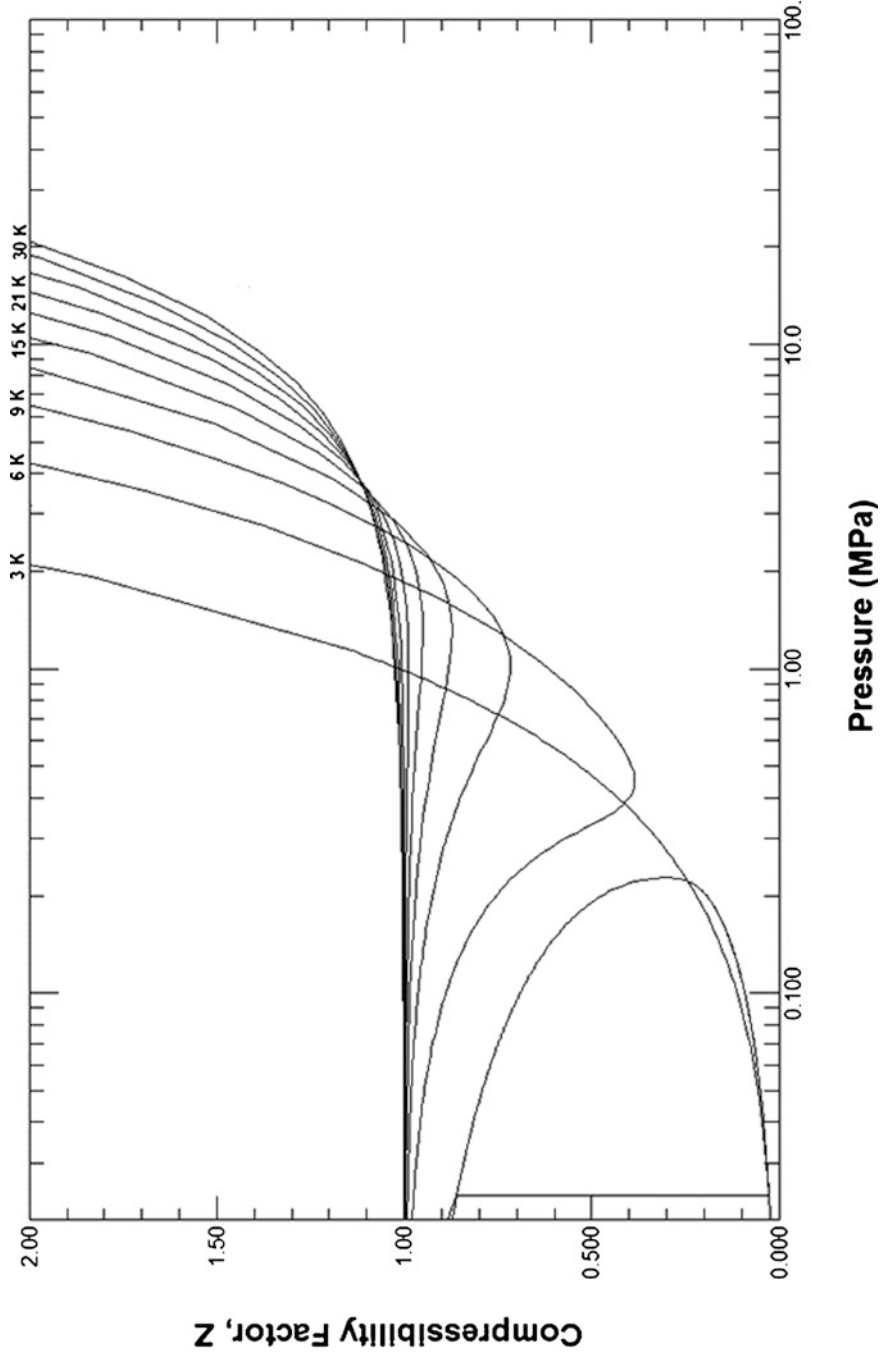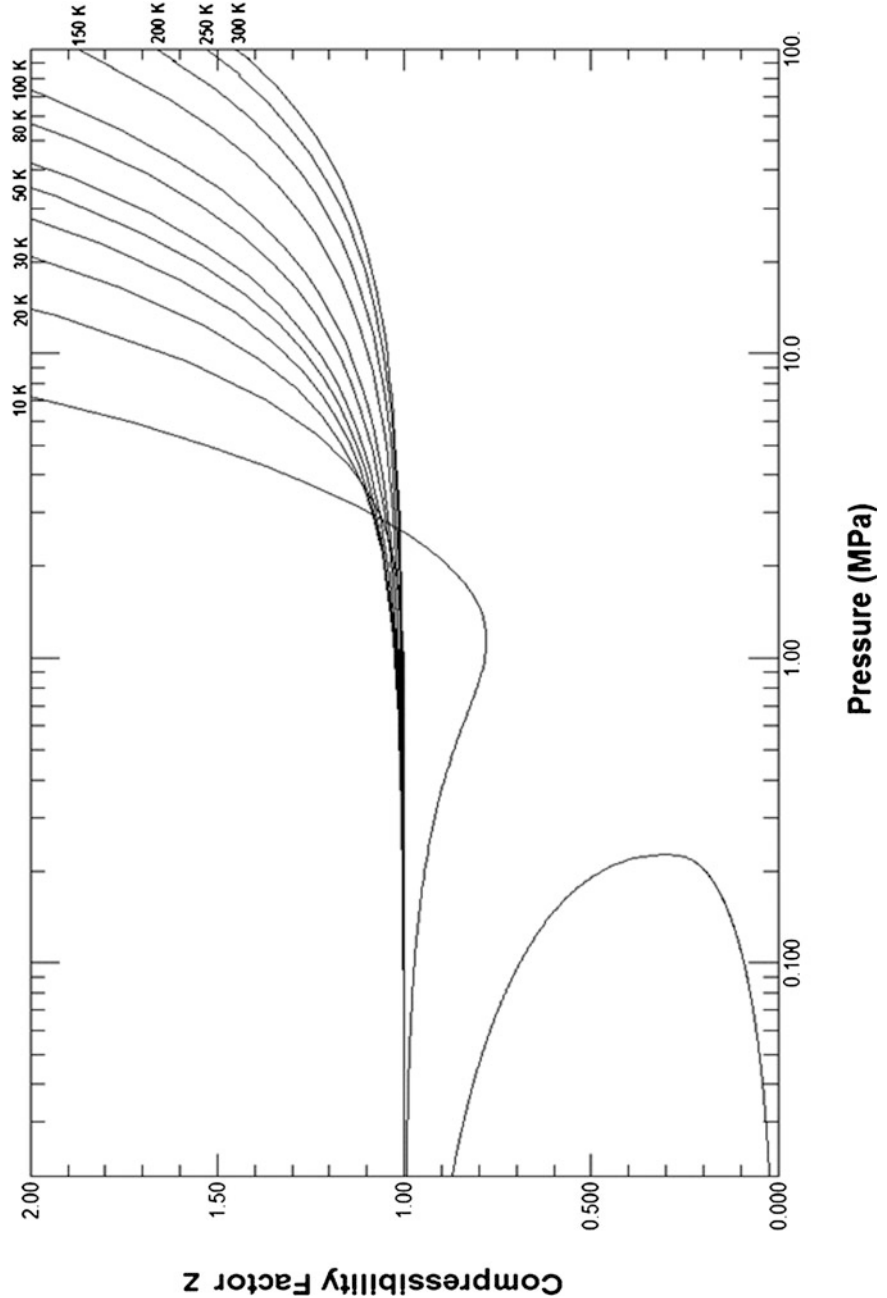# Appendix 1
Compressibility Factor for Helium

