

RESULTS

The results are presented in Tables IV and V and in Figure 1. It should be remembered that the *B-W-R* equation gave a poor fit to the *P-V-T* points above 60 atm., so the tabulated and graphed results are probably not accurate much above 60 atm.

The internal consistency of the results was checked by using the relations:

$$\left(\frac{\partial \ln P}{\partial H}\right)_S = \frac{1}{PV}$$

$$\left(\frac{\partial H}{\partial S}\right)_P = T$$

The slopes measured on the appropriate graphs were compared with the quantities on the right hand side of the above equations. Agreement was within 0.4% at the 10 points that were checked. The error introduced into the entropy and enthalpy owing to the use of the *B-W-R* equation of state is estimated at about 1% in the enthalpy and 0.5% in the entropy. This error was estimated by observing the variation in *H* and *S* as the *B-W-R* equation was made to fit the experimental data more and more closely.

NOMENCLATURE

A, B, C, D	= constants in the modified Antoine equation
A_0, B_0, C_0	
a, b, c, α, γ	= constants in the Benedict-Webb-Rubin equation of state
H	= enthalpy of real gas state, B.t.u./lb.
H°	= enthalpy of ideal gas state, B.t.u./lb.
ΔH_v	= latent heat of vaporization, B.t.u./lb.
P	= absolute pressure, atm.
P_c	= critical pressure, atm.
R	= gas constant for isopentane

S	= entropy of real gas state, B.t.u./lb., °R.
S°	= entropy of ideal gas state, B.t.u./lb., °R.
t	= temperature, °F.
T	= absolute temperature, °R., = t °F. + 459.688
V	= specific vapor volume, cu. ft./lb.
V_s	= specific volume of saturated vapor, cu. ft./lb.
V_l	= specific volume of saturated liquid, cu. ft./lb.
z	= compressibility factor, pV/RT

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Compressibility Factors for Helium-Nitrogen Mixtures

FRANK B. CANFIELD¹, T. W. LELAND, and RIKI KOBAYASHI

Department of Chemical Engineering, William Marsh Rice University, Houston, Tex.

Experimental compressibility factors for the helium-nitrogen system from -140° to 0° C. up to 500 atm. were determined by the Burnett method. A total of 1186 compressibility factors for the two pure components and six mixtures are reported. Derived thermodynamic properties of this system are compared with recent calorimetric determinations.

THIS PAPER presents compressibility factors for the helium-nitrogen system from 0° to 140° C. at pressures to 500 atm. Compressibility data for this system have been reported by a number of previous investigators, but no data in the present temperature range have been published. Pfefferle, Goff, and Miller (13), Kramer and Miller (6), and

Witonsky and Miller (17) have published data on the helium-nitrogen system at temperatures from 30° to 475° C. and at pressures to 100 atm. Other data have been collected by Ku (7) at 38.48° and 100° C. up to 295 atm. Miller, Brandt, and Stroud (10) report compressibility factors at 70° F. up to 4000 p.s.i.a. Such an abundance of data has been published for pure helium and pure nitrogen that it will be left to the writers of monographs to review these data. The present authors collected data for the pure components

¹ Present address: School of Chemical Engineering and Materials Science, University of Oklahoma, Norman, Okla.

mainly for the sake of having an internally consistent set of data available for the helium-nitrogen system at low temperature.

EXPERIMENTAL METHOD

The compressibility factors presented in this paper were collected using the Burnett method (1). Temperature and pressure are the only variables measured when using this method. The temperature was measured with a Leeds and Northrup calibrated platinum resistance thermometer and a Type G1 Mueller Bridge to an accuracy approaching $\pm 0.01^\circ\text{C}$. of the International Temperature Scale. The pressure was measured with a set of two Ruska piston gages with ranges from 5 to 2400 p.s.i.g. and 30 to 12,000 p.s.i.g. The effective area of both gages was calibrated as a function of pressure by direct comparison to similar gages which had been calibrated by the National Bureau of Standards to $\pm 0.01^\circ\text{C}$. Details of the original apparatus are given by

Mueller and coworkers (11, 12), and the apparatus, as modified for use in this study, is described by Canfield and coworkers (2, 3).

The gas mixtures were prepared from U. S. Bureau of Mines Grade A helium and Matheson's prepurified grade of nitrogen. The composition of the mixtures and the purity of the helium and nitrogen were determined by several mass spectrographic analyses and an experimental determination of molecular weights. The recommended compositions are presented in Table I. A complete discussion of the purity and composition analyses has been published (2).

RESULTS

Compressibility factors were determined for pure helium, pure nitrogen, and six helium-nitrogen mixtures whose compositions are given in Table I. In each case, isotherms were measured at 0° , -50° , -90° , -115° , -130° , and -140°C .

