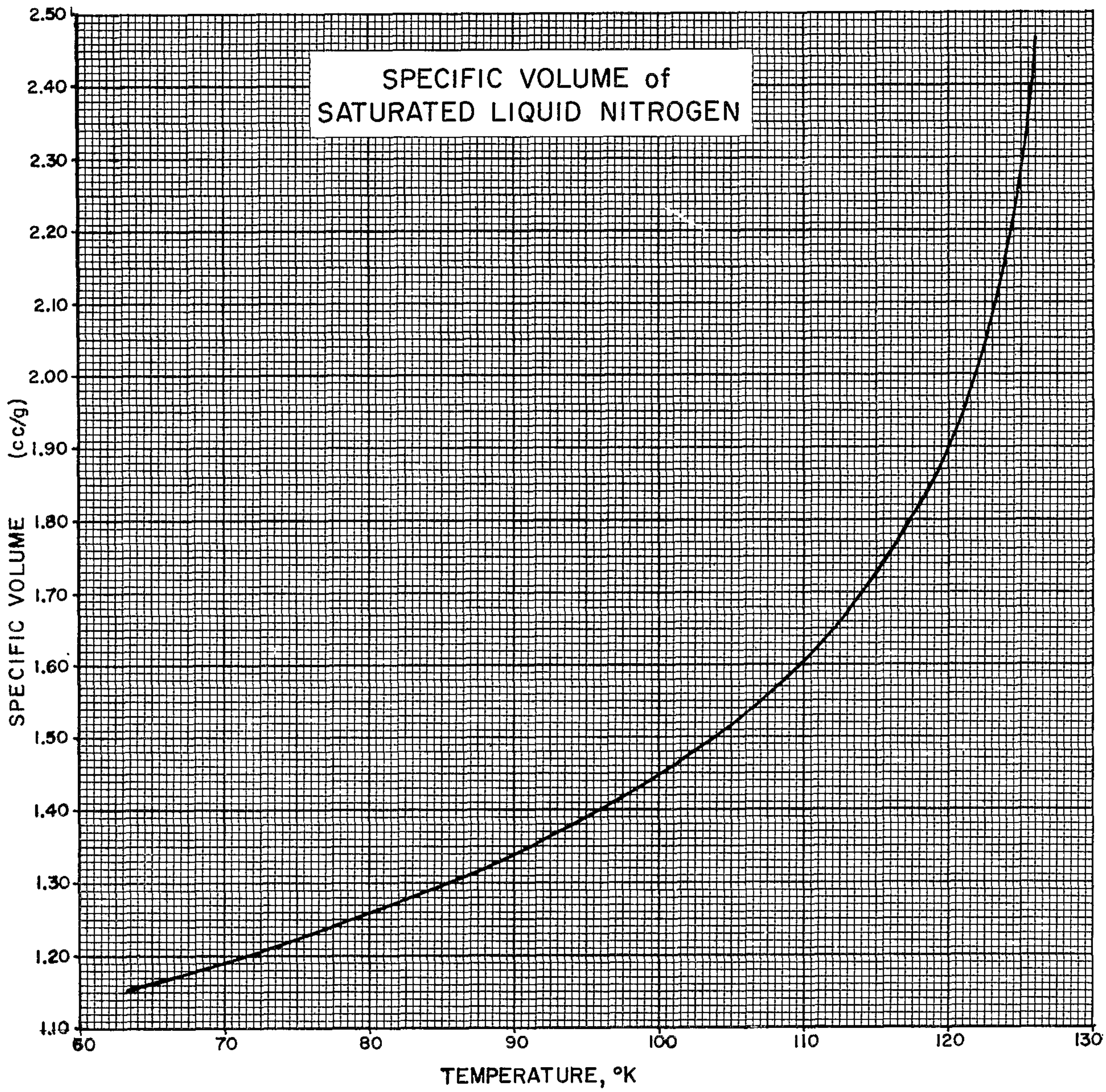
Reprinted from Table 2 NBS Tech. Note 129

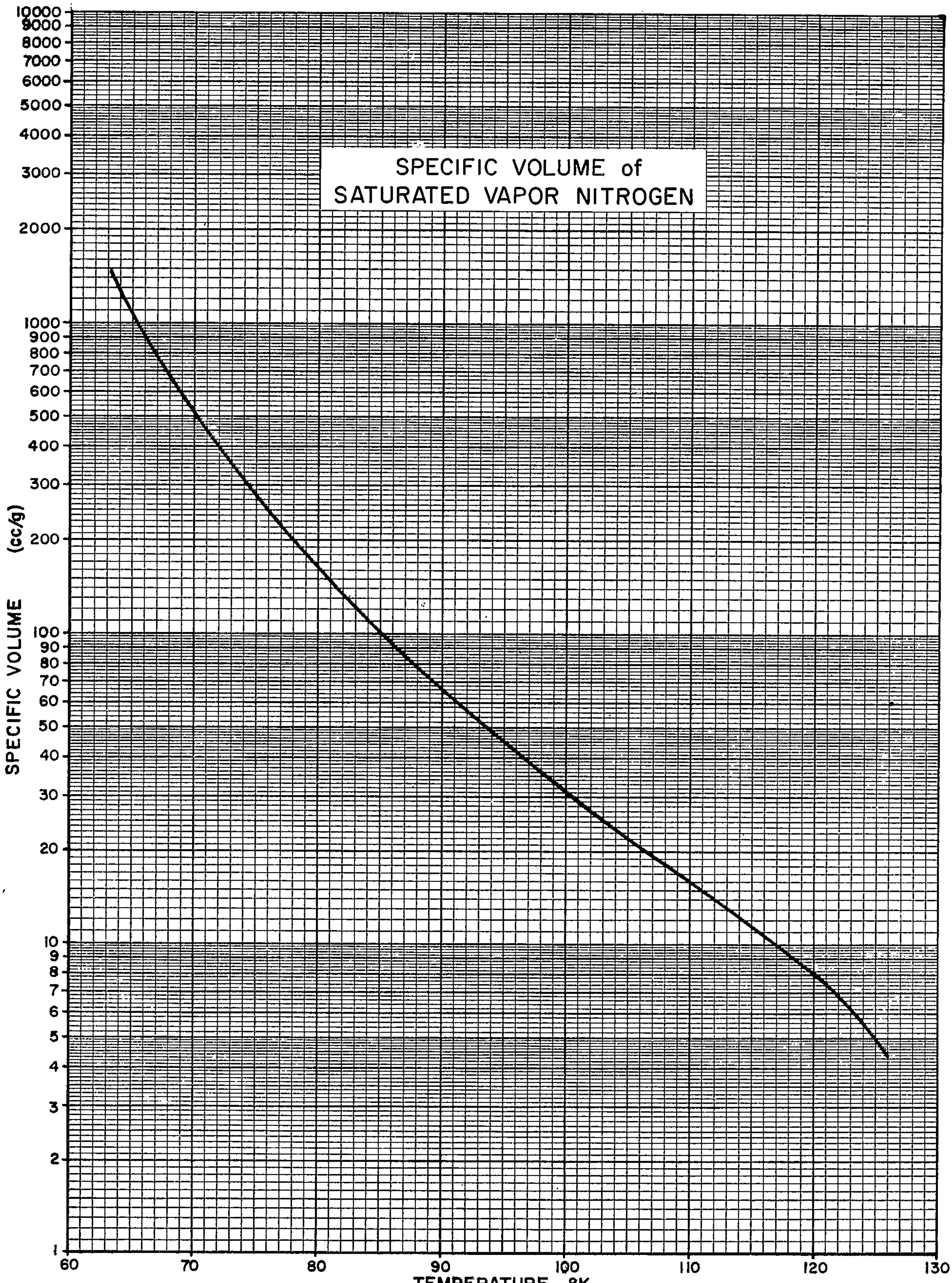

VAPOR PRESSURE of SATURATED NITROGEN
PRESSURE (psia)
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
60
70
80
90
100
110
120
130
TEMPERATURE, °K

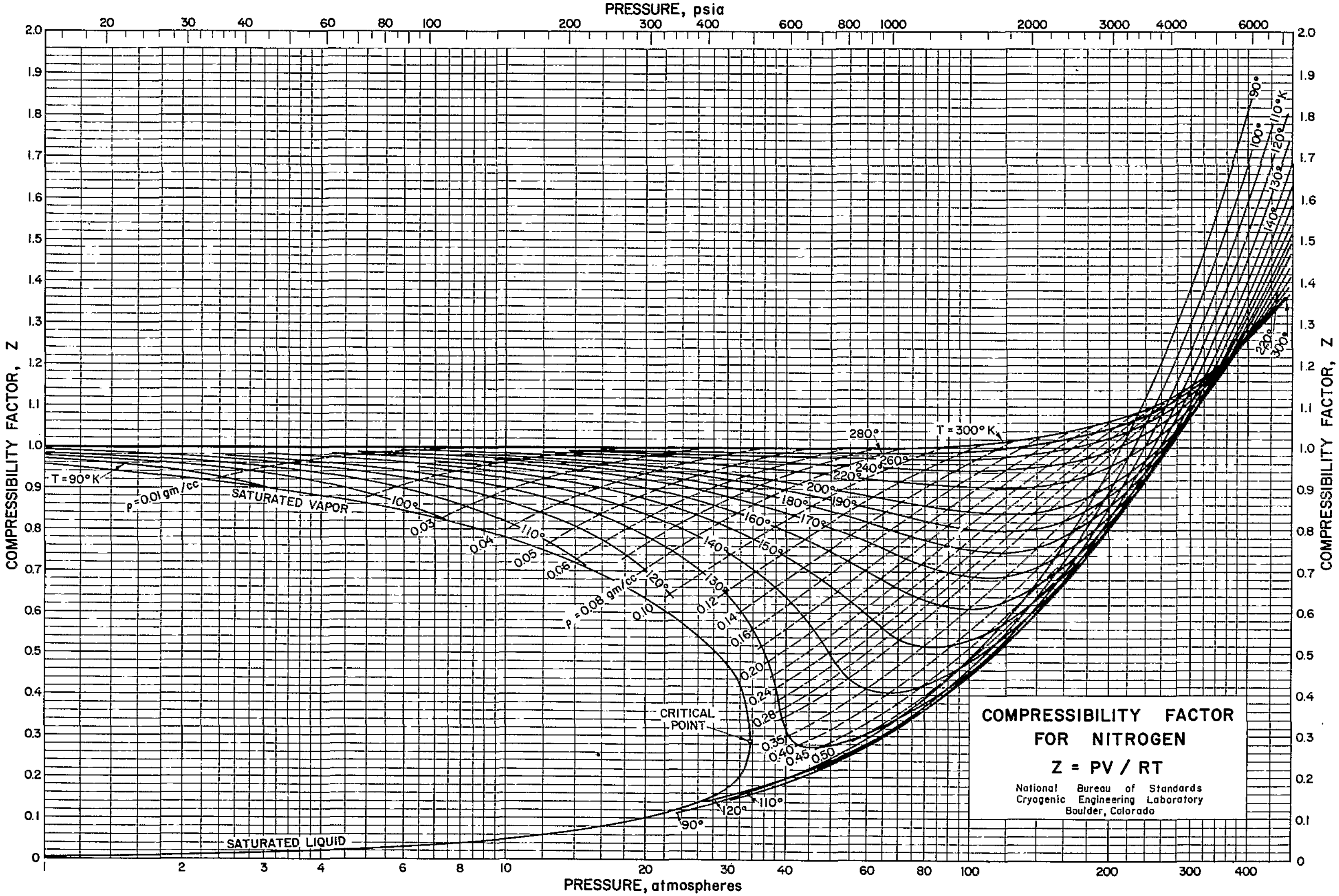
Specific Volume of Nitrogen
at Saturation

TEMPERATURE (K)	SPECIFIC VOLUME (CC/GM)	
	LIQUID	VAPOR
63.150	1.1515	1486.57
64.000	1.1560	1289.79
65.000	1.1615	1097.25
66.000	1.1670	938.648
67.000	1.1727	807.194
68.000	1.1784	697.613
69.000	1.1843	605.762
70.000	1.1903	528.365
71.000	1.1965	462.819
72.000	1.2028	407.042
73.000	1.2091	359.360
74.000	1.2157	318.419
75.000	1.2223	283.117
76.000	1.2291	252.555
77.000	1.2360	225.994
77.364	1.2386	217.194
78.000	1.2431	202.825
79.000	1.2503	182.544
80.000	1.2577	164.729
81.000	1.2652	149.030
82.000	1.2729	135.153
83.000	1.2807	122.848
84.000	1.2887	111.907
85.000	1.2970	102.151
86.000	1.3054	93.429
87.000	1.3140	85.611
88.000	1.3228	78.586
89.000	1.3318	72.258
90.000	1.3411	66.546
91.000	1.3506	61.378
92.000	1.3604	56.693
93.000	1.3705	52.436
94.000	1.3808	48.560
95.000	1.3915	45.026
96.000	1.4024	41.796
97.000	1.4138	38.839
98.000	1.4255	36.127
99.000	1.4376	33.636
100.000	1.4501	31.344
101.000	1.4631	29.231
102.000	1.4765	27.281
103.000	1.4906	25.478
104.000	1.5051	23.808
105.000	1.5204	22.259
106.000	1.5363	20.821
107.000	1.5529	19.482
108.000	1.5704	18.235
109.000	1.5889	17.071
110.000	1.6083	15.983
111.000	1.6289	14.964
112.000	1.6507	14.009
113.000	1.6741	13.111
114.000	1.6991	12.265
115.000	1.7260	11.467
116.000	1.7552	10.712
117.000	1.7870	9.995
118.000	1.8221	9.314
119.000	1.8611	8.662
120.000	1.9049	8.036
121.000	1.9551	7.432
122.000	2.0136	6.843
123.000	2.0839	6.263
124.000	2.1718	5.680
125.000	2.2890	5.074
126.000	2.4645	4.390

Reprinted from Table 2 NBS Tech Note 129


SPECIFIC VOLUME of
SATURATED LIQUID NITROGEN
SPECIFIC VOLUME (cc/g)
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
60
70
80
90
100
110
120
130
TEMPERATURE, °K


SPECIFIC VOLUME of
SATURATED VAPOR NITROGEN
SPECIFIC VOLUME (cc/g)
TEMPERATURE, °K
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
60
70
80
90
100
110
120
130


PRESSURE, psia
PRESSURE, atmospheres
COMPRESSIBILITY FACTOR, Z
COMPRESSIBILITY FACTOR FOR NITROGEN
Z = PV / RT
National Bureau of Standards
Cryogenic Engineering Laboratory
Boulder, Colorado
SATURATED VAPOR
SATURATED LIQUID
CRITICAL POINT
T = 90° K
T = 300° K
ρ = 0.01 gm/cc
ρ = 0.08 gm/cc

SPECIFIC HEAT (C_σ) of Liquid Nitrogen

(at saturation)