Appendix 2
Properties of Liquid Helium

Appendix A2.1 Properties of helium at saturated vapor pressure

T(K)	p_{svp}(Pa)	ρ_L(kg/m³)	ρ_v(kg/m³)	h(kJ/kg)	s(kJ/kg K)	h_{fg}(kJ/kg)	σ(mN/m)	κ(1/MPa)	β(1/K)	μ(μPa s)	k(mW/m K)
1.0	15.57	145.157	0.008	0.0127	0.0163	20.083	0.3489	0.1214	0.000185		
1.2	81.48	145.162	0.033	0.0518	0.0510	21.024	0.3439	0.1219	−0.000579		
1.4	282.00	145.199	0.098	0.1579	0.1308	21.861	0.3365	0.1223	−0.001738		
1.6	746.36	145.278	0.230	0.3923	0.2839	22.533	0.3268	0.1254	−0.003211		
1.8	1,638.41	145.416	0.455	0.8422	0.5437	22.977	0.3151	0.1284	−0.005283		
2.0	3,129.26	145.654	0.794	1.6420	0.9578	23.046	0.3016	0.1341	−0.009960		
2.1768	5,041.80	146.150	1.192	2.9490	1.5740	22.796	0.2880	0.1466	−0.051060		
2.2	5,335.15	146.150	1.251	3.0900	1.6380	22.461	0.2865	0.1424	0.010264	2.60404	13.630
2.4	8,354.10	145.494	1.828	3.6780	1.8860	22.623	0.2700	0.1470	0.033190	3.04356	14.500
2.6	12,372.07	144.429	2.549	4.1610	2.0680	22.906	0.2522	0.1589	0.045730	3.28415	15.265
2.8	17,551.76	143.035	3.433	4.6620	2.2400	23.132	0.2334	0.1756	0.057890	3.44756	15.946
3.0	24,047.07	141.354	4.499	5.1950	2.4080	23.255	0.2138	0.1940	0.070030	3.56870	16.550
3.2	32,009.97	139.442	5.767	5.7870	2.5810	23.265	0.1935	0.2162	0.082680	3.63809	17.087
3.4	41,594.70	137.267	7.267	6.4480	2.7600	23.146	0.1728	0.2449	0.096970	3.61874	17.548
3.6	52,956.31	134.813	9.033	7.1830	2.9460	22.870	0.1518	0.2826	0.113800	3.47190	17.937
3.8	66,247.39	132.050	11.111	7.9980	3.1400	22.406	0.1309	0.3337	0.134870	3.37654	18.247
4.0	81,619.69	128.929	13.564	8.8990	3.3400	21.724	0.1101	0.4053	0.162220	3.28009	18.481
4.2	99,233.46	125.372	16.487	9.9010	3.5510	20.790	0.0896	0.5112	0.200050	3.17862	18.644
4.4	119,269.30	121.252	20.035	11.0200	3.7740	19.537	0.0697	0.6803	0.256600	3.07087	18.754
4.6	141,930.40	116.339	24.489	12.3100	4.0180	17.829	0.0506	0.9831	0.351500	2.95366	18.843
4.8	167,429.50	110.162	30.445	13.8400	4.2960	15.397	0.0324	1.3840	0.544370	2.81969	18.973
5.0	196,003.90	100.890	39.327	15.9200	4.6640	11.726	0.0153	4.1530	1.207200	2.63572	19.300
5.1953	227,462.30	69.641	69.641	21.9500	5.7680	0.000	0.0000				