Table I. Experimental Compressibility Factors

$T = 273.15^\circ\text{K.}$		$T = 223.13^\circ\text{K.}$		$T = 183.15^\circ\text{K.}$		$T = 158.15^\circ\text{K.}$		$T = 143.14^\circ\text{K.}$		$T = 133.15^\circ\text{K.}$	
$P,$ atm.	$Z =$ PV/RT	$P,$ atm.	$Z =$ PV/RT	$P,$ atm.	$Z =$ PV/RT	$P,$ atm.	$Z =$ PV/RT	$P,$ atm.	$Z =$ PV/RT	$P,$ atm.	$Z =$ PV/RT
Helium											
520.329	1.26434	525.808	1.33180	524.037	1.40479	532.043	1.47822	523.063	1.51931	517.286	1.55392
320.158	1.16605	317.470	1.20508	309.939	1.24504	308.424	1.28388	299.261	1.30378	293.245	1.32100
202.661	1.10654	198.651	1.13029	191.587	1.15350	188.453	1.17559	181.534	1.18650	176.933	1.19551
130.621	1.06929	127.122	1.08430	121.698	1.09831	118.895	1.11158	113.979	1.11773	110.786	1.12291
85.1711	1.04541	82.5174	1.05518	78.6385	1.06387	76.5069	1.07207	73.1064	1.07571	70.9500	1.07884
55.9599	1.02991	54.0599	1.03639	51.3719	1.04186	49.8517	1.04705	47.5245	1.04930	46.0828	1.05123
36.9518	1.01974	35.6299	1.02410	33.7988	1.02760	32.7450	1.03087	31.1594	1.03234	30.1999	1.03354
24.4801	1.01300	23.5768	1.01600	22.3402	1.01825	21.6265	1.02052	20.5431	1.02130	19.9064	1.02208
16.2535	1.00852	15.6424	1.01065	14.8120	1.01211	14.3302	1.01360	13.5941	1.01414	13.1711	1.01457
10.8080	1.00561	10.3958	1.00703	9.8402	1.00801	9.5166	1.00897	9.0162	1.00932	8.7363	1.00963
7.1939	1.00370	6.9178	1.00472	6.5465	1.00536	6.3304	1.00604	5.9903	1.00628	5.8043	1.00638
4.7918	1.00250	4.6067	1.00314	4.3588	1.00352			3.9833	1.00409	3.8607	1.00427
3.1931	1.00172	3.0697	1.00220	2.9044	1.00247			2.6510	1.00279	2.5698	1.00292
417.210	1.21432	418.874	1.26752	425.300	1.33198	418.459	1.38074	420.118	1.42123	408.996	1.44275
260.389	1.13608	257.445	1.16762	256.520	1.20399	248.890	1.23055	246.570	1.25123	238.617	1.26240
166.317	1.08791	162.889	1.10743	160.478	1.12897	154.454	1.14443	151.866	1.15621	146.438	1.16210
107.822	1.05745	104.976	1.06993	102.710	1.08313	98.3806	1.09254	96.2733	1.09976	92.6383	1.10283
70.5727	1.03778	68.4524	1.04596	66.6869	1.05421	63.6882	1.06008	62.1042	1.06450	59.7069	1.06633
46.4846	1.02496	44.9765	1.03035	43.6992	1.03561	41.6580	1.03932	40.5190	1.04214	38.9375	1.04326
30.7451	1.01652	29.7008	1.02011	28.8090	1.02350	27.4319	1.02584	26.6296	1.02775	25.5836	1.02838
20.3897	1.01086	19.6779	1.01331	19.0676	1.01555	18.1431	1.01698	17.5840	1.01835	16.8922	1.01870
13.5483	1.00719	13.0675	1.00889	12.6531	1.01030	12.0364	1.01130	11.6464	1.01211	11.1890	1.01234
9.0131	1.00473	8.6894	1.00585	8.4106	1.00677	7.9997	1.00749	7.7301	1.00806	7.4271	1.00815