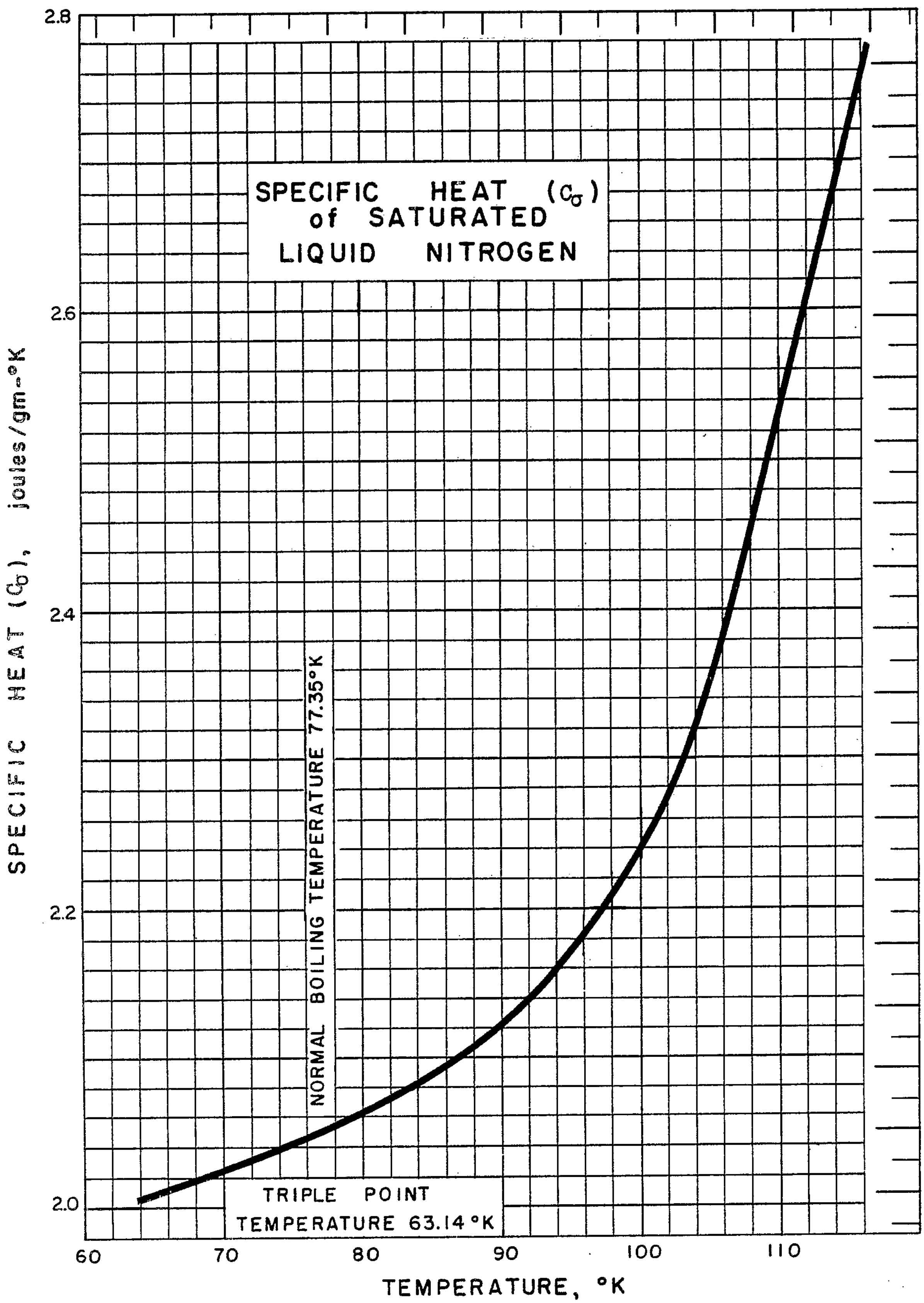
Sources of Data: Clusius, K., Z. physik Chem. Abt. B3, 41-79 (1929); Giauque, W. R. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933); Keesom, W. H. and Onnes, H. K., Comm. Phys. Lab. Univ. Leiden, Comm. No. 149a (1916); Wiebe, R. and Brevoort, M. J., J. Am. Chem. Soc. 52, 622-33 (1930).

Comments: The above references are not in complete agreement as can be seen by the table below. The graph on the previous page is an average of all the tabulated data.

Table of Selected Values

Temp. °K	C_σ cal/gm-mole -°K	Temp. °K	C_σ cal/gm-mole -°K
63.95	13.34	79.17	13.76
65.02	13.33	82.64	13.95
66.9	13.54	89.50	14.16
68.4	13.64	95.39	14.50
68.41	13.45	95.46	14.71
69.15	13.40	99.55	15.04
70.2	13.63	103.31	15.63
70.28	13.45	103.72	15.56
71.8	13.66	107.72	15.99
72.69	13.56	107.48	16.10
73.5	13.69	111.57	17.30
74.57	13.59	112.97	17.60
75.46	13.74	115.25	18.27
76.58	13.68	116.99	18.72
77.74	13.64		

*Reprinted from WADD TECH. REPORT 60-56

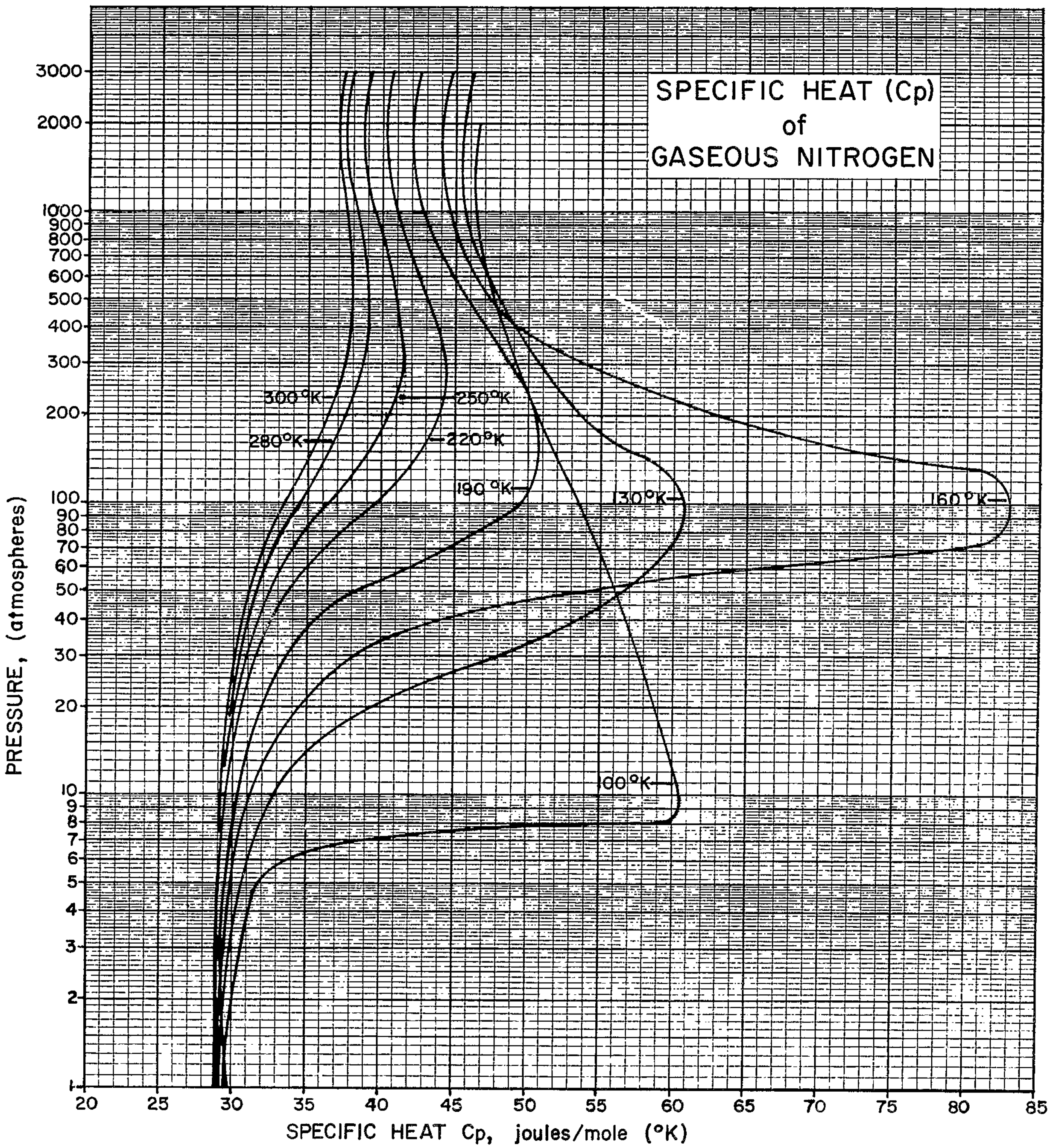

SPECIFIC HEAT (Cσ)
of SATURATED
LIQUID NITROGEN
SPECIFIC HEAT (Cσ), joules/gm-°K
2.8
2.6
2.4
2.2
2.0
NORMAL BOILING TEMPERATURE 77.35°K
TRIPLE POINT
TEMPERATURE 63.14°K
60
70
80
90
100
110
TEMPERATURE, °K

Specific Heat (C_p) of Gaseous Nitrogen

Source of Data:

Din, F.; Thermodynamic Functions of Gases, Vol. 3, London (1961)

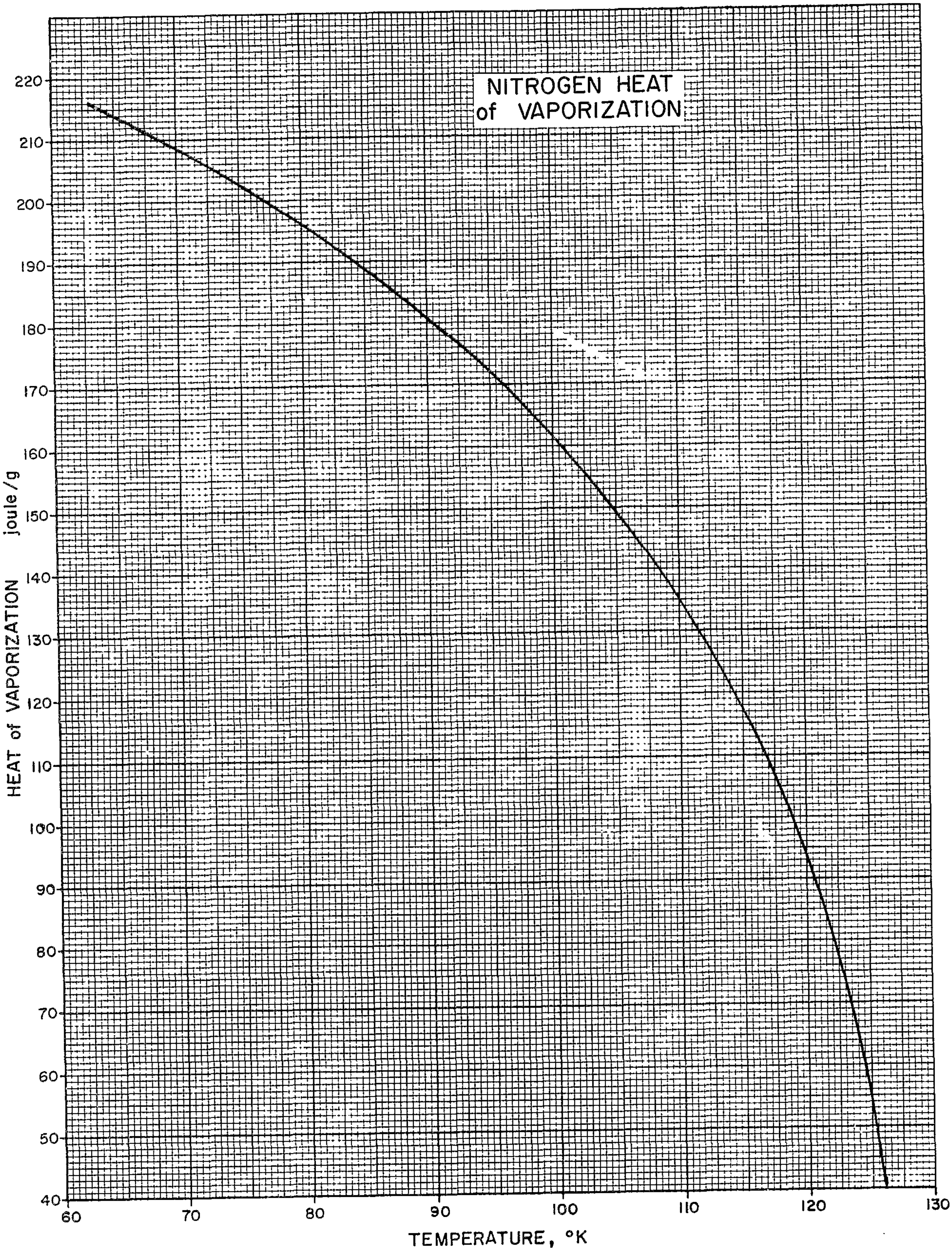
Pressure Atm	Specific Heat cp joules/male °K							
	100°	130°	160°	190°	220°	250°	280°	300°
1	29.58	29.27	29.07	29.98	28.95	28.95	28.96	28.98
3	30.62	29.95	29.51	29.26	29.11	29.07	29.05	29.06
5	31.94	30.68	29.98	29.54	29.27	29.18	29.14	29.14
10	60.63	32.80	31.25	30.27	29.70	29.48	29.39	29.35
30	57.88	-----	38.28	33.56	31.66	30.84	30.42	30.21
50	55.92	-----	54.3	38.01	33.87	32.39	31.54	31.12
100	53.37	60.9	83	49.50	39.60	36.35	34.42	33.45
200	50.44	53.7	63.1	50.45	43.89	40.21	37.62	36.25
300	49.11	50.97	54.3	48.55	44.25	41.31	38.94	37.61
400	48.29	49.19	49.52	47.13	43.97	41.17	39.09	37.95
600	47.28	47.13	46.41	44.96	42.79	40.55	38.86	37.96
800	46.79	46.28	45.21	43.63	41.81	40.06	38.60	37.82
1000	46.62	45.84	44.53	42.91	41.18	39.65	38.37	37.68
1500	46.46	45.59	44.10	42.17	40.32	38.83	37.80	37.28
2000	46.71	45.72	44.09	42.12	40.27	38.75	37.66	37.10
2500		45.91	44.27	42.31	40.40	38.86	37.74	37.18
3000		46.12	44.91	42.61	40.69	39.15	38.01	37.44


SPECIFIC HEAT (Cp)
of
GASEOUS NITROGEN
PRESSURE, (atmospheres)
SPECIFIC HEAT Cp, joules/mole (°K)
300°K
250°K
280°K
220°K
190°K
130°K
160°K
100°K
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
20
25
30
35
40
45
50
55
60
65
70
75
80
85

Nitrogen Heat of Vaporization

Source of Data: Table 2 NBS Technical Report 129

TEMPERATURE (K)	ENTHALPY (J/GM)		
	LIQUID	VAPOR	ΔH_{vap}
63.150	.000	216.061	216.061
64.000	1.744	216.885	215.141
65.000	3.802	217.846	214.045
66.000	5.864	218.797	212.933
67.000	7.931	219.737	211.807
68.000	10.000	220.666	210.666
69.000	12.072	221.582	209.511
70.000	14.144	222.486	208.341
71.000	16.218	223.375	207.157
72.000	18.291	224.249	205.959
73.000	20.364	225.109	204.745
74.000	22.435	225.951	203.516
75.000	24.506	226.777	202.271
76.000	26.576	227.585	201.009
77.000	28.644	228.374	199.730
77.364	29.397	228.657	199.260
78.000	30.712	229.144	198.432
79.000	32.779	229.893	197.115
80.000	34.845	230.621	195.776
81.000	36.912	231.328	194.416
82.000	38.980	232.011	193.031
83.000	41.050	232.671	191.621
84.000	43.122	233.307	190.184
85.000	45.198	233.917	188.718
86.000	47.279	234.500	187.221
87.000	49.366	235.057	185.690
88.000	51.461	235.585	184.124
89.000	53.564	236.084	182.520
90.000	55.677	236.553	180.876
91.000	57.802	236.991	179.189
92.000	59.940	237.396	177.456
93.000	62.092	237.767	175.675
94.000	64.261	238.104	173.843
95.000	66.449	238.405	171.957
96.000	68.656	238.669	170.013
97.000	70.884	238.893	168.009
98.000	73.135	239.077	165.942
99.000	75.411	239.219	163.808
100.000	77.714	239.316	161.603
101.000	80.044	239.368	159.324
102.000	82.405	239.372	156.967
103.000	84.797	239.325	154.528
104.000	87.223	239.226	152.003
105.000	89.684	239.070	149.386
106.000	92.157	238.855	146.698
107.000	94.660	238.578	143.918
108.000	97.195	238.234	141.039
109.000	99.766	237.819	138.053
110.000	102.375	237.327	134.953
111.000	105.025	236.753	131.728
112.000	107.727	236.090	128.363
113.000	110.470	235.328	124.858
114.000	113.281	234.459	121.178
115.000	116.153	233.471	117.318
116.000	119.096	232.348	113.252
117.000	122.104	231.074	108.969
118.000	125.199	229.624	104.425
119.000	128.401	227.970	99.569
120.000	131.733	226.073	94.340
121.000	135.330	223.877	88.547
122.000	139.385	221.303	81.918
123.000	143.846	218.228	74.382
124.000	148.834	214.443	65.609
125.000	154.646	209.527	54.881
126.000	161.990	202.287	40.296



NITROGEN HEAT
of VAPORIZATION
HEAT of VAPORIZATION joule/g
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
60
70
80
90
100
110
120
130
TEMPERATURE, °K

NITROGEN

Properties of Saturated Liquid and Saturated Vapor*

Temp	Pressure	Volume (cm³/g)		Enthalpy (j/g)		Entropy (j/g °K)		Temp	Pressure	Volume (cm³/g)		Enthalpy (j/g)		Entropy (j/g °K)	
°K	atm	Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	°K	atm	Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor	Sat Liquid	Sat Vapor
63.15[1]	.123	1.152	1487	0.0	216.1	.000	3.421	100	7.676	1.450	31.34	77.7	239.3	.955	2.571
65	.172	1.162	1097	3.8	217.8	.059	3.352	105	10.69	1.520	22.26	89.7	239.1	1.067	2.490
70	.380	1.190	528.4	14.1	222.5	.212	3.189	110	14.48	1.608	15.98	102.4	237.3	1.180	2.407
75	.750	1.222	283.1	24.5	226.8	.355	3.052	115	19.14	1.726	11.47	116.2	233.5	1.295	2.315
80	1.349	1.258	164.7	34.8	230.6	.487	2.934	120	24.80	1.905	8.036	131.7	226.1	1.419	2.206
85	2.254	1.297	102.2	45.2	233.9	.611	2.831	125	31.63	2.289	5.074	154.6	209.5	1.595	2.034
90	3.551	1.341	66.55	55.7	236.6	.729	2.739	126.2[2]	33.5	3.215	3.215				
95	5.327	1.392	45.03	66.4	238.4	.843	2.653								

[1] Triple point, [2] Critical point, * From published data, National Bureau of Standards, Technical Note 129 (Jan. 1962)

Properties of Liquid and Vapor*

Temp °K	P = 0.1 atm			P = 1 atm (Sat temp = 77.36 °K)			P = 4 atm (Sat temp = 91.41°K)			P = 7 atm (Sat temp = 98.69°K)			P = 10 atm (Sat temp = 103.95°K)		
T	v cm³/g	h j/g	s j/g°K	v cm³/g	h j/g	s j/g°K	v cm³/g	h j/g	s j/g°K	v cm³/g	h j/g	s j/g°K	v cm³/g	h j/g	s j/g°K
(Sat Liq)				1.239	29.4	.418	1.355	58.7	.761	1.434	74.7	.926	1.504	87.1	1.043
(Sat Vapor)				217.2	228.7	2.994	59.39	237.2	2.714	34.39	239.2	2.592	23.89	239.2	2.507
70	2040	223.3	3.592	1.190	14.1	.212	1.189	14.4	.210	1.189	14.7	.208	1.188	14.9	.206
80	2335	233.7	3.731	225.5	231.5	3.030	1.257	35.0	.485	1.255	35.2	.483	1.254	35.4	.481
90	2629	244.1	3.854	256.5	242.3	3.157	1.341	55.7	.729	1.339	55.8	.726	1.337	56.0	.723
100	2923	254.5	3.963	287.0	253.0	3.270	67.02	247.5	2.822	35.16	241.0	2.610	1.447	77.7	.952
110	3217	264.9	4.063	317.3	263.6	3.371	75.48	259.0	2.932	40.72	254.0	2.734	26.61	248.2	2.591
120	3511	275.3	4.153	347.4	274.2	3.463	83.66	270.3	3.030	45.87	266.2	2.840	30.66	261.7	2.708
130	3804	285.7	4.236	377.3	284.8	3.548	91.65	281.4	3.119	50.77	277.9	2.934	34.37	274.2	2.809
140	4098	296.1	4.313	407.1	295.3	3.626	99.50	292.4	3.200	55.52	289.4	3.019	37.90	286.2	2.898
150	4391	306.5	4.385	436.8	305.8	3.698	107.3	303.2	3.275	60.16	300.6	3.097	41.30	297.9	2.978
160	4684	316.9	4.452	466.4	316.2	3.766	114.9	314.0	3.344	64.72	311.7	3.168	44.62	309.3	3.052
170	4977	327.3	4.515	496.0	326.7	3.829	122.6	324.7	3.409	69.21	322.6	3.235	47.87	320.6	3.120
180	5271	337.7	4.574	525.6	337.1	3.889	130.2	335.3	3.470	73.66	333.5	3.297	51.06	331.7	3.184
190	5564	348.1	4.631	555.1	347.6	3.945	137.7	346.0	3.528	78.07	344.3	3.355	54.22	342.7	3.243
200	5857	358.5	4.684	584.6	358.0	3.999	145.2	356.5	3.582	82.45	355.1	3.410	57.35	353.6	3.299
220	6443	379.2	4.783	643.5	378.9	4.098	160.2	377.7	3.683	91.14	376.4	3.512	63.53	375.2	3.402
240	7029	400.0	4.873	702.3	399.7	4.189	175.1	398.7	3.774	99.76	397.7	3.605	69.64	396.6	3.495
260	7615	420.8	4.956	761.1	420.5	4.272	189.9	419.7	3.858	108.3	418.8	3.689	75.70	417.9	3.581
280	8201	441.6	5.033	819.8	441.3	4.349	204.7	440.6	3.936	116.9	439.9	3.767	81.72	439.1	3.659
300	8787	462.3	5.105	878.5	462.1	4.421	219.5	461.5	4.008	125.4	460.9	3.840	87.72	460.3	3.732

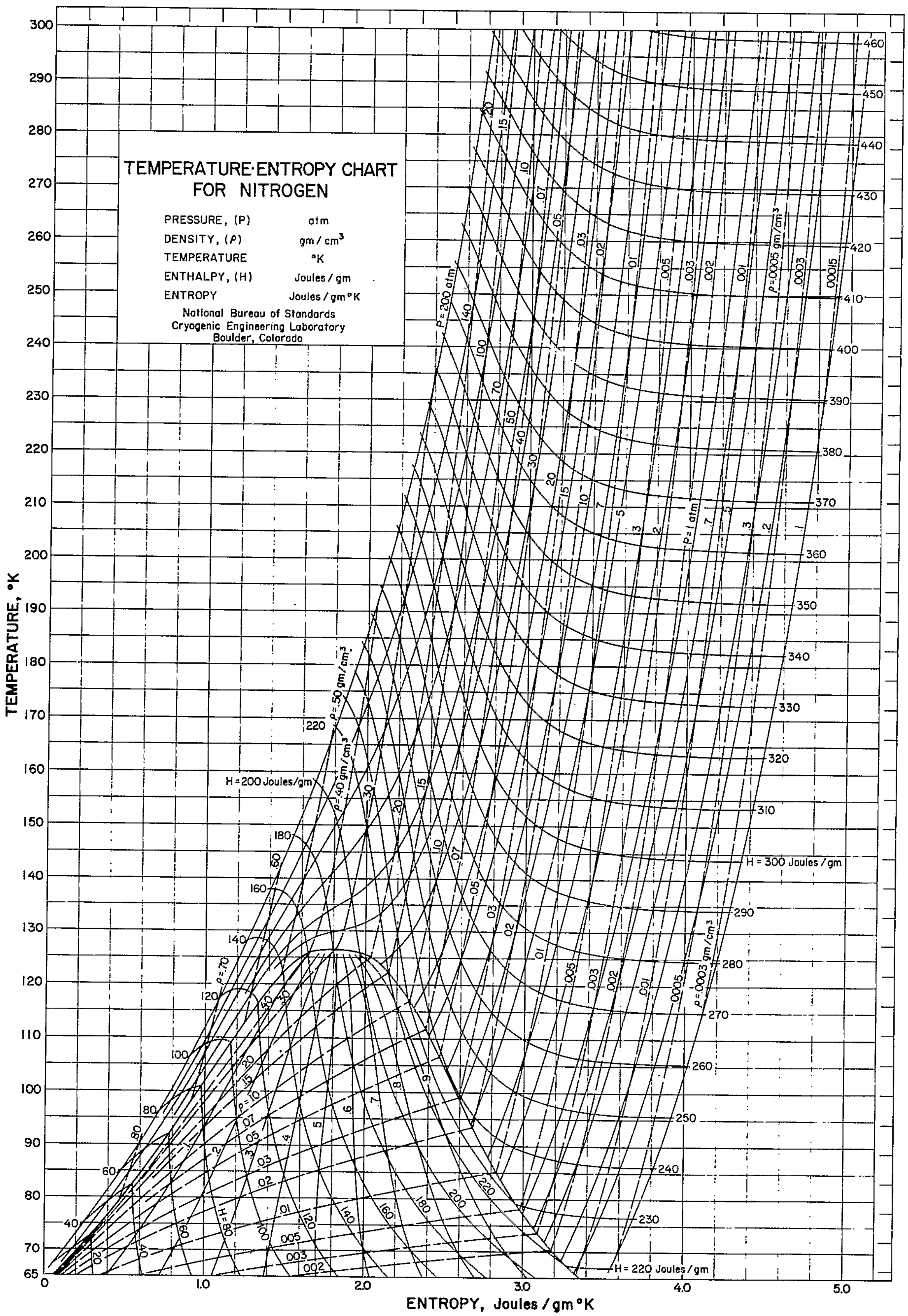
Temp °K	P = 40 atm			P = 70 atm			P = 100 atm			P = 140 atm			P = 200 atm		
70	1.180	17.2	.189	1.173	19.6	.172	1.167	22.1	.156	1.158	25.4	.135	1.1-7	30.1	.107
80	1.243	37.5	.459	1.232	39.7	.439	1.223	41.9	.420	1.211	44.9	.397	1.195	49.6	.364
90	1.318	57.6	.696	1.302	59.4	.672	1.288	61.3	.649	1.271	64.1	.622	1.249	68.4	.586
100	1.414	78.4	.915	1.387	79.6	.884	1.365	81.1	.857	1.340	83.4	.825	1.309	87.2	.784
110	1.545	101.1	1.131	1.496	101.0	1.088	1.459	101.6	1.053	1.420	103.2	1.014	1.377	106.3	.966
120	1.768	126.4	1.352	1.648	122.9	1.279	1.579	121.9	1.231	1.518	122.3	1.181	1.454	124.5	1.124
130	3.102	185.6	1.820	1.898	149.6	1.493	1.745	145.0	1.416	1.638	143.3	1.351	1.544	144.0	1.282
140	6.472	243.3	2.253	2.430	184.4	1.751	1.991	170.9	1.608	1.792	165.7	1.516	1.649	164.3	1.432
150	8.071	265.3	2.406	3.418	222.5	2.014	2.367	198.7	1.799	1.992	188.3	1.672	1.771	184.2	1.569
160	9.355	282.7	2.518	4.408	251.2	2.200	2.875	226.3	1.978	2.244	211.3	1.820	1.914	204.0	1.697
170	10.49	298.0	2.611	5.253	273.1	2.332	3.430	251.2	2.129	2.543	233.9	1.957	2.078	223.7	1.816
180	11.54	312.1	2.692	5.996	291.5	2.438	3.969	272.7	2.252	2.871	255.4	2.081	2.260	243.2	1.928
190	12.53	325.5	2.764	6.672	307.9	2.527	4.476	291.8	2.355	3.207	275.5	2.189	2.456	262.3	2.031
200	13.47	338.3	2.830	7.301	323.1	2.604	4.951	309.0	2.443	3.540	294.1	2.285	2.661	280.7	2.125
220	15.27	362.9	2.947	8.465	351.0	2.738	5.829	340.0	2.591	4.179	327.8	2.445	3.078	315.3	2.291
240	16.99	386.6	3.050	9.546	376.9	2.850	6.637	368.1	2.713	4.778	358.0	2.577	3.491	347.2	2.429
260	18.65	409.5	3.142	10.57	401.6	2.949	7.397	394.4	2.819	5.344	386.1	2.689	3.891	376.9	2.548
280	20.28	432.1	3.225	11.56	425.5	3.038	8.124	419.5	2.912	5.885	412.6	2.788	4.276	404.8	2.652
300	21.87	454.3	3.302	12.52	448.7	3.118	8.825	443.7	2.995	6.405	438.0	2.875	4.650	431.5	2.744

* From published data, National Bureau of Standards, Technical Note 129 (Jan 1962)
Bold horizontal line indicates phase change (liquid above, vapor below the line).

Conversions for Units, to Equivalent in British System of Units:

To convert temperature in degrees Kelvin (°K) to degrees Rankine (°R), multiply (°K) by 1.8
To convert pressure in atmospheres (atm) to (psia), multiply (atm) by 14.696
To convert volume (v) in cubic centimeters per gram (cm³/g) to (cu ft/lb), multiply (cm³/g) by .016018
To convert enthalpy (h) in joules per gram (j/g) to (Btu/lb), multiply (j/g) by .42993
To convert entropy (s) in joules per gram °K (j/g°K) to (Btu/lb°R), multiply (j/g°K) by .23885

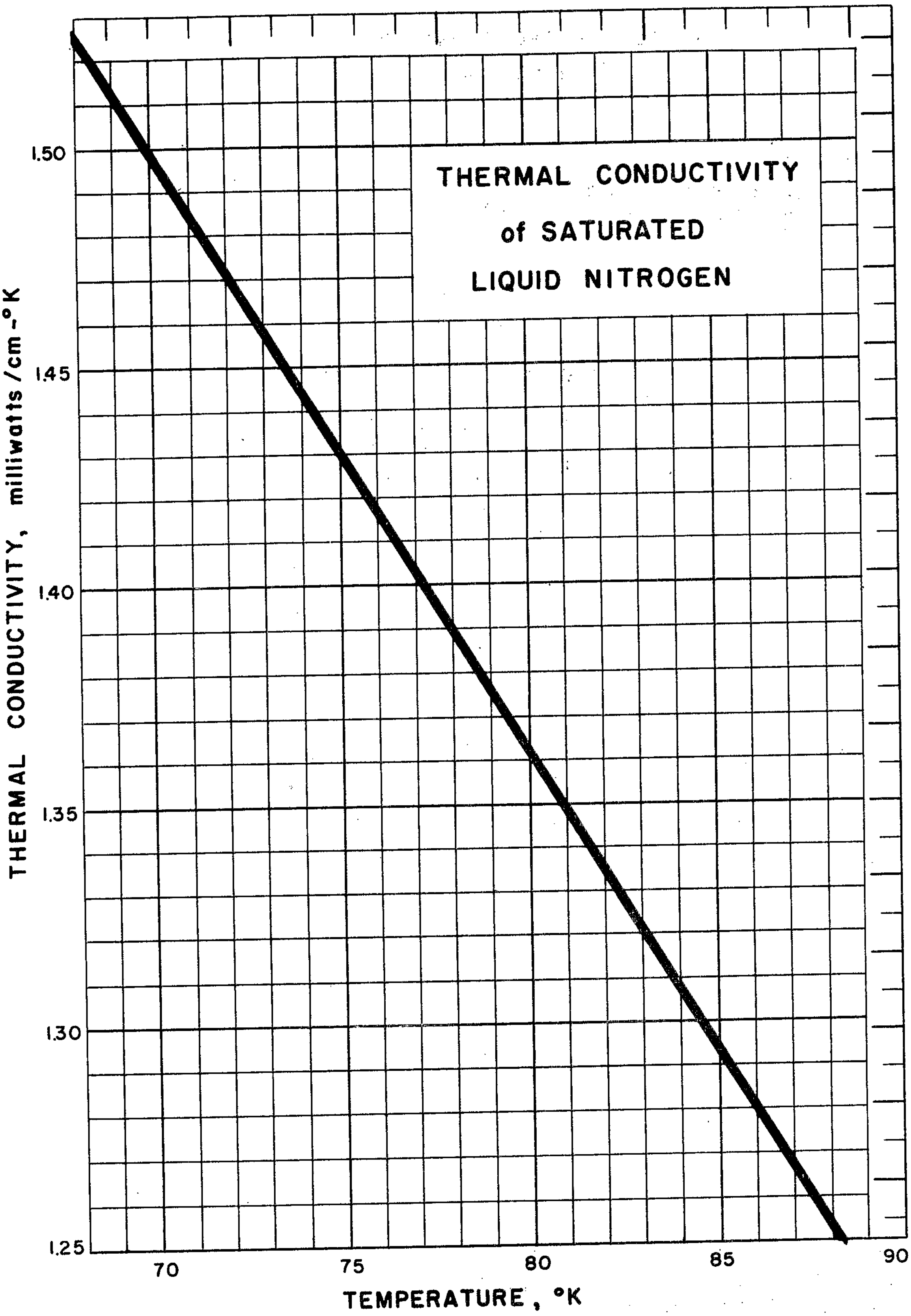
B-62365



Prepared from National Bureau of Standards, Technical Note, TN 1[illegible] (PL [illegible]) January 19[illegible].
"The Thermodynamic Properties of Nitrogen from [illegible] to [illegible]°K between [illegible] and [illegible] Atmospheres".
Thomas R. Strobridge, by the Cryogenic Data Center, National Bureau of Standards, Boulder, Colorado