6.0013	1.00316	5.7847	1.00396	5.5975	1.00449	5.3236	1.00498	5.1375	1.00533	4.9370	1.00543
3.9983	1.00220	3.8531	1.00263					3.4177	1.00359	3.2847	1.00358
			2.5676	1.00173				2.2751	1.00252	2.1870	1.00252
Mixture A, 0.8768 Mole Fraction of Helium											
523.079	1.31512	528.125	1.38705	526.139	1.46444	526.612	1.53551	68.7748	1.06995	516.978	1.61702
316.473	1.19261	312.507	1.23027	303.816	1.26716	297.289	1.29873	44.7605	1.04489	283.330	1.32893
198.510	1.12147	193.603	1.14268	185.851	1.16180	179.851	1.17742	29.3805	1.02917	169.078	1.18951
127.299	1.07824	123.246	1.09069	117.533	1.10133	113.100	1.10971	19.3855	1.01898	105.629	1.11477
82.7612	1.05106	79.7798	1.05867	75.8035	1.06479	72.7329	1.06961	12.8360	1.01245	67.6977	1.07181
54.2783	1.03361	52.1824	1.03836	49.4823	1.04196	47.4035	1.04489	8.5175	1.00814	44.0342	1.04590
35.8003	1.02224	34.3591	1.02526	32.5461	1.02740	31.1525	1.02926	5.6610	1.00545	28.8985	1.02977
23.7005	1.01476	22.7217	1.01672	21.5098	1.01793	20.5792	1.01915	3.7659	1.00369	19.0695	1.01947
15.7286	1.00981	15.0678	1.01108	14.2612	1.01178	13.6411	1.01261	2.5069	1.00259	12.6276	1.01281
10.4549	1.00651	10.0104	1.00731	9.4742	1.00768	9.0623	1.00835			8.3807	1.00847
6.9571	1.00433	6.6597	1.00495	6.3039	1.00518	6.0298	1.00567			5.5705	1.00566
4.6331	1.00292	4.4332	1.00320	4.1977	1.00344					3.7063	1.00387
		2.9533	1.00219	2.7972	1.00243					2.4678	1.00282
425.213	1.25710	428.435	1.31515	411.813	1.36311	412.702	1.41846	402.427	1.44622	400.830	1.47442
261.602	1.15933	258.848	1.19090	244.734	1.21402	240.832	1.24030	232.069	1.25094	228.779	1.26211
165.767	1.10136	162.358	1.11972	152.197	1.13163	148.411	1.14546	142.171	1.14968	139.514	1.15450
106.972	1.06561	104.149	1.07679	97.1828	1.08316	94.3180	1.09105	90.0695	1.09277	88.2067	1.09499
69.8233	1.04291	67.7383	1.04996	63.0462	1.05338	61.0357	1.05826	58.1745	1.05897	56.9204	1.06005
45.9118	1.02826	44.4421	1.03277	41.3063	1.03461	39.9326	1.03777	38.0065	1.03806	37.1767	1.03870
30.3330	1.01866	29.3236	1.02167	27.2312	1.02251	26.3052	1.02469	25.0075	1.02483	24.4584	1.02521
20.1034	1.01234	19.4178	1.01432	18.0284	1.01485	17.4042	1.01621	16.5283	1.01633	16.1652	1.01656
13.3515	1.00817	12.8891	1.00946	11.9638	1.00963	11.5476	1.01065	10.9546	1.01071	10.7153	1.01096
8.8800	1.00546	8.5685	1.00614	7.9569	1.00666	7.6771	1.00714	7.2748	1.00712	7.1164	1.00730
5.9110	1.00361	5.7033	1.00410	5.2956	1.00441	5.1097	1.00478	4.8371	1.00477	4.7317	1.00484
3.9373	1.00241	3.7989	1.00275	3.5275	1.00303			3.2186	1.00319	3.1491	1.00331
2.6241	1.00180	2.5317	1.00193					2.1428	1.00214		