R. D. McCarty, L. J. Fricks (January 19[illegible])

NBS FILE No. [illegible]


THERMAL CONDUCTIVITY
of SATURATED
LIQUID NITROGEN
THERMAL CONDUCTIVITY, milliwatts /cm -°K
1.50
1.45
1.40
1.35
1.30
1.25
70
75
80
85
90
TEMPERATURE, °K

THERMAL CONDUCTIVITY of LIQUID NITROGEN
(at saturation)

Source of Data:

Powers, R. W., Mattox, R. W. and Johnston, H. L., J. Am. Chem. Soc. 76, 5968-73 (1954).

Table of Selected Values

Temperature °K	Thermal Conductivity cal/cm·sec-°K
68.68	3.64×10^{-4}
69.92	3.53 "
70.94	3.59 "
73.66	3.44 "
76.26	3.39 "
77.66	3.33 "
78.73	3.31 "
81.11	3.18 "
81.77	3.15 "
83.77	3.12 "
86.44	3.07 "
88.12	3.00 "

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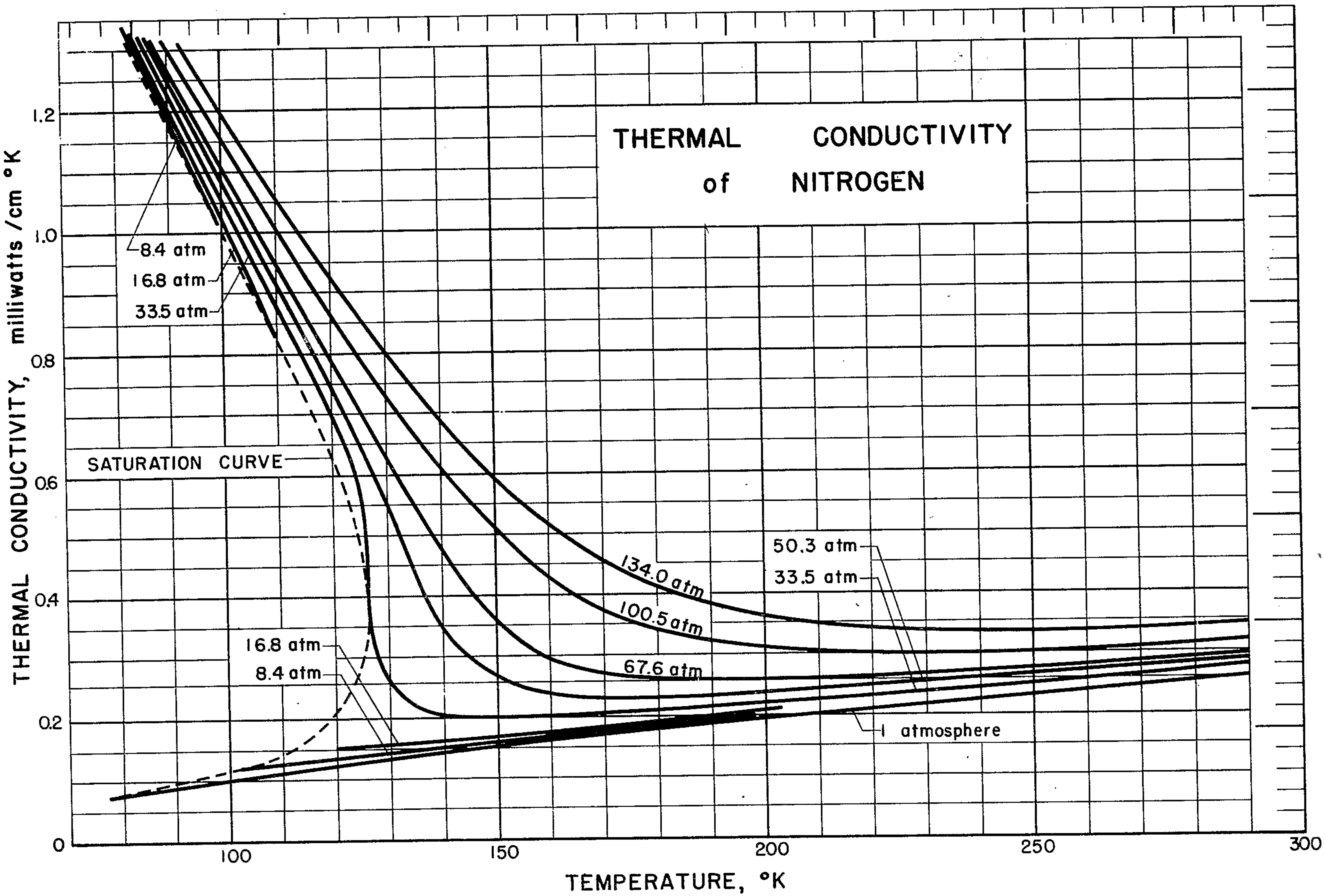
THERMAL CONDUCTIVITY of NITROGEN
THERMAL CONDUCTIVITY, milliwatts /cm °K
TEMPERATURE, °K
0
0.2
0.4
0.6
0.8
1.0
1.2
100
150
200
250
300
8.4 atm
16.8 atm
33.5 atm
SATURATION CURVE
134.0 atm
100.5 atm
67.6 atm
50.3 atm
33.5 atm
16.8 atm
8.4 atm
1 atmosphere

THERMAL CONDUCTIVITY of NITROGEN
(Liquid and Gas)

Source of Data:

Borovik, E., Matveev, A. and Panina, E., J. Tech. Phys. (U.S.S.R.) 10, 988-98 (1940).

Franck, E. U., Z. Elektrochem. 55, 636-43 (1951).

Keyes, F. G., Trans. ASME 77, 1395-6 (1955).

Lenoir, J. M. and Comings, E. W., Chem. Eng. Progr. 47, 223-31 (1951).

Uhlir, A. Jr., J. Chem. Phys. 20, 463-72 (1952).

Ziebland, H. and Burton, J. T. A., Brit. J. Appl. Phys. 9, 52-9 (1958).

Comments:

At low pressures and temperatures between 90 and 823°K, the following equation may be used to calculate the thermal conductivity of gaseous nitrogen, where k is in cal/cm-sec-°K and T is in °K.

$$k = \frac{6.15 \times 10^{-6} \sqrt{T}}{1 + (235.5/T)\,(10^{-12/T})}$$

Table of Selected Values

Temp. °K	Thermal Cond. cal/cm-sec-°K
1 atm	
92	0.208 x10^{-4}
100	0.223 "
125.9	0.300 "
134.1	0.315 "
150.0	0.329 "
158.6	0.370 "
172.3	0.400 "
187.9	0.430 "
200.0	0.437 "
202.0	0.460 "
250.0	0.528 "
273.0	0.571 "
300.0	0.616 "
314.3	0.647 "
8.4 atm	
*88.2	2.79 x 10^{-4}
158.5	0.385 "
172.2	0.410 "
187.9	0.440 "
201.9	0.470 "

Temp. °K	Thermal Cond. cal/cm-sec-°K
16.8 atm	
*87.7	2.84 x 10^{-4}
124.7	0.365 "
133.4	0.360 "
158.3	0.400 "
172.0	0.425 "
187.4	0.455 "
201.8	0.480 "
31.3 atm	
164.2	0.460 x 10^{-4}
188.8	0.490 "
202.5	0.510 "
33.5 atm (Pc)	
76.6	3.32 x 10^{-4}
85.0	3.00 "
87.7	2.90 "
88.7	2.92 "
97.3	2.56 "
105.8	2.17 "
111.0	2.01 "
114.6	1.810 "

Temp. °K	Thermal Cond. cal/cm-sec-°K
116.1	1.750 x 10^{-4}
120.6	1.555 "
121.6	1.56 "
124.1	1.410 "
124.1	1.415 "
124.2	1.390 "
126.0	0.85 "
128.4	0.660 "
129.9	0.600 "
131.2	0.565 "
132.0	0.56 "
132.6	0.506 "
138.3	0.475 "
143.4	0.454 "
145.0	0.47 "
147.0	0.470 "
147.0	0.50 "
154.2	0.438 "
157.6	0.460 "
171.0	0.465 "
171.6	0.475 "
187.3	0.495 "
201.5	0.515 "

*Liquid

THERMAL CONDUCTIVITY of NITROGEN (cont.)

Temp. °K	Thermal Cond. cal/cm-sec-°K
50.3 atm	
105.9	2.25 x 10^{-4}
116.4	1.830 "
125.9	1.440 "
127.0	1.380 "
128.4	1.330 "
128.9	1.355 "
129.5	1.335 "
136.2	1.085 "
136.9	0.890 "
139.0	0.835 "
139.0	0.885 "
139.3	0.805 "
139.4	0.810 "
147.3	0.645 "
156.9	0.555 "
67.0 atm	
76.9	3.40 x 10^{-4}
83.3	3.18 "
85.0	3.12 "

Temp. °K	Thermal Cond. cal/cm-sec-°K
87.3	2.98 x 10^{-4}
89.8	2.96 "
98.3	2.60 "
100.7	2.57 "
105.6	2.32 "
114.5	2.03 "
116.4	1.935 "
125.0	1.57 "
126.8	1.555 "
127.2	1.63 "
132.0	1.22 "
142.1	1.10 "
145.0	0.88 "
145.1	0.940 "
155.3	0.730 "
169.0	0.641 "
171.0	0.60 "
171.1	0.620 "
184.3	0.597 "
186.5	0.595 "
201.0	0.600 "

Temp. °K	Thermal Cond. cal/cm-sec-°K
100.5 atm	
87.2	3.08 x 10^{-4}
98.2	2.70 "
105.6	2.46 "
116.1	2.11 "
126.6	1.755 "
145.1	1.257 "
155.2	1.065 "
170.9	0.845 "
185.8	0.755 "
200.5	0.710 "
134.0 atm	
87.3	3.16 x 10^{-4}
97.9	2.82 "
105.4	2.57 "
114.5	2.24 "
126.3	1.935 "
144.8	1.530 "
154.9	1.260 "
170.5	1.040 "
185.5	0.915 "
200.8	0.840 "

Press. atm.	Temp. °K	Thermal Cond. cal/cm-sec-°K	Press. atm.	Temp. °K	Thermal Cond. cal/cm-sec-°K
3.9	92.0	0.223 x 10^{-4}	56.5	314.3	0.705 x 10^{-4}
5.8	77.2	3.23 "	73.9	314.3	0.725 "
7.6	273.1	0.582 "	82.7	314.3	0.737 "
8.2	76.4	3.31 "	96.3	314.3	0.758 "
10.6	273.1	0.586 "	121.7	314.3	0.786 "
10.9	91.8	2.70 "	136.0	314.3	0.824 "
27.6	80.9	3.18 "	144.7	314.3	0.828 "
28.1	80.7	3.19 "	167.6	314.3	0.861 "
38.4	107.2	2.23 "	170.3	314.3	0.865 "
38.7	121.3	1.65 "	196.1	314.3	0.915 "
47.6	314.3	0.691 "	205.7	314.3	0.918 "

T_c = 126.135°K
P_c = 33.49 atm

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DIELECTRIC CONSTANT OF LIQUID NITROGEN

Sources of Data:

Ebert, L., and Keesom, W. H. (1926), Voorloopige metingen van de dielectrische constante van vloeibare en vaste stikstof. (Preliminary Measurements of the Dielectric Constants of Liquid and Solid Nitrogen.), Verslag. Gewone Vergader. Afdel. Natuurk. Koninkl. Ned. Akad. Wetenschap. Amsterdam 35, 875-9; Proc. Koninkl. Nederland Akad. Wet. 29, 1188 (1926); Communs. Phys. Lab. Univ. Leiden No. 182d; C.A. 21, 1401 (1927).

McLennan, J. C., Jacobsen, R. C., and Wilhelm, J. G. (1930), Dielectric Constants of Liquefied Gases., Trans. Roy. Soc. Canada [3], 24, 37-46; C.A. 25, 2340 (1931).

Guillien, R., (1938), Sur la variation de la constante diélectrique a la solidification des liquides homopolaires. (Regarding the Change of the Dielectric Constant of Homopolar Liquids on Solidification.), Compt. rend. 207, 393-5; C.A. 32, 7791 (1938).

Guillien, R. (1940), La constante diélectrique au voisinage du point de fusion. (The Dielectric Constant in the Region of the Point of Fusion.), J. Phys. Radium [8], 1, 29-33; C.A. 34, 3145 (1940).

Maryott, A. A., and Smith, E. R. (1951), Table of Dielectric Constants of Pure Liquids., Natl. Bur. Standards Circ. No. 514; C.A. 46, 2357 (1952).

Comments:

Ebert and Keesom determined the zero capacity of their condenser before and after the measurement with liquid nitrogen between the plates and list ϵ_1, the value when determined before, and ϵ_2, when determined after the experiment. They also report certain values between parentheses, and state that those values without parentheses are to be preferred. They report data between 63.9 and 76.54°K.

McLennan et al. obtained values between 63.3 and 78.5°K which, according to Guillien, are all too high.

Guillien states: "The study of the dielectric constant of carbon bisulphide having shown me (Compt. rend. 206, 1001 (1938)) that, contrary to what had previously been published, (H. Isuardi, Z. Physik 9, 178 (1922); J. Masur, Acta Phys. Polon. 1, 47 (1932)) that this constant increases on solidification, I asked myself if all homopolar substances show this phenomenon (at least in those cases where the density is greater in the solid state. - - - However, Isuardi had indicated that carbon disulphide, toluene, metaxylene and carbon tetrachloride have a dielectric constant which decreases on solidification. According to Ebert and Keesom's measurements this should also be true for nitrogen." Guillien showed that it was necessary to bring about solidification slowly in order to observe the increase in the dielectric constant. He therefore reinvestigated toluene, metaxylene and carbon tetrachloride, and observed that in all three cases, as in the preceding case, there is an increase in the dielectric constant on solidification. The increase was most easily observed in the case of carbon tetrachloride.