(Continued on page 94)

Table I. Experimental Compressibility Factors (Continued)

T = 273.15° K.		T = 223.13° K.		T = 183.15° K.		T = 158.15° K.		T = 143.14° K.		T = 133.15° K.	
P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT
Mixture B, 0.7523 Mole Fraction of Helium											
521.545	1.35033	527.855	1.42554	522.135	1.49737	526.936	1.57101	539.040	1.63931	524.840	1.66038
310.915	1.20656	306.480	1.24051	294.458	1.26536	288.145	1.28707	286.013	1.30445	274.579	1.30256
193.753	1.12720	188.558	1.14411	178.952	1.15259	172.983	1.15791	169.634	1.16059	162.222	1.15429
123.897	1.08069	119.782	1.08965	113.127	1.09219	108.875	1.09227	106.281	1.09092	101.632	1.08482
80.4466	1.05211	77.5182	1.05729	73.0729	1.05756	70.2401	1.05618	68.4488	1.05414	65.5281	1.04930
52.7330	1.03410	50.7188	1.03722	47.7852	1.03675	45.9282	1.03514	44.7226	1.03340	42.8670	1.02980
34.7730	1.02249	33.4097	1.02446	31.4778	1.02382	30.2629	1.02235	29.4537	1.02116	28.2612	1.01856
23.0181	1.01491	22.1004	1.01612	20.8280	1.01557	20.0377	1.01465	19.4852	1.01363	18.7112	1.01173
15.2745	1.00988	14.6602	1.01068	13.8204	1.01025	13.2984	1.00937	12.9244	1.00881	12.4201	1.00754
10.1530	1.00657	9.7413	1.00698	9.1872	1.00680	8.8450	1.00630	8.5882	1.00584	8.2567	1.00489
6.7561	1.00437	6.4818	1.00469	6.1145	1.00455	5.8896	1.00439	5.7124	1.00386	5.4939	1.00315
4.4991	1.00294	4.3160	1.00311	4.0723	1.00301	3.9238	1.00303	3.8023	1.00260	3.6579	1.00206
2.9973	1.00191	2.8756	1.00214	2.7141	1.00216	2.6155	1.00216	2.5323	1.00193	2.4367	1.00148
421.936	1.28229	419.701	1.33476	406.636	1.37882	415.785	1.43803	411.140	1.46886	403.014	1.48487
256.778	1.16976	250.568	1.19434	237.953	1.20918	237.088	1.22866	230.221	1.23367	223.036	1.23242
161.940	1.10601	156.546	1.11855	147.442	1.12303	145.372	1.12904	140.217	1.12720	135.408	1.12234
104.275	1.06778	100.332	1.07472	94.1891	1.07542	92.5013	1.07674	89.0174	1.07364	85.9578	1.06881
67.9976	1.04404	65.2677	1.04813	61.2005	1.04750	60.0280	1.04731	57.7225	1.04456	55.7881	1.04065
44.6914	1.02891	42.8401	1.03143	40.1606	1.03047	39.3805	1.02984	37.8567	1.02788	36.6218	1.02486
29.5210	1.01911	28.2769	1.02071	26.5121	1.01981	25.9989	1.01911	24.9836	1.01782	24.1892	1.01558
19.5631	1.01268	18.7315	1.01375	17.5656	1.01294	17.2340	1.01258	16.5483	1.01156	16.0332	1.00991
12.9920	1.00845	12.4364	1.00911	11.6657	1.00851	11.4475	1.00818	10.9850	1.00755	10.6486	1.00630
8.6399	1.00563	8.2691	1.00600	7.7591	1.00561	7.6160	1.00539	7.3026	1.00500	7.0819	1.00407
5.7508	1.00370	5.5045	1.00403	5.1657	1.00369	5.0718	1.00359	4.8585	1.00328	4.7134	1.00259
3.8305	1.00249	3.6666	1.00273	3.4418	1.00256	3.3799	1.00249	3.2348	1.00229	3.1390	1.00174
				2.2946	1.00202	2.2532	1.00177	2.1545	1.00167	2.0913	1.00127
Mixture C, 0.6041 Mole Fraction of Helium											
523.288	1.38135	522.593	1.44733	534.754	1.53493	524.282	1.59010	535.528	1.65911	524.548	1.68863
306.241	1.21166	296.478	1.23051	289.386	1.24463	272.837	1.23971	266.380	1.23753	254.119	1.22664
189.684	1.12510	181.475	1.12901	174.339	1.12384	162.674	1.10770	156.678	1.09186	148.610	1.07600
121.113	1.07706	115.414	1.07640	110.460	1.06736	103.080	1.05199	99.1226	1.03630	94.1967	1.02312
78.6564	1.04881	74.8844	1.04704	71.7035	1.03864	67.1195	1.02669	64.6607	1.01422	61.6376	1.00435
51.5909	1.03149	49.1225	1.02973	47.1108	1.02300	44.2472	1.01448	42.7222	1.00538	40.8345	0.99822