He then restudied the case of nitrogen, which was very favorable for such an investigation, because the crystals are not very compact, and hence permit the liquid to penetrate during solidification. Here again he found an increase in ϵ on solidification. During these studies he also determined the change of ϵ with temperature of liquid nitrogen. His curve, based on many points falling close to the curve, is definitely below that of Mc Lennan et al., but his data agrees generally with that of Ebert and Keesom. His values are within the temperature range 63.3 to 78°K.

Maryott and Smith select a value of 1.454 at 70.15°K and 1 atmosphere.

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DIELECTRIC CONSTANT OF LIQUID NITROGEN

(cont.)

Ebert and Keesom (1926)

(Saturated Liquid)

Temp. °K	Dielectric Constant
63.9	1.472
63.9	(1.461)
66.7	1.464
66.7	(1.453)
74.8	1.451
74.8	1.438
76.54	(1.451)
76.54	1.440

McLennan et al. (1930)

(Saturated Liquid)

Temp. °K	Dielectric Constant
78.5	1.455
77.9	1.456
77.1	1.457
76.2	1.462
75.3	1.465
73.8	1.469
72.3	1.472
70.5	1.478
69.6	1.481
69.5	1.480
68.3	1.484
66.0	1.492
63.3	1.500

Guillien (1938)

(Saturated Liquid)

Temp. °K	Dielectric Constant
78.0	1.4318
75.0	1.4400
72.0	1.4483
69.0	1.4568
66.0	1.4657
63.3	1.4746

DIELECTRIC CONSTANT OF GASEOUS NITROGEN

Sources of Data:

Scheel, K. (1907), Bestimmung der Breckungsexponenten von Gasen bei Zimmertemperatur und bei der Temperature der Flüssigen Luft. (Determination of the Index of Refraction of Gases at Room Temperature and at the Temperature of Liquid Air.), Verhandl. deut. physik. Ges. 9, 24-36.

Tangl, K. (1908), Über die Dielektrizitätskonstante einiger Gase bei hohem Druck. (Concerning the Dielectric Constants of Several Gases at High Pressure.), Ann. Physik 26, 59-78; C.A. 2, 2492 (1908).

*Cuthbertson, C., and Cuthbertson, M. (1910) On the Refraction and Dispersion of Air, Oxygen, Nitrogen and Hydrogen and their Relations., Proc. Roy. Soc. (London) 83A, 151; P.A. 13, 362 (1910).

*Koch, J. (1913), The Dispersion of Gaseous Substances in the Ultraviolet Spectrum., Arkiv Mat. Astron. Fysik 8, No. 20; C.A. 7, 2711 (1913).

*Koch, J. (1913), The Dispersion of Light in Gases in the Ultraviolet Region., Arkiv Mat. Astron. Fysik 9, No. 6; P.A. 17, 233 (1914).

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Fritts, E. C. (1924), A Determination of the Dielectric Constants of Five Gases by a High Frequency Method., Phys. Rev. 23, 345-56; C.A. 18, 1423 (1924).

Zahn, C. T. (1924), The Electric Moment of Gaseous Molecules of Halogen Hydrides., Phys. Rev. 24, 400-17; C.A. 19, 426 (1925).

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Uhlig, H. H., Kirkwood, J. G., and Keyes, F. G. (1933), The Dependence of Dielectric Constants of Gases on Temperature and Density., J. Chem. Phys. 1, 155-9; C.A. 27, 1790 (1933).

Watson, H. E., Rao, G. G., and Ramaswamy, K. L. (1934), The Dielectric Coefficients of Gases. - Part II. The Lower Hydrides of Carbon and Silicon, Oxygen, Nitrogen, Oxides of Nitrogen and Carbon, and Fluorides of Silicon and Sulphur., Proc. Roy. Soc. 143A, 558-88; C.A. 28, 2583 (1934).

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Bennett, C. E. (1934), Precise Measurements of Dispersion in Nitrogen., Phys. Rev. 45, 200-7; C.A. 28, 3305 (1934).

Fox, G. W., and Ryan, A. A. (1939), The Dielectric Constants of Ammonia, Nitrogen, and Carbon Dioxide at Ultra-High Frequency., Phys. Rev. 56, 1132-6; C.A. 34, 2221 (1940).

Bennett, C. E. (1940), Optical Dispersion and Molar Refraction at Zero Frequency for Compressed Nitrogen, Argon, and Carbon Dioxide Measure nctions of Density., Phys. Rev. 58, 263-6; C.A. 34, 6866 (1940).

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Miller, J. G. (1948), VI - Dielectric-Constant and Refractivity Data., Trans. A.S.M.E. 70, 645-9; C.A. 42, 7117 (1948).

Birnbaum, G., Kryder, S. J., and Lyons, H. (1951), Microwave Measurements of the Dielectric Properties of Gases., J. Appl. Phys. 22, 95-102; C.A. 45, 3213 (1951).

Essen, L., and Froome, K. D. (1951), The Refractive Indices and Dielectric Constants of Air and its Principal Constituents at 24,000 Mc/s., Proc. Phys. Soc. (London) 64B, 862-75; Nature 167, 512-3; C.A. 45, 7397 (1951).

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Heineken, F. W., and Bruin, F. (1954), Some Measurements on Refractive Indices of Gases in the Microwave Region., Physica 20, 350-60; C.A. 49, 686 (1955).

Froome, K. D. (1955), The Refractive Indices of Water Vapor, Air, Oxygen, Nitrogen, and Argon at 72 K Mc/s., Proc. Phys. Soc. (London) 68B, 833-5; C.A. 50, 6118 (1956).

De Wijn, H. W., and Heineken, F. W. (1959), The Lorentz-Lorenz Functions of Argon, Nitrogen and Carbon Dioxide up to 50 Atmospheres at a Wavelength of 12mm., Physica 25, 615-25; C.A. 54, 5196 (1960).

Johnston, D. R., Oudemans, G. J., and Cole, R. H. (1960), Dielectric Constants of Imperfect Gases. I. Helium, Argon, Nitrogen, and Methane., J. Chem. Phys. 33, 1310-17; C.A. 55, 15032 (1961).

Comments:

Scheel reported a dielectric constant of 1.00058122 at 0°C and 1 atmosphere.

Tangl determined dielectric constants of gaseous nitrogen at 20°C at pressures up to 100 atmospheres. He calculated the value at 0°C and 1 atmosphere to be 1.000581, which he found to be almost identical with the value of 1.000580 determined from the index of refraction for the sodium line ($1.000290^2 = 1.000580$).

Bodareu made measurements at pressures between 87 and 226 atmospheres, from which he calculated the dielectric constant at 1 atmosphere to be 1.000587, which he states compares favorably with Tangl's value of 1.000581. However, the comparison is not clear, since he made measurements at about 23°C. He uses the word normal, which assumes room temperatures, whereas Tangl's data is for standard conditions, namely 0°C and 1 atmosphere.

Using a high frequency method Fritts made measurements at pressures near atmospheric and found a value of 1.000555 calculated for 0°C and 1 atm. from a series of 39 observations.

In 1924 Zahn reported a value of 1.000581 calculated from 41 measurements and reduced to 0°C and 760 mm Hg. A paper by the same author in 1926 gives a value of 1.000580.

DIELECTRIC CONSTANT OF GASEOUS NITROGEN

(cont.)

Broxon made observations at pressures up to 150 atmospheres and observed a linear relation between dielectric constant and pressure in the case of commercial nitrogen (above 99%). He found a value of 1.000556 at 1 atmosphere and 16.5°C. The rate of change of dielectric constant as a function of pressure at 16.5°C is given as 0.000556 per atmosphere.

The average value found by Andrews at 0°C and 1 atmosphere, using a frequency of 884 Kc was given as 1.000589, which he considers to be correct to 0.5% of the value (ϵ-1) of 0.000589.

Michels and Michels made measurements at 25, 75 and 125°C and at pressures up to 150 atmospheres from which they calculated a value at 0°C and 1 atm. of 1.000573. They used a frequency of 508 Kc. Only the 25°C isotherm is tabulated here.

Uhlig, Kirkwood and Keyes made measurements at 0 and 100°C and pressures up to 250 atmospheres using a heterodyne beat method. The 100°C values are not tabulated here.

Watson et al. report a value for 25°C and 1 atmosphere of 1.000538 for nitrogen.

Michels et al. made measurements between 25 and 150°C at pressures up to 1000 atmospheres. Very extensive tables of data are given, from which they finally calculate the value of the dielectric constant at 0°C and 1 atm. to be $1.0005824 \pm 6 \times 10^{-7}$. The tabular values for above 50°C are not reproduced in this report. The authors indicate that the Clausius-Mossotti function is valid within experimental error.

Bennett used an improved displacement interferometer to measure simultaneously refractive index and dispersion constants for gases over a range of pressures above atmospheric. From the Cauchy dispersion constant $A_0 - 1 = 0.0002932$, which is the extrapolated infinite wave-length refractive index less one, he calculates the dielectric constant, ϵ, to be 1.0005864, in which ϵ-1 is considered to be accurate to one fifth of one percent. In a later paper Bennett reports values of $A_0 - 1$ for 0, 30, and 50°C from 300 to 1000 cm of Hg pressure. From these values the dielectric constant was calculated with the Cauchy relation.

Fox and Ryan used a heterodyne beat method at the ultra high frequency of 56 megacycles on nitrogen of 99.9% purity. They find a value of 1.0005808 at 0°C and 1 atmosphere, as the result of averaging 120 separate readings.

Using the heterodyne beat method, Hector and Woernley found a value of 1.000580 at NTP which probably means 0°C and 1 atmosphere.

Miller presents a review of dielectric constant and refractivity data. He includes a compilation of dielectric constant values for 0°C and 1 atmosphere. Because index of refraction data extrapolated to infinite wave-length are regarded as a more accurate source of dielectric constant values, Miller gives for comparison values of n^2.

Birnbaum et al. used a frequency of 9280 Mc at 0°C and 760 mm Hg and found ϵ for N_2 to be 1.0005869 ± 0.0000029.

Essen and Froome using a frequency of 24,000 Mc/s arrived at a value of the dielectric constant of nitrogen at 0°C and 760 mm Hg of 1.0005883 ± 0.0000002.

Zieman used a frequency of 9470 Mc and came up with a value for the dielectric constant of 1.0005870 ± 0.0000020.

Essen reports the index of refraction of gaseous nitrogen at 0°C and 760 mm of Hg as 1.0002941. Using the relation $\epsilon = n^2$, we obtain $\epsilon = 1.0005882$.

Maryott and Buckley made a critical review of dielectric constants obtained by radio frequency, microwave and optical methods and recalculated by one of two systematic procedures in order to place the work of various experimentors on a more comparable basis than exists in the literature. They recommend a value of 1.0002538 ± 0.0000003 at 20°C and 1 atmosphere.

DIELECTRIC CONSTANT OF GASEOUS NITROGEN

(cont.)

Heineken and Bruin used a resonant cavity method at a frequency of 25 KMc/Sec to determine the index of refraction. The Cauchy relation yields a value of 1.000588 for the dielectric constant at 0°C and 1 atmosphere.

Froome measured the refractive index with a cavity resonator and reports a value of 1.0002941 at 0°C and 1 atmosphere. Through the Cauchy relation this yields a value of 1.0005882 for the dielectric constant at 0°C and 1 atmosphere.

De Wijn and Heineken report values for the Lorentz-Lorenz function $(N^2-1)/\rho(N^2+2)$=LL where N = index of refraction and ρ = density in Amagats). Through the Cauchy relation $N^2 = \epsilon$ where ϵ is the dielectric constant the Lorentz-Lorenz function reduces to the Clausius-Mossotti function, $(\epsilon-1)/\rho(\epsilon+2)$. Their data at densities from 1 to 45 Amagats and 295°K can be represented well within experimental error by the equation LL = 0.0001960 + ρ(0.00000002).

Johnston et al. indicate the behavior of the Clausius-Mossotti function up to a density of 4 moles/liter at 242°K and 296°K but do not give dielectric constant values.

Tangl (1908) at 293.15°K	
P(atm)	Dielectric Constant
1	1.000538
20	1.01086
40	1.02185
60	1.03299
80	1.04406
100	1.05498

Bodareu (1913) at 296.15°K	
P(atm)	Dielectric Constant
87	1.04750
114	1.06276
143	1.07828
174	1.09373
205	1.10953
226	1.11867

Zahn (1926) at 1 atmosphere	
Temp. °K	Dielectric Constant
84.1	1.001898
197.8	1.000792
273.0	1.000581
562.1	1.000283

Uhlig et al. (1933) at 273.15°K	
P(atm)	Dielectric Constant
10	1.00609
20	1.01220
40	1.02468
60	1.03732
80	1.04999
100	1.06262
150	1.09343
200	1.1217
250	1.1473

DIELECTRIC CONSTANT OF GASEOUS NITROGEN

(cont.)

Michels et al. (1934)

Temp. °C	P(atm)	Dielectric Constant	Temp. °C	P(atm)	Dielectric Constant
25.28	1.02	1.00052	49.68	1.06	1.00054
25.28	2.02	1.00104	49.68	2.10	1.00109
25.28	3.01	1.00155	49.68	2.12	1.00105
25.28	8.09	1.00423	49.65	2.97	1.00149
25.28	13.44	1.00711	49.66	9.16	1.00452
25.28	18.91	1.01010	49.66	13.34	1.00662
25.28	24.41	1.01303	49.66	18.86	1.00935
25.28	29.96	1.01614	49.66	24.40	1.01208
25.28	35.48	1.01904	49.66	29.99	1.01489
25.28	41.06	1.02206	49.66	35.53	1.01761
25.28	46.58	1.02510	49.66	41.13	1.02036
25.28	52.07	1.02806	49.66	46.50	1.02305
25.28	57.51	1.03109	49.66	51.96	1.02576
25.28	61.39	1.03313	49.66	57.42	1.02848
25.28	61.40	1.03311	49.66	61.23	1.03034
25.28	87.98	1.04760	49.58	57.42	1.02836
25.27	114.60	1.06170	49.58	62.68	1.03097
25.28	114.67	1.06176	49.66	87.87	1.04326
25.27	141.29	1.07561	49.66	87.96	1.04337
25.28	141.36	1.07567	49.66	87.96	1.04343
25.28	141.38	1.07565	49.66	114.51	1.05614
25.28	168.05	1.08910	49.66	130.04	1.06349
25.28	168.08	1.08897	49.58	141.34	1.06866
25.28	194.99	1.10190	49.58	168.33	1.08103
25.28	221.57	1.11413	49.59	194.94	1.09274
25.28	254.74	1.12875	49.59	221.96	1.10401
25.28	366.88	1.17008	49.59	254.64	1.11728
25.28	478.66	1.20289	49.61	366.92	1.15653
25.28	590.34	1.22873	49.60	478.52	1.18791
25.28	702.08	1.25076	49.60	590.21	1.21406
25.28	814.17	1.26937	49.60	702.03	1.23555
25.28	925.89	1.28526	49.60	814.12	1.25426
25.28	1011.56	1.29633	49.60	925.90	1.27051
			49.60	1011.49	1.28154

Bennett (1940)

Temp. °C	P(cm Hg)	Dielectric Constant	Temp. °C	P(cm Hg)	Dielectric Constant
50	309.75	1.002025	30	800.59	1.005554
50	582.91	1.003806	30	803.64	1.005593
50	1022.20	1.006677	30	1075.36	1.007465
30	309.80	1.002156	0	321.09	1.002467
30	331.22	1.002308	0	437.68	1.003362
30	356.04	1.002476	0	549.42	1.004225
30	497.49	1.003456	0	662.69	1.005107
30	566.56	1.003932	0	791.48	1.006104
30	566.61	1.003938	0	1000.57	1.007717
30	626.23	1.004354			

NITROGEN - SURFACE TENSION

Sources of Data:

Baly, E. C. C., and Donnan, F. G., "The Variation with Temperature of the Surface Energies and Densities of Liquid Oxygen, Nitrogen, Argon, and Carbon Monoxide," J. Chem. Soc. (London) 81, 907-23 (1902).