34.0414	1.02055	32.4265	1.01911	31.1510	1.01407	29.3383	1.00824	28.3748	1.00185	27.1786	0.99676
22.5455	1.01351	21.4855	1.01240	20.6700	1.00874	19.5078	1.00489	18.8851	1.00043	18.1189	0.99693
14.9667	1.00888	14.2687	1.00804	13.7500	1.00598	12.9895	1.00295	12.5801	0.99989	12.0844	0.99755
9.9515	1.00589	9.4904	1.00524	9.1524	1.00385	8.6563	1.00185	8.3826	0.99966	8.0593	0.99810
6.6235	1.00392	6.3191	1.00353	6.0979	1.00269	5.7713	1.00122	5.5877	0.99979	5.3743	0.99857
4.4111	1.00255	4.2093	1.00225	4.0645	1.00194			3.7242	0.99980	3.5836	0.99898
2.9395	1.00180	2.8059	1.00169	2.7102	1.00158			2.4824	0.99993	2.3895	0.99933
414.328	1.29532	430.846	1.35776	425.466	1.40351	392.221	1.40253	402.945	1.44783		
249.409	1.16881	251.950	1.19000	241.137	1.19206	218.584	1.17119	216.553	1.16700		
156.820	1.10180	156.582	1.10861	148.457	1.10003	134.418	1.07938	131.775	1.06530		
100.959	1.06352	100.364	1.06527	95.0364	1.05560	86.3496	1.03926	84.5771	1.02578		
65.8793	1.04057	65.3960	1.04063	62.0083	1.03248	56.5749	1.02058	55.5068	1.01001		
43.3340	1.02631	43.0020	1.02590	40.8504	1.01968	37.4048	1.01139	36.7633	1.00366		
28.6437	1.01723	28.4271	1.01679	27.0510	1.01225	24.8345	1.00652	24.4425	1.00118		
18.9922	1.01137	18.8522	1.01099	17.9639	1.00775	16.5241	1.00384	16.2760	1.00027		
12.6174	1.00751	12.5271	1.00722	11.9490	1.00492	11.0074	1.00234	10.8437	0.99988		
8.3931	1.00497	8.3344	1.00470	7.9568	1.00320	7.3369	1.00145	7.2269	0.99982		
5.5876	1.00324	5.5500	1.00312	5.3016	1.00209	4.8925	1.00098	4.8165	0.99978		
3.7224	1.00220	3.6978	1.00206	3.5343	1.00152			3.2104	0.99988		
2.4808	1.00153	2.4650	1.00152	2.3568	1.00122			2.1400	0.99999		
Mixture D, 0.4456 Mole Fraction of Helium											
529.835	1.40741	522.722	1.46197	530.211	1.54225	527.064	1.60652	521.460	1.64900	527.688	1.70504
302.775	1.20544	286.894	1.20245	271.991	1.18544	252.519	1.15306	235.200	1.11528	224.209	1.08621
186.459	1.11289	174.805	1.09823	163.071	1.06526	149.358	1.02207	137.521	0.97821	129.368	0.94011
119.118	1.06595	111.630	1.05137	104.290	1.02122	96.0045	0.98465	88.8622	0.94829	83.9981	0.91571
77.5232	1.04018	72.8440	1.02855	68.4654	1.00501	63.5883	0.97752	59.3691	0.95053	56.6066	0.92578
50.9583	1.02522	48.0266	1.01669	45.4174	0.99943	42.5274	0.97990	39.9970	0.96078	38.4326	0.94298
33.6843	1.01617	31.8269	1.01013	30.2484	0.99787	28.5026	0.98440	26.9488	0.97125	26.0453	0.95873
22.3379	1.01047	21.1479	1.00632	20.1743	0.99773	19.0969	0.98862	18.1166	0.97964	17.5835	0.97106
14.8439	1.00687	14.0731	1.00403	13.4609	0.99802	12.7834	0.99197	12.1515	0.98587	11.3289	0.98007
9.8760	1.00452	9.3733	1.00263	8.9824	0.99840	8.5495	0.99443	8.1356	0.99033	7.9353	0.98639
6.5760	1.00296	6.2463	1.00176	5.9943	0.99885	5.7137	0.99618	5.4398	0.99354	5.3130	0.99083
4.3810	1.00194	4.1635	1.00113	3.9998	0.99919	3.8170	0.99752	3.6334	0.99568	3.5520	0.99382
2.9202	1.00146	2.7760	1.00080	2.6687	0.99948			2.4255	0.99725	2.3725	0.99593
421.952	1.30936	416.689	1.34166	414.035	1.37618	395.667	1.38324	400.923	1.41993	339.977	1.31740
249.795	1.16191	239.486	1.15569	227.068	1.13104	208.034	1.08972	199.120	1.05765	171.199	0.99494
156.500	1.09137	148.966	1.07761	140.008	1.04532	127.779	1.00313	121.022	0.96433	105.747	0.92189
100.838	1.05434	96.0283	1.04140	90.5727	1.01368	83.2849	0.97996	79.2625	0.94755	70.2321	0.91853
65.9270	1.03357	62.9393	1.02330	59.7320	1.00216	55.4290	0.97755	53.1536	0.95334	47.5825	0.93360
43.4459	1.02131										