Reilly, M. L., and Furukawa, G. T., "Surface Tension of Oxygen, Nitrogen, and their Mixtures," Natl. Bur. Std. Rept. 3958 (1955).

Stansfield, D., "The Surface Tensions of Liquid Argon and Nitrogen," Proc. Phys. Soc. (London) 72, 854-66 (1958).

Comments:

The surface tension of nitrogen has been reported by three experimenters from measurements using the capillary rise method. Reilly and Furukawa estimate their values of surface tension to have an accuracy of ± 1%. Stansfield compared his results up to 90°K with those of Baly and Donnan and report an agreement to nearer than 1%.

The data for surface tension of nitrogen have been fitted to an equation of the form

$$\gamma = \gamma_0 \ (1 - T/T_c)^{\beta},$$

where γ is the surface tension in dynes/cm at temperature T, T_c is the critical temperature, and γ_0 and β are variable parameters. The estimated parameters determined by a least squares fit to the data are,

$$\gamma_0 = 29.7074 \text{ dynes/cm}$$

$$\beta = 1.27135 \quad .$$

Deviations between this equation and the experimental data are given in the following graph. The table of values of surface tension were calculated from this equation.

Guggenheim* suggested a value of $\beta = 11/9$. A least squares fit of γ_0 with $\beta = 11/9$ was also made, which resulted in the value $\gamma_0 = 28.3008$ dynes/cm. The equation with $\beta = 1.27135$ is a better fit of the data near the critical point.

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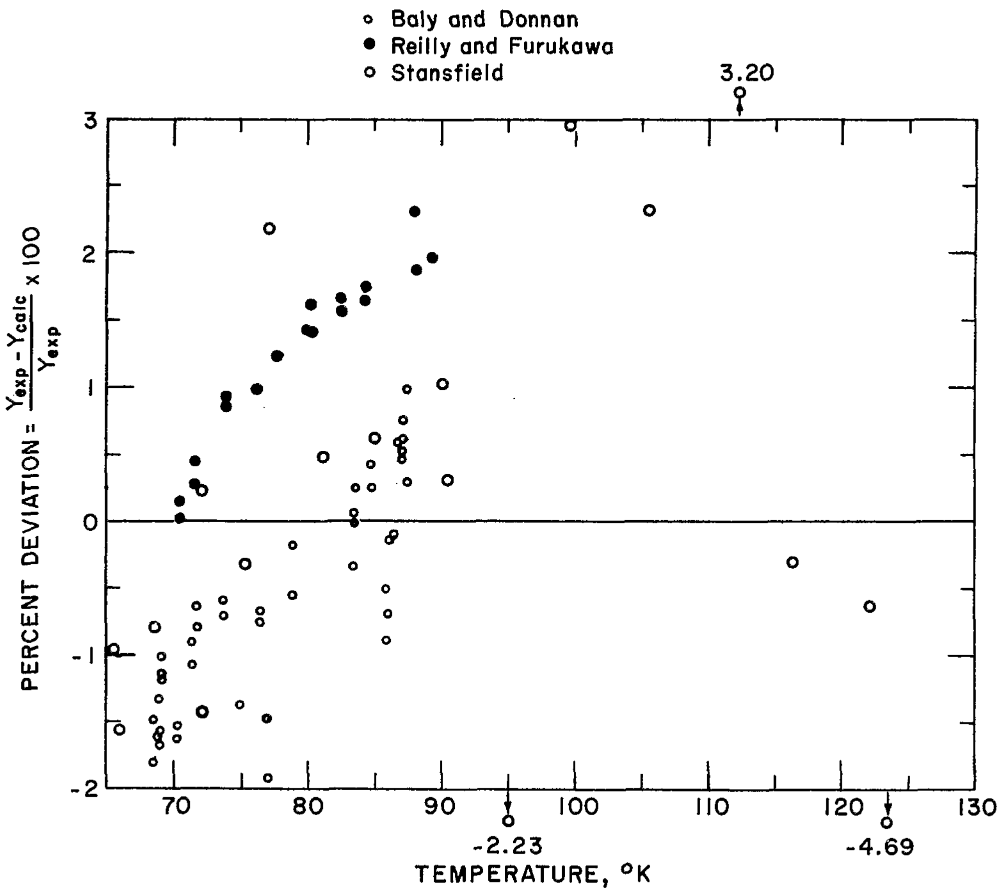
* Guggenheim, E. A., J. Chem. Phys. 13, 253-61 (1945)

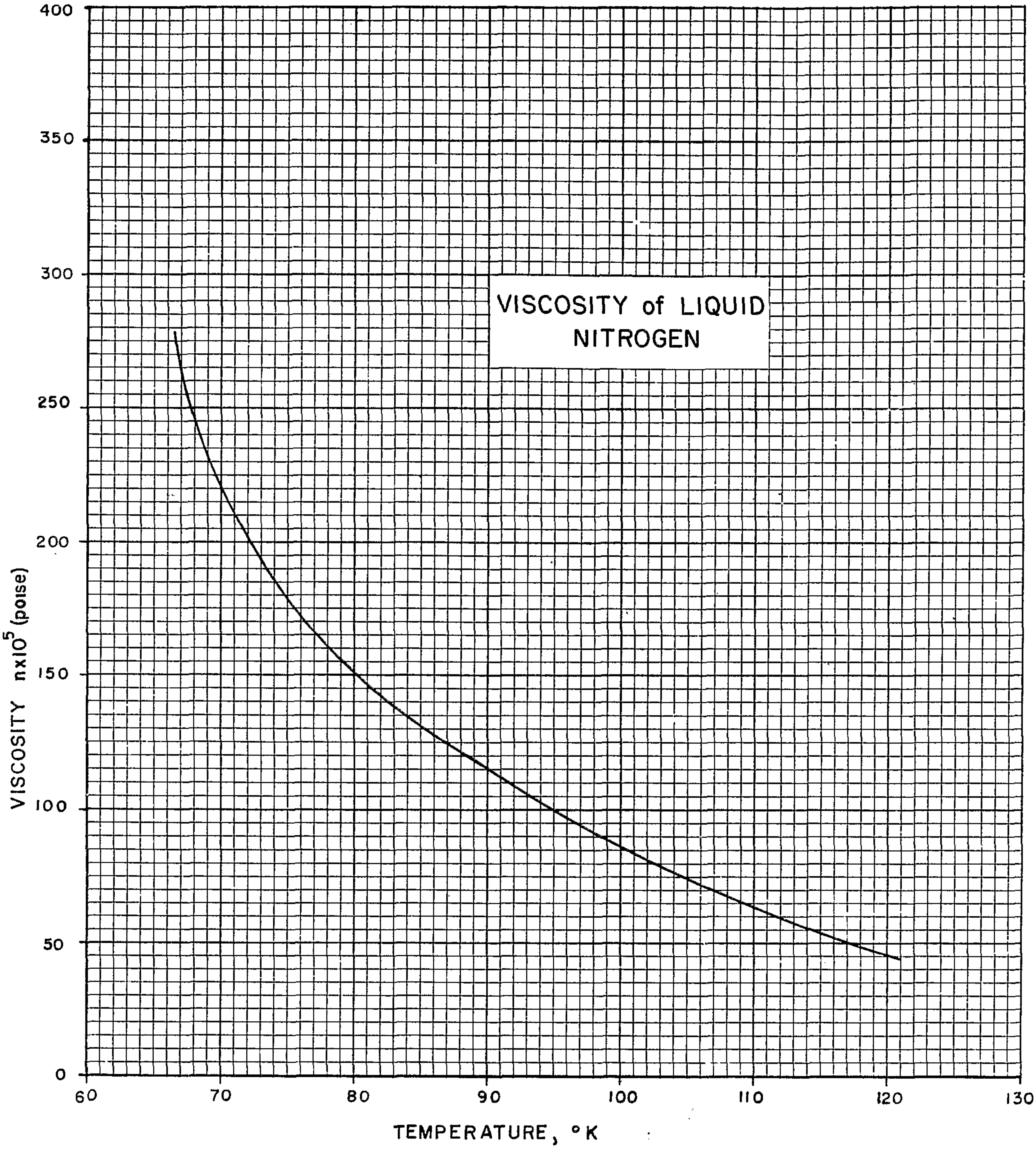
Surface Tension for Nitrogen from $\gamma = \gamma_0 (1 - T/T_c)^\beta$ where $\gamma_0 = 29.707$ and $\beta = 1.2713$					
Temp. °K	Surface Tension (dynes/cm)	Temp. °K	Surface Tension (dynes/cm)	Temp. °K	Surface Tension (dynes/cm)
64.0	12.08	88.0	6.49	112.0	1.84
66.0	11.58	90.0	6.06	114.0	1.51
68.0	11.10	92.0	5.64	116.0	1.20
70.0	10.61	94.0	5.22	118.0	0.911
72.0	10.14	96.0	4.81	119.0	0.771
74.0	9.66	98.0	4.41	120.0	0.637
76.0	9.19	100.0	4.02	121.0	0.508
78.0	8.73	102.0	3.63	122.0	0.386
80.0	8.27	104.0	3.25	123.0	0.271
82.0	7.82	106.0	2.88	124.0	0.167
84.0	7.37	108.0	2.52	125.0	0.0749
86.0	6.93	110.0	2.18	126.0	0.00520



Viscosity of Liquid Nitrogen

Source of Data: Forster, S.,"Viscosity Measurements in Liquid Neon, Orgon, and Nitrogen, Cryogenics, Vol. 3, 176-177, (1963).

Temp. °K	Viscosity $\eta \times 10^5$ Poise
66.55	278
70.00	223
77.1	165
86.9	127
94.6	102
97.8	92
104.1	79
110.0	65
116.2	53
121.1	45


VISCOSITY of LIQUID NITROGEN
VISCOSITY n x 10^5 (poise)
TEMPERATURE, °K
400
350
300
250
200
150
100
50
0
60
70
80
90
100
110
120
130

VISCOSITY OF GASEOUS NITROGEN*

(PRELIMINARY TABLE)

TEMP K	VISCOSITY G/CM-SEC $\eta \times 10^6$
100	69.3
110	75.8
120	82.2
130	88.5
140	94.7
150	100.7
160	106.7
170	112.4
180	118.1
190	123.7
200	129.2
210	134.5
220	139.8
230	144.9
240	149.9
250	154.8
260	159.7
270	164.4
280	169.1
290	173.7
300	178.2
310	182.7
320	187.1
330	191.4
340	195.6
350	199.8
360	203.9
370	207.9
380	211.9
390	215.8
400	219.7
410	223.6
420	227.4
430	231.2
440	234.9
450	238.6
460	242.2
470	245.8
480	249.4
490	252.9
500	256.4
510	259.8
520	263.3
530	266.6
540	270.0
550	273.3
560	276.6
570	279.9
580	283.1
590	286.4
600	289.5
610	292.7
620	295.8
630	299.0
640	302.1
650	305.0
660	308.0
670	311.1
680	314.1
690	317.1
700	320.0
710	323.0
720	325.9
730	328.8
740	331.7
750	334.6
760	337.5
770	340.3
780	343.2
790	346.0
800	348.8
810	351.6
820	354.4
830	357.1
840	359.8
850	362.5
860	365.1
870	367.9
880	370.6
890	373.3
900	375.9
910	378.5
920	381.2
930	383.8
940	386.4
950	389.0
960	391.6
970	394.2
980	396.7
990	399.3

* Calculated for the dilute gas by the Kihara potential, with $\gamma = .2$, $\sigma = 3.55$ Å, $\epsilon/k = 116.7$°K.

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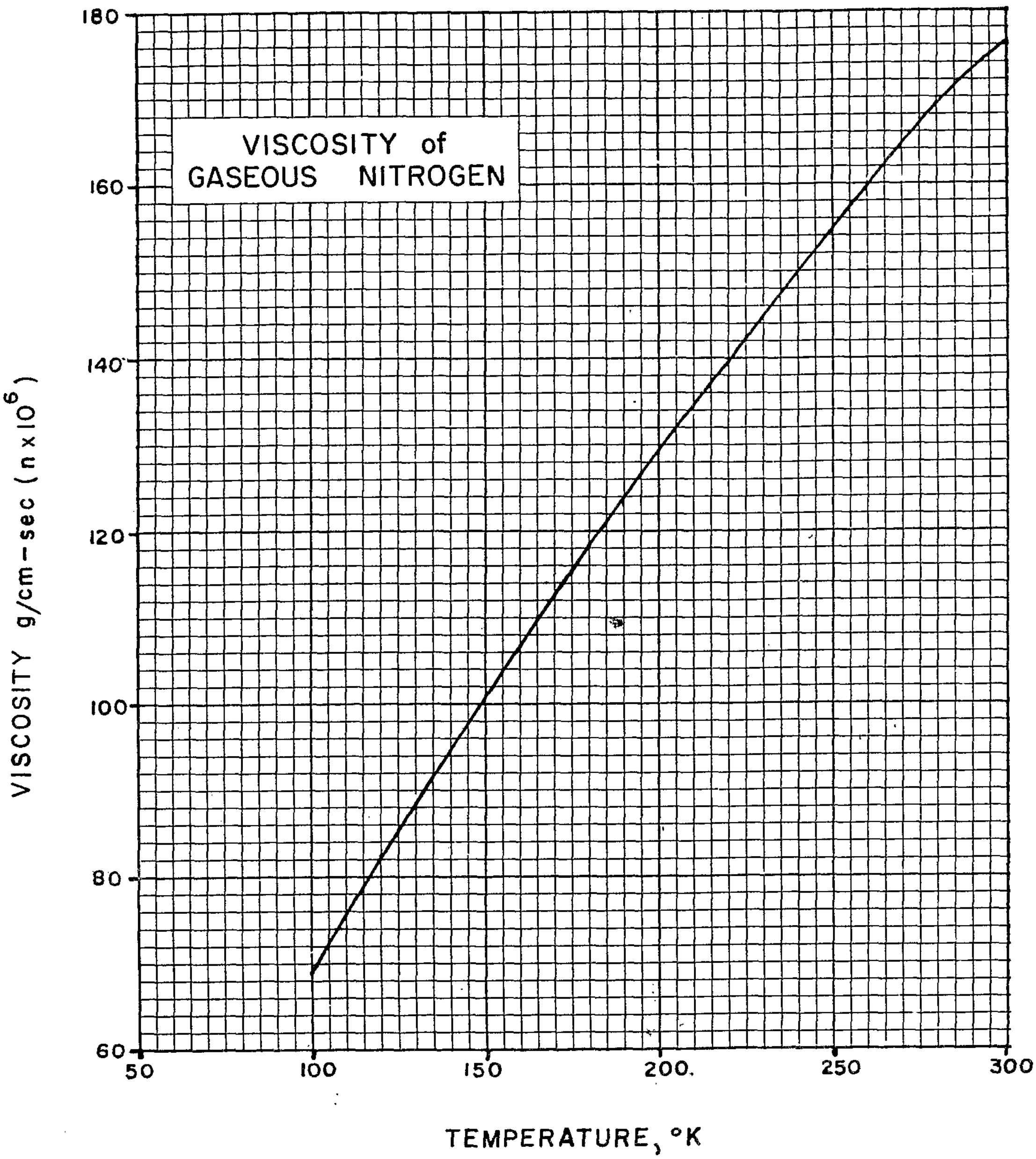
VISCOSITY of
GASEOUS NITROGEN
VISCOSITY g/cm-sec (n x 10⁶)
180
160
140
120
100
80
60
50
100
150
200.
250
300
TEMPERATURE, °K

VELOCITY of SOUND in LIQUID NITROGEN

Sources of Data:

Van Itterbeek, A., de Bock, A. and Verhaegen, L.; Physica 15, 624 (1949)

Van Itterbeek, A., and Van Dael, W.; Bull. inst. intern. froid. Annexe 1958-1, 295 (1958)

Other References:

Hirschlaff, E.; Proc. Cambridge Phil. Soc. 34, 296 (1938)

Liepmann, H. W.; Helv. Phys. Acta. 12, 421 (1939)

Galt, J. K; J. Chem. Phys. 16, 505 (1948)

Van Itterbeek, A., Van den Berg, G. J. and Limburg, W.; Physica 20, 307 (1954)

Venkatasubramanian, F. S.; J. Indian Inst. Sci. 37, 227 (1955)

Comments:

The velocity of sound in liquid nitrogen is presented here as a function of pressure and temperature between the temperatures of 64.5°K and 90.25°K at various pressures from 1 to 67 atmospheres. The data tabulated below and illustrated on the graphs are from the references listed above under "Sources of Data".