Table I. Experimental Compressibility Factors (Continued)

T = 273.15° K.		T = 223.13° K.		T = 183.15° K.		T = 158.15° K.		T = 143.14° K.		T = 133.15° K.	
P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT	P, atm.	Z = PV/RT
Mixture E, 0.3006 Mole Fraction of Helium											
523.466	1.41228	521.476	1.46656	523.228	1.53821	523.509	1.61025	523.895	1.66879	528.813	1.73125
292.503	1.18278	274.831	1.15825	250.451	1.10319	224.478	1.03433	202.581	0.96755	185.957	0.91272
179.741	1.08961	166.968	1.05478	149.835	0.98925	132.266	0.91334	117.664	0.84303	106.375	0.78320
115.242	1.04743	107.421	1.01733	97.2862	0.96282	87.0476	0.90093	78.4808	0.84360	71.8614	0.79373
75.3322	1.02662	70.6970	1.00376	64.9016	0.96289	59.1021	0.91685	54.2100	0.87425	50.5034	0.83686
49.7061	1.01571	46.9417	0.99922	43.6126	0.96999	40.3106	0.93731	37.4897	0.90711	35.4133	0.88037
32.9514	1.00965	31.2731	0.99805	29.3218	0.97765	27.4036	0.95509	25.7338	0.93422	24.5487	0.91558
21.8982	1.00611	20.8586	0.99805	19.6869	0.98405	18.5439	0.96877	17.5245	0.95453	16.8282	0.94162
14.5725	1.00396	13.9164	0.99835	13.1961	0.98886	12.4967	0.97857	11.8562	0.96893	11.4368	0.96009
9.7047	1.00256	9.2868	0.99888	8.8335	0.99237	8.3953	0.98541	7.9843	0.97901	7.7252	0.97295
6.4664	1.00171	6.1962	0.99923	5.9070	0.99484	5.6281	0.99022	5.3585	0.98583	5.1951	0.98164
4.3099	1.00114	4.1337	0.99946	3.9473	0.99664	3.7674	0.99357	3.5887	0.99059	3.4838	0.98763
2.8734	1.00085	2.7577	0.99970	2.6363	0.99788			2.3995	0.99378	2.3317	0.99171
419.658	1.30516	398.893	1.30726	395.322	1.32639	376.377	1.32016	356.597	1.29909	352.798	1.30987
244.678	1.14066	225.235	1.10631	208.474	1.04823	185.105	0.97282	164.721	0.90000	151.460	0.84332
153.225	1.07093	140.725	1.03617	129.392	0.97520	114.689	0.90336	102.077	0.83670	93.2899	0.77921
99.0806	1.03830	91.5454	1.01052	85.0710	0.96113	76.6480	0.90488	69.3431	0.85275	64.3215	0.80599
65.0343	1.02187	60.5133	1.00144	56.9612	0.96473	52.2027	0.92374	48.0096	0.88580	45.2716	0.85106
42.9967	1.01303	40.2480	0.99860	38.2999	0.97244	35.5804	0.94371	33.1288	0.91708	31.6400	0.89235
28.5332	1.00803	26.8304	0.99806	25.7412	0.97979	24.1511	0.96015	22.6756	0.94179	21.8517	0.92460
18.9720	1.00504	17.8981	0.99821	17.2734	0.98566	16.3184	0.97244	15.4037	0.95989	14.9355	0.94811
12.6295	1.00323	11.9416	0.99854	11.5740	0.99011	10.9844	0.98116	10.4033	0.97268	10.1285	0.96462
8.4124	1.00204	7.9675	0.99890	7.7450	0.99327	7.3733	0.98722	6.9971	0.98158	6.8307	0.97601
5.6061	1.00132	5.3155	0.99915	5.1776	0.99548	4.9401	0.99144	4.6921	0.98760	4.5894	0.98383
3.7371	1.00092	3.5465	0.99949	3.4594	0.99712	3.3054	0.99436	3.1404	0.99175	3.0753	0.98906
2.4916	1.00067	2.3659	0.99970	2.3103	0.99834			2.0995	0.99479	2.0575	0.99277
Mixture F, 0.1578 Mole Fraction of Helium											
521.246	1.41523	523.699	1.47321	526.831	1.55311	511.460	1.60111	512.249	1.66473	520.348	1.74358
282.760	1.15064	260.633	1.09867	226.217	0.99916	187.198	0.87781	158.122	0.77044	135.914	0.68272
173.422	1.05797	157.961	0.99813	135.080	0.89428	111.000	0.78008	92.9334	0.67931	79.0776	0.59588
111.798	1.02259	102.768	0.97351	89.7068	0.89026	76.0262	0.80082	65.6784	0.72028	57.6498	0.65172
73.5360	1.00852	68.4472	0.97207	61.2035	0.91054	53.5188	0.84498	47.7148	0.78509	43.2531	0.73358
48.7711	1.00294	45.8901	0.97709	41.8475	0.93331	37.4845	0.88708	34.2026	0.84435	31.7396	0.80760