The data by Van Itterbeek, de Bock and Verhaegen tabulated below are illustrated in the graph of the velocity of sound versus temperature. The authors report these values as being observed at the pressures of the saturated liquid with sound having a frequency of 535 kilocycles per second. No mention is made of the purity of the sample used or the estimated accuracy of the measurements taken.

The data illustrated in the graph of the velocity of sound in liquid nitrogen versus pressure at constant temperature are from Van Itterbeek and Van Dael. These isotherms terminate on the low pressure end at saturation as indicated on the graph, and therefore should not be extrapolated to lower pressures. The authors report sound frequency of 528.58 kc/sec used to take the measurements at 77.40°K and sound of 519.00 kc/sec used to take the measurements at 90.25°K. No mention is made by the investigators as to the purity of the sample or the estimated accuracy of the measurements.

The units of the velocity of sound in liquid nitrogen used in the tabulations below and on the graphs are: temperature in degrees Kelvin (0°C = 273.16°K), pressure in atmospheres (g = 980.665) and the velocity of sound in meters per second.

(Continued on following page)

Comments: (cont.)

Velocity of Sound in Liquid Nitrogen
at Saturation Pressures as a Function of Temperature

Van Itterbeek, de Bock and Verhaegan			
Temp. °K	Velocity m/sec	Temp. °K	Velocity m/sec
64.5	1009.6	70.2	945.8
65.4	1002.5	71.9	921.3
66.4	998.2	74.7	907.2
67.5	964.7	77.5	857.1

Velocity of Sound in Liquid Nitrogen
as a Function of Pressure

Van Itterbeek and Van Dael			
Pressure atm.	Velocity m/sec	Pressure atm.	Velocity m/sec
77.40°K		8.3	735.7
4.2	861.6	10.2	737.3
9.2	863.2	15.5	743.3
13.9	868.0	15.9	743.0
31.8	881.2	19.2	743.4
42.0	885.4	24.8	753.2
42.1	889.1	28.8	756.2
49.6	894.7	32.3	759.7
51.9	896.5	38.6	769.2
54.1	898.1	39.3	767.4
60.9	902.0	39.3	768.7
66.7	907.1	43.7	775.4
90.25°K		44.2	773.9
4.6*	731.2	47.4	777.7
8.1	732.3	49.3	780.7
		55.7	787.5
* Value appears on both graphs			

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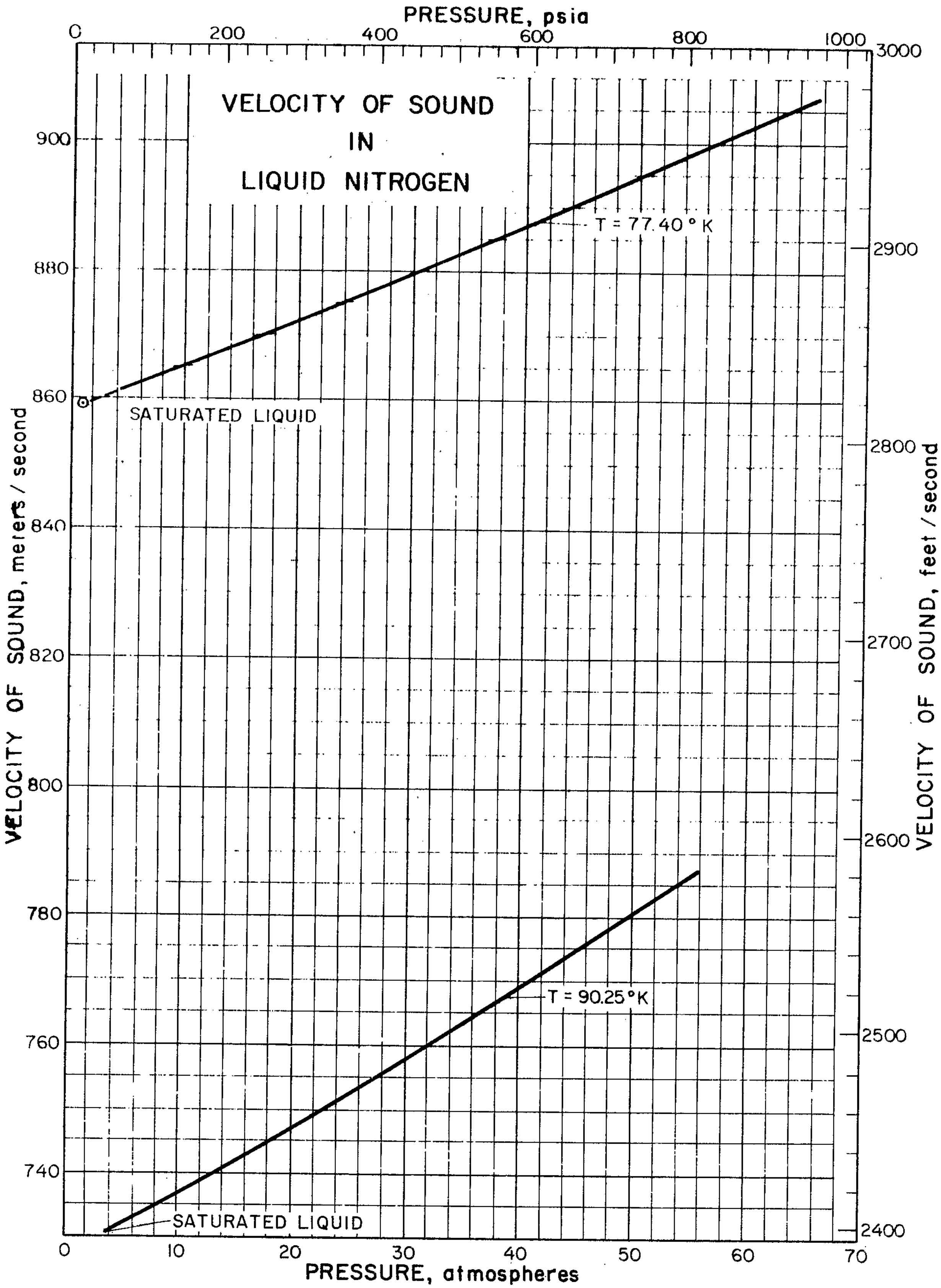
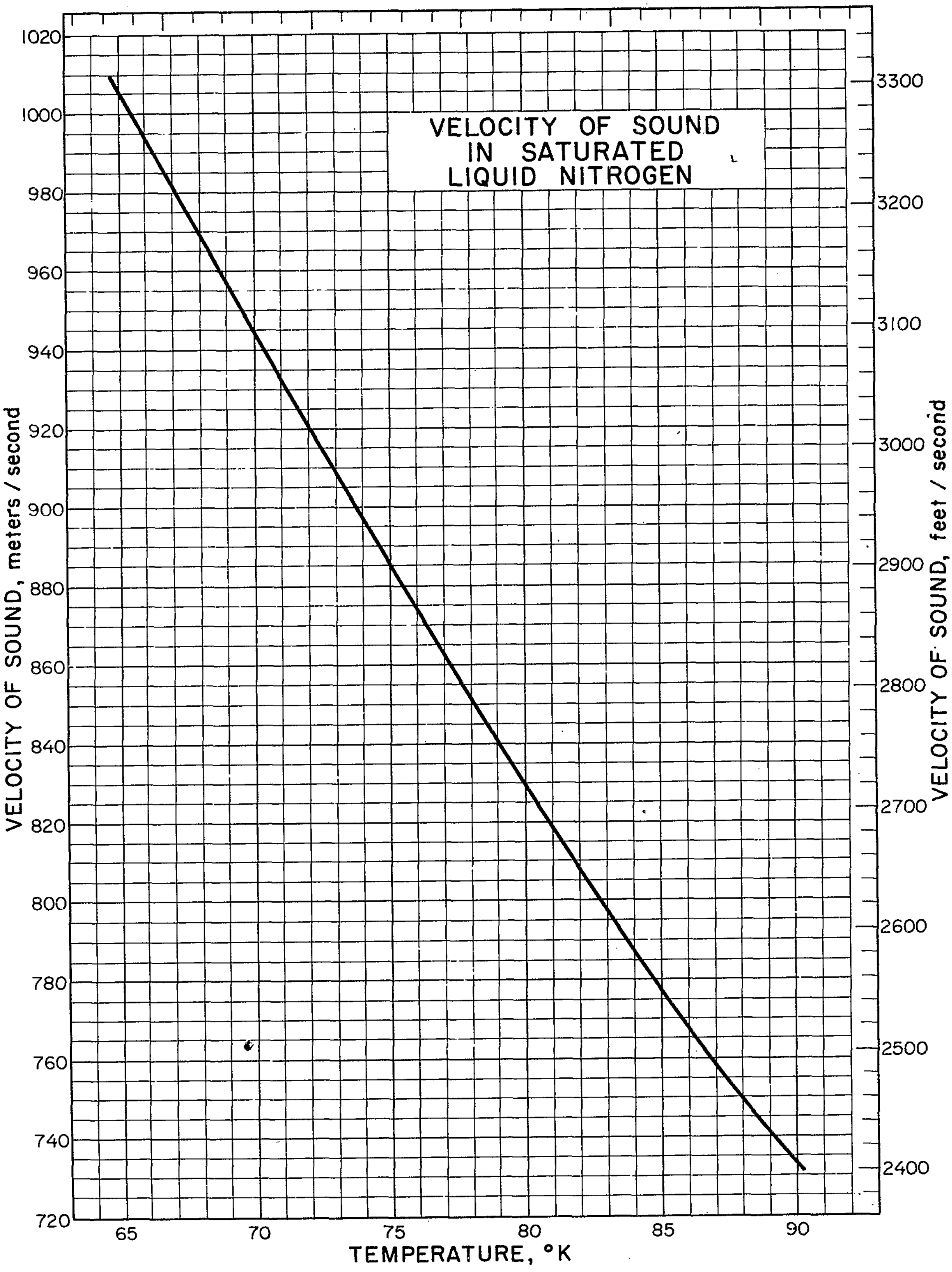

PRESSURE, psia
0
200
400
600
800
1000
VELOCITY OF SOUND
IN
LIQUID NITROGEN
T = 77.40 ° K
SATURATED LIQUID
T = 90.25 °K
SATURATED LIQUID
900
880
860
840
820
800
780
760
740
VELOCITY OF SOUND, meters / second
3000
2900
2800
2700
2600
2500
2400
VELOCITY OF SOUND, feet / second
0
10
20
30
40
50
60
70
PRESSURE, atmospheres


VELOCITY OF SOUND
IN SATURATED
LIQUID NITROGEN
VELOCITY OF SOUND, meters / second
VELOCITY OF SOUND, feet / second
TEMPERATURE, °K
1020
1000
980
960
940
920
900
880
860
840
820
800
780
760
740
720
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
65
70
75
80
85
90

VELOCITY of SOUND in GASEOUS NITROGEN

Sources of Data:

Keesom, W. H. and Van Lammeren, J. A.; Koninkl. Akad. Amsterdam, Proc. 35, 727 (1932)

Hilsenrath, J., et al.; Natl. Bur. Standards Circ. 564 (1955) 488 pp.

Lunbeck, R. J., Michels, A. and Wolkers, G. J.; Appl. Sci. Research A3, 197 (1952)

Other References:

Foley, A. L., International Critical Tables of Numerical Data, Physics, Chemistry and Technology VI, 1st Edition Published for the National Research Council by the McGraw-Hill Book Co., Inc. (1929) p. 46

Van Itterbeek, A. and Mariens, P.; Physica 4, 207 (1937)

Shilling, W. G. and Partington, J. R.; Phil. Mag. 6, 920 (1928)

Hodge, A. H.; J. Chem. Phys. 5, 974 (1937)

Colwell, R. C. and Gibson, L. H.; J. Acoust. Soc. Am. 12, 436 (1941)

Van Itterbeek, A. and Van Doninck, W.; Ann. phys. 19, 88 (1944)

Michels, A., Lunbeck, R. J. and Wolkers, G. J.; Physica 17, 801 (1951)

Dixon, H. B., Campbell, C. and Parker, A.; Proc. Roy. Soc. (London) A100, 1 (1921)

Comments:

The values of the velocity of sound in gaseous nitrogen are given here as functions of temperature and pressure. Three graphs are given with accompanying tabular data. The first graph illustrates the velocity of sound in nitrogen near one atmosphere pressure, versus temperature between 77.395°K (the normal boiling point) and 280°K. The final two graphs present the velocity of sound in nitrogen versus pressure, with pressures of 0 to 1 atmosphere and 0 to 3000 atmospheres, respectively. The data illustrated in the graphs and tabulated below are from the references listed above under "Sources of Data". The data illustrated in the plot of velocity of sound as a function of temperature and in the graph of the velocity of sound as a function of pressure between 0 and 1 atmosphere are from Keesom and Van Lammeren; and Hilsenrath, et al. The values of the velocity of sound at 0 pressure were calculated for the ideal gas, i.e., $c = \sqrt{RT\gamma}$, where c is the velocity of sound, R is the gas constant, T is the temperature, and γ is the specific heat ratio. The data by Hilsenrath, et al., are reported by the authors as the velocity of sound at low frequency. A comparison of these data with experimental values appears in National Bureau of Standards Circular 564, and indicates an agreement with the experimental values of less than 1% maximum deviation. Hilsenrath, et al., present their data as ratios in the form of a/a_o, where a is the value of the velocity of

(Continued on following page)

Comments: (Cont.)

low frequency sound at a given temperature and pressure, and a_o (a_o = 336.96 m/sec) is the velocity of sound at 0°C and 1 atmosphere of pressure. All values from Hilsenrath, et al., tabulated here have been converted to specific values of velocity of sound. Keesom and Van Lammeren make no mention of the frequency of the sound used in their determinations but do claim 0.15% accuracy in their measurements. All of the above data are for a pressure of approximately 1 atm.

The data by Lunbeck, Michels and Wolkers tabulated below and illustrated in the plot of the velocity of sound in nitrogen gas as a function of pressure between 0 and 3000 atmospheres were calculated by the authors from a correlation of their own experimental data. The authors estimate a maximum error in these calculations of 10%. However, in the temperature range reported here, the maximum error should be substantially smaller.

The units of the velocity of sound in nitrogen gas used in the tabulations below and on the graphs are: temperature in degrees Kelvin (0°C = 273.16° K), pressure in atmospheres (g = 980.665) and the velocity of sound in meters per second.

Velocity of Sound in Gaseous Nitrogen as a Function of Pressure*

Press.	Velocity, m/sec					
atm.	-125°C	-100°C	-75°C	-50°C	-25°C	0°C
0	248.1	268.2	286.9	304.6	321.1	337.0
10	241	264	285	304	322	338
30	229	260	284	306	324	342
50	230	261	286	310	329	346
100	362	298	310	326	345	362
200	566	462	415	404	405	414
300	689	588	527	496	483	481
400	776	681	620	580	559	549
600	904	822	760	719	688	670
800	1007	930	870	827	796	774
1000	1092	1020	961	917	886	863
1200	1167	1100	1040	996	963	941
1500	1265	1202	1146	1101	1068	1044
2000	1408	1347	1295	1250	1218	1197
2500	1531	1473	1423	1381	1348	1329
3000	1636	1587	1535	1495	1462	1448

* Values are from Lunbeck, Michels and Wolkers

(Continued on following page)

<u>Comments:</u> (cont.)