32.4550	1.00077	30.7889	0.98286	28.4869	0.95245	25.9516	0.92056	24.0480	0.89072	22.6695	0.86538
21.6272	0.99998	20.6377	0.98774	19.2904	0.96691	17.7771	0.94521	16.6393	0.92469	15.8435	0.90738
14.4198	0.99976	13.8164	0.99144	13.0057	0.97730	12.0793	0.96270	11.3775	0.94866	10.9049	0.93698
9.6154	0.99966	9.2398	0.99408	8.7409	0.98469	8.1596	0.97477	7.7155	0.96523	7.4266	0.95736
6.4127	0.99971	6.1746	0.99600	5.8596	0.98960	5.4901	0.98309	5.2024	0.97651	5.0220	0.97127
4.2768	0.99978	4.1236	0.99728	3.9222	0.99306	3.6838	0.98879	3.4948	0.98424	3.3798	0.98068
2.8524	0.99988	2.7528	0.99817	2.6229	0.99558			2.3418	0.98952	2.2675	0.98712
411.465	1.28771	400.992	1.28950	380.807	1.27502	367.695	1.27607	345.763	1.24597		
236.078	1.10747	217.796	1.04969	188.248	0.94454	159.449	0.82910	133.155	0.71961		
148.120	1.04174	136.314	0.98485	117.991	0.88742	100.123	0.78028	84.3898	0.68422		
96.3622	1.01615	89.6707	0.97125	79.4125	0.89534	69.4747	0.81153	60.5393	0.73642		
63.6226	1.00597	59.9221	0.97305	54.2941	0.91766	48.9162	0.85644	43.9040	0.80128		
42.2602	1.00193	40.1989	0.97868	37.0831	0.93960	34.1633	0.89655	31.3155	0.85751		
28.1406	1.00041	26.9653	0.98427	25.2011	0.95726	23.5820	0.92763	21.9201	0.90057		
18.7564	0.99986	18.0678	0.98878	17.0397	0.97033	16.1167	0.95028	15.1152	0.93173		
12.5063	0.99969	12.0917	0.99213	11.4753	0.97964	10.9319	0.96617	10.3096	0.95350		
8.3398	0.99963	8.0844	0.99454	7.7053	0.98616	7.3761	0.97717	6.9795	0.96852		
5.5619	0.99968	5.4013	0.99624	5.1631	0.99065	4.9588	0.98469	4.7010	0.97876		
3.7094	0.99973	3.6071	0.99751	3.4549	0.99380	3.3253	0.98980	3.1554	0.98571		
2.4741	0.99987	2.4081	0.99847	2.3098	0.99606			2.1133	0.99053		
Nitrogen											
541.075	1.44686	536.243	1.50112	519.691	1.55607	517.724	1.64644	505.494	1.68821	527.944	1.81943
277.185	1.11084	241.830	1.01436	188.539	0.84574	139.252	0.66327	99.2795	0.49706	70.2686	0.36297
168.959	1.05152	146.072	0.91845	113.650	0.76417	84.5387	0.60351	62.2366	0.46749	45.7880	0.35483
109.719	0.98836	96.7838	0.91230	78.7369	0.79364	62.6301	0.67016	50.1297	0.56496	40.7436	0.47370
72.8169	0.98352	65.6591	0.92789	55.6883	0.84147	46.8375	0.75121	39.8150	0.67323	34.6327	0.60409
48.6554	0.98539	44.6523	0.94606	39.0684	0.88500	34.1654	0.82135	30.1855	0.76580	27.3702	0.71625
32.5585	0.98874	30.2669	0.96145	27.0649	0.91910	24.2914	0.87533	21.9790	0.83661	20.4350	0.80229
21.7813	0.99184	20.4318	0.97308	18.5434	0.94405	16.9302	0.91446	15.5465	0.88787	14.6773	0.86452
14.5620	0.99432	13.7450	0.98147	12.6001	0.96167	11.6350	0.94200	10.7810	0.92380	10.2759	0.90808
9.7286	0.99610	9.2217	0.98726	8.5111	0.97384	7.9185	0.96097	7.3777	0.94851	7.0756	0.93809
6.4963	0.99740	6.1759	0.99132	5.7278	0.98252	5.3534	0.97382	5.0047	0.96540	4.8187	0.95848
4.3361	0.99827	4.1314	0.99427	3.8428	0.98823			3.3750	0.97682	3.2583	0.97234
2.8936	0.99893	2.7606	0.99609	2.5738	0.99227			2.2673	0.98457	2.1926	0.98166
415.028	1.27817	392.254	1.25318	347.981	1.18104	325.698	1.15307	306.066	1.12328	303.459	1.14269
230.431	1.06374	201.333	0.96401	156.331	0.79512	116.391	0.61739	83.5415	0.45981	58.2948	0.32917
144.724	1.00163	127.019	0.91171	100.808	0.76857	77.5440	0.61651	58.8964	0.48635	44.5394	0.37731
94.9597	0.98540	85.1700	0.91650	70.7242	0.80832	58.0531	0.69181	47.6794	0.59073	39.5641	0.50283
63.2324	0.98387	57.8967	0.93405	49.9608	0.85601	43.1725	0.77115</				