Velocity of Sound in Gaseous Nitrogen as a Function of Pressure

Temp. °K	Press. atm.	Velocity m/sec	Temp. °K	Press. atm.	Velocity m/sec
Keesom and Van Lammeren			77.95	0.9026*	176.0
				0.7122	176.9
90.37	0.9299*	191.0		0.5789	177.5
	0.7293	191.7		0.4380	178.0
	0.5541	192.2		0.3029	178.7
	0.4380	192.6		0.2025	179.2
	0.3207	192.9		0.1183	179.7
	0.1973	193.3	71.92	0.3879	170.9
	0.1176	193.3		0.3382	171.1
82.95	1.0146*	181.8		0.2627	171.6
	0.7957	182.8		0.1931	172.0
	0.5953	183.4		0.1188	172.6
	0.4179	184.0	Hilsenrath, et al.		
	0.2923	184.6			
	0.1921	185.0	100.0	0.01	203.86
	0.1022	185.5		0.1	203.52
				1.0	201.50

* These values also appear on the velocity of sound as a function of temperature plot.

Velocity of Sound in Gaseous Nitrogen as a Function of Temperature*

Temp. °K	Velocity m/sec	Temp. °K	Velocity m/sec
Pressure = 1 atm.		Pressure = 1 atm.	
100	201.50	200	288.10
110	212.28	210	295.18
120	222.06	220	302.25
130	231.15	230	308.99
140	240.25	240	315.73
150	249.01	250	322.13
160	257.10	260	328.54
170	265.19	270	334.94
180	273.27	280	341.34
190	280.69		

* Values are from Hilsenrath, et al.

(Continued on following page)

Comments: (cont.)

Work done by other investigators is also of interest. Foley made a critical review of all work on the velocity of sound in nitrogen prior to 1928 for inclusion in the section on sound in the International Critical Tables and reported 337.7 m/sec at 0°K and 1 atm. pressure. Dixon and co-workers gave a value 337.6 at 0°C and 720.6 m/sec at 1000°C. Shilling and Partington worked with nitrogen from which the rare gases had not been removed but which had been freed from moisture by passage over sodium hydroxide and phosphorus pentoxide. Measurements were carried out from 16.7 to 1000°C yielding values from 347.6 to 720.6 m/sec at these limiting temperatures.

Hodge made measurements on impure nitrogen at 27°C at pressures from 1 to 100 atmospheres. Since water vapor and other impurities of unknown amounts had not been removed, no importance can be attached to his results. Colwell and Gibson used a rapid succession of sound pulses and an oscilloscope and found no variation in velocity at 0°C for pressures from 26 to 176 cm Hg. The average of 2100 measurements gave a value of 337.12 m/sec at 0°C.

The above authors also give values for the velocity as a function of pressure ranging from 183.1 m/sec at zero pressure and 80°K to about 180 m/sec at 0.8 atmospheres.

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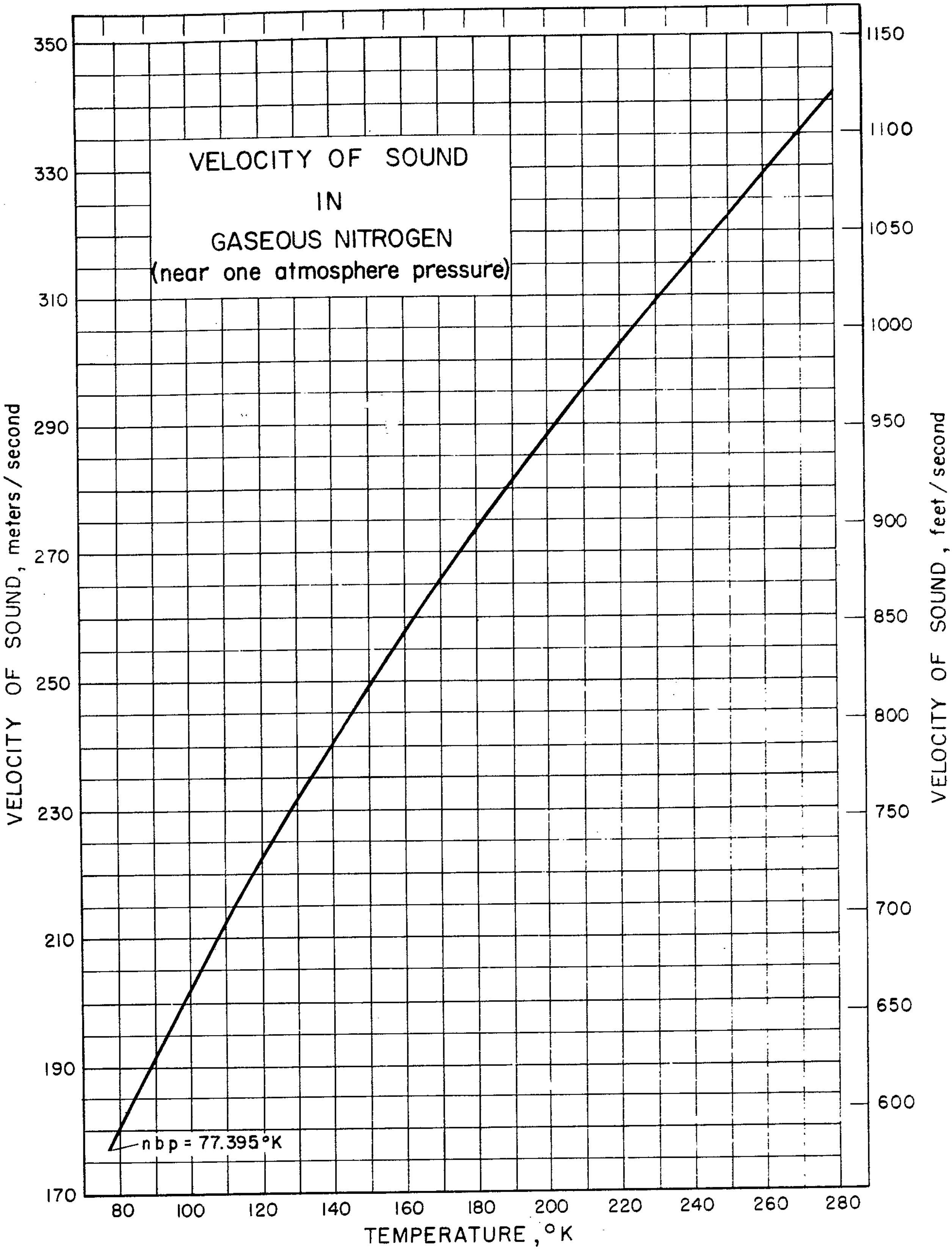
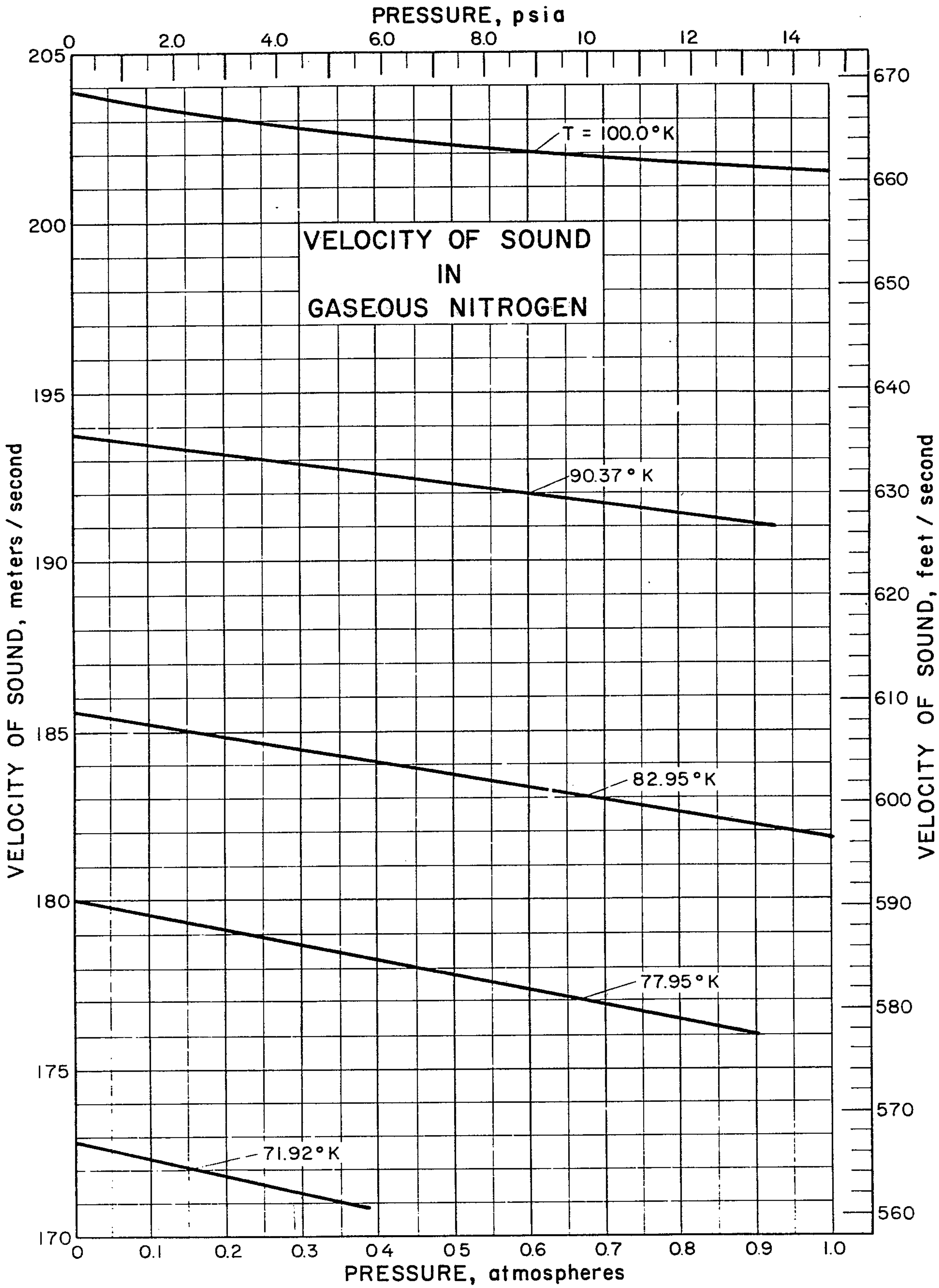
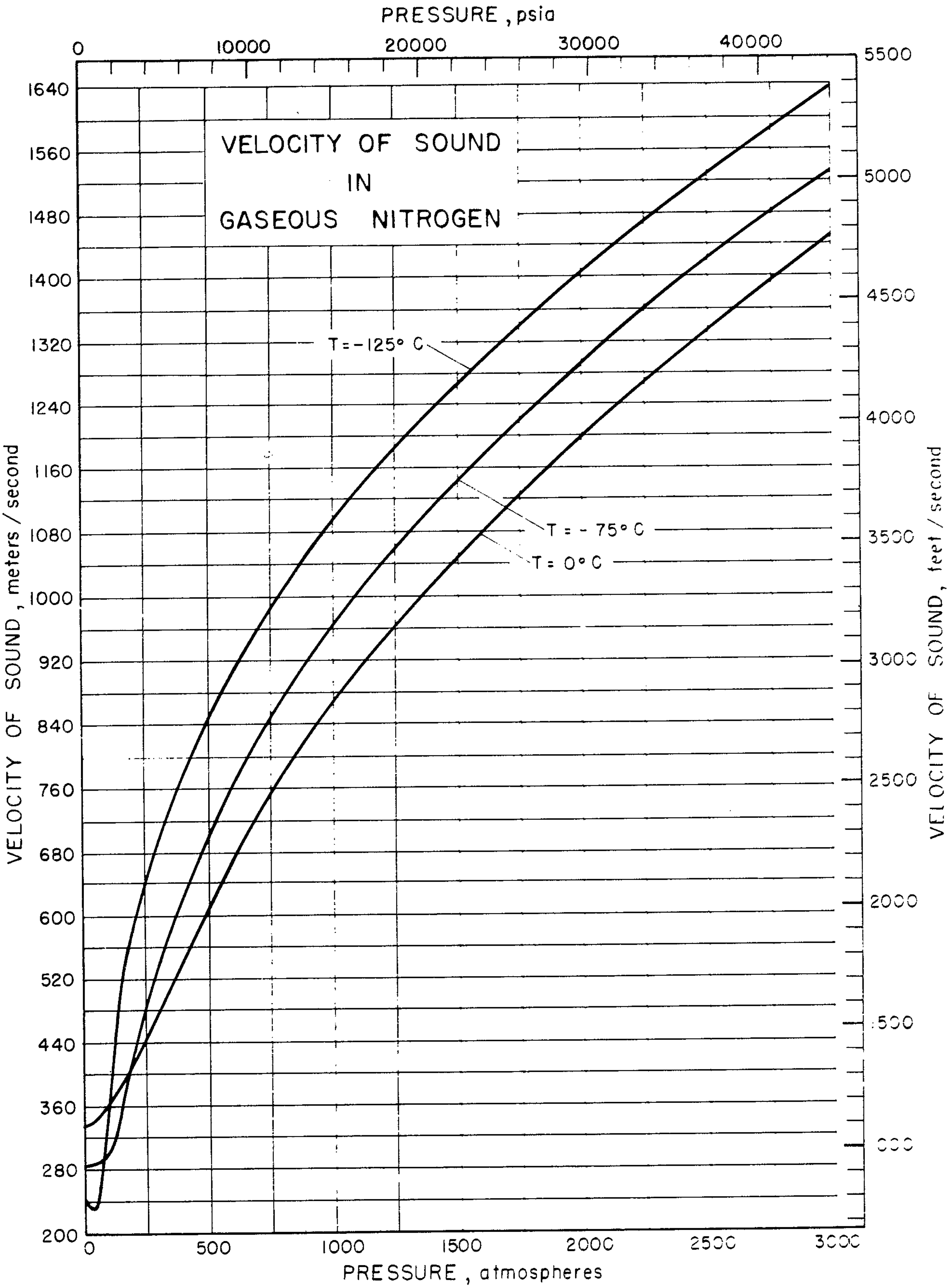


VELOCITY OF SOUND
IN
GASEOUS NITROGEN
(near one atmosphere pressure)
nbp = 77.395°K
VELOCITY OF SOUND, meters / second
350
330
310
290
270
250
230
210
190
170
VELOCITY OF SOUND, feet / second
1150
1100
1050
1000
950
900
850
800
750
700
650
600
TEMPERATURE, °K
80
100
120
140
160
180
200
220
240
260
280


PRESSURE, psia
0
2.0
4.0
6.0
8.0
10
12
14
VELOCITY OF SOUND
IN
GASEOUS NITROGEN
T = 100.0°K
90.37°K
82.95°K
77.95°K
71.92°K
205
200
195
190
185
180
175
170
VELOCITY OF SOUND, meters / second
670
660
650
640
630
620
610
600
590
580
570
560
VELOCITY OF SOUND, feet / second
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
PRESSURE, atmospheres



PRESSURE, psia
0
10000
20000
30000
40000
VELOCITY OF SOUND IN GASEOUS NITROGEN
T=-125° C
T = - 75° C
T= 0° C
VELOCITY OF SOUND, meters / second
1640
1560
1480
1400
1320
1240
1160
1080
1000
920
840
760
680
600
520
440
360
280
200
VELOCITY OF SOUND, feet / second
5500
5000
4500
4000
3500
3000
2500
2000
PRESSURE, atmospheres
0
500
1000
1500
2000
2500
3000