With the exception of mixtures *C* and *F* at -140° C., two series of Burnett expansions were made in order to define each isotherm. The first series was initiated at a pressure slightly in excess of 500 atm., and the second series was initiated at a pressure approximately equal to the average of the first two pressures of the first series. As a result, there were usually 24 to 26 points available for each of the 48 isotherms. Table I presents 1186 compressibility factors which define the volumetric behavior of the helium-nitrogen system from 0° to -140° C. up to 500 atm.

DISCUSSION OF RESULTS

The following methods are commonly used when attempting to establish the validity of experimental compressibility data: direct comparison with the results obtained by other investigators; fitting the data to a smooth curve, either graphically or by least squares; performing an error analysis on the experimental method; and comparison of derived thermodynamic data with the same data obtained by more direct methods. The reliability of the present results has been established by all four methods.

Because no other data for helium-nitrogen mixtures have been published in the present temperature range, comparison of results with other work is restricted to the pure components. For nitrogen at 0° C., the average difference in compressibility factors of comparisons made at 50, 100, and 200 atm. between this work and Michels and coworkers (9) was +0.12%, between this work and Holborn and Otto (5) was +0.05%, and between this work and Friedman (4) was +0.02%. At 0° C. and 400 atm., the present value for nitrogen is 0.2% higher than Michels and coworkers (9). For nitrogen at -50° C., the average difference of comparisons made at 50, 100, 200, and 400 atm. between this work and Michels and others (9) was +0.17% with a maximum difference of 0.48% occurring at 50 atm. For helium at 0° C. and 25 atm., the present compressibility factor is 0.03% lower than the value obtained by White and coworkers (16), but 0.03% higher than the value given by Schneider (15). For comparisons made at 25, 50, 100, and 200 atm., the present values are an average of 0.05% higher than the results of Holborn and Otto (5) at 0° C. and at -50° C. for the first three pressures. On the basis of the above comparisons, and also more comprehensive comparisons given by Canfield (2), it was concluded that the present compressibility factors tend to be slightly higher than previous measurements. In a prior publication (3), the same trend was observed in the second virial coefficients derived from the present data.

The compressibility factors for both of the pure components and all of the mixtures have been fitted by least squares to equations of state. Canfield (2) gives the coefficients for the Leiden virial equation for each mixture at each of the six temperatures. Using equations which varied from third degree in density for helium to seventh degree for nitrogen, each isotherm was fitted to 500 atm. An indication of the smoothness or precision of the data was that the average of the absolute value of the difference between the experimental compressibility factors and those calculated from the fitted virial equations was less than 0.01%. More recently, Pfenning, Canfield, and Kobayashi (14) fitted each mixture to a modified form of the Benedict-Webb-Rubin equation of state. Included in each fit were some high temperature data of Kramer and Miller (6) and Miller, Brandt, and Stroud (10). The average deviation in the compressibility factors ranged from 2.9×10^{-4} for helium to 9.1×10^{-4} for nitrogen.

To establish the limits of error in the present results, an error analysis was performed on the Burnett method. The details of this analysis are given elsewhere (3); only the results will be restated here. At the higher limit of error, it was estimated that for nitrogen at -140° C. and 528 atm., the maximum error in the compressibility factor, due to errors in the experimental method, was $\pm 0.15\%$. At the lower limit, the maximum error for helium at 0° C. and 3.2 atm. was estimated to be $\pm 0.02\%$.

The thermodynamic properties of the helium-nitrogen system have been calculated between -220° and 100° F. to 7500 p.s.i.a. using principally the present compressibility factors (14). Mage (8) has experimentally measured the isothermal effect of pressure on enthalpy using a flow calorimeter, and he presents extensive comparisons between his work and similar values calculated from the present data. In summary, differences usually on the order of 1% were found for the isothermal effect of pressure on enthalpy (8). At the lower temperature limits of the present data, differences up to 4% were noted. Because Mage's estimated error was on the order of 0.5%, it is difficult to assign the usually observed difference of 1% to error in one work or the other.

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NOMENCLATURE

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|----------|--|
| <i>P</i> | = absolute pressure |
| <i>R</i> | = gas constant |
| <i>T</i> | = absolute temperature, 0° C. = 273.15° K. |
| <i>V</i> | = volume per mole |
| <i>Z</i> | = compressibility factor |

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