Appendix A2.2 Pressure 0.1 MPa

T(K)	ρ(kg/m^3)	h(kJ/kg)	s(kJ/kg K)	C$_p$(kJ/kg K)	C$_v$(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	146.90	0.697	0.016	0.102	0.102		
1.2	146.90	0.737	0.051	0.322	0.322		
1.4	146.90	0.843	0.132	0.787	0.787		
1.6	147.00	1.075	0.287	1.614	1.612		
1.8	147.20	1.522	0.548	2.959	2.953		
2.0	147.50	2.319	0.966	5.249	5.227		
T$_\lambda$ = 2.168	148.00	3.56	1.56	27.88	25.67		
2.2	148.00	3.719	1.631	3.777	3.765	2.715	13.859
2.4	147.40	4.257	1.866	2.282	2.173	3.140	14.746
2.6	146.30	4.696	2.042	2.233	2.029	3.364	15.529
2.8	145.00	5.147	2.209	2.308	1.978	3.515	16.226
3.0	143.30	5.623	2.373	2.496	2.017	3.634	16.844
3.2	141.40	6.150	2.543	2.784	2.135	3.715	17.383
3.4	139.10	6.739	2.721	3.108	2.253	3.718	17.838
3.6	136.50	7.395	2.909	3.463	2.353	3.585	18.204
3.8	133.50	8.128	3.107	3.874	2.432	3.456	18.469
4.0	129.90	8.952	3.318	4.396	2.495	3.327	18.624
4.2	125.40	9.902	3.550	5.161	2.547	3.181	18.651
T$_{svp}$ = 4.2163	125.01	9.987	3.570	5.243	2.551	3.168	18.648
T$_{svp}$ = 4.2163	16.533	31.81	8.510	9.015	3.240	1.241	9.004
4.4	14.940	32.37	8.872	8.056	3.217	1.274	9.275
4.6	13.640	33.92	9.215	7.436	3.194	1.312	9.586
4.8	12.620	35.36	9.523	7.027	3.175	1.350	9.901
5.0	11.780	36.74	9.803	6.735	3.159	1.389	10.216
5.2	11.070	38.06	10.06	6.517	3.146	0.000	10.528
6	9.028	43.05	10.96	6.011	3.120	1.579	11.736
7	7.426	48.89	11.86	5.724	3.111	1.761	13.161
8	6.344	54.54	12.61	5.575	3.111	1.935	14.491
9	5.555	60.06	13.26	5.485	3.113	2.100	15.729
10	4.949	65.52	13.84	5.426	3.115	2.258	16.889
12	4.074	76.29	14.82	5.353	3.118	2.557	19.025
14	3.468	86.95	15.64	5.310	3.120	2.835	20.983
16	3.023	97.54	16.35	5.282	3.120	3.097	22.811
18	2.680	108.1	16.97	5.264	3.121	3.345	24.543
20	2.408	118.6	17.52	5.250	3.121	3.582	26.198
22	2.187	129.1	18.02	5.240	3.121	3.808	27.792
24	2.003	139.6	18.48	5.232	3.120	4.025	29.333
26	1.848	150.0	18.90	5.226	3.120	4.235	30.831
28	1.716	160.5	19.28	5.221	3.120	4.437	32.290
30	1.601	170.9	19.64	5.218	3.120	4.634	33.716
40	1.200	223.0	21.14	5.206	3.119	5.542	40.444
50	0.961	275.0	22.30	5.201	3.118	6.360	46.678
60	0.801	327.0	23.25	5.198	3.118	7.116	52.552
70	0.686	379.0	24.05	5.196	3.117	7.827	58.149

Appendix A2.2 (continued)

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
80	0.601	431.0	24.75	5.195	3.117	8.503	63.518
90	0.534	482.9	25.36	5.195	3.117	9.152	68.697
100	0.481	534.9	25.91	5.194	3.117	9.778	73.713
125	0.385	664.7	27.07	5.194	3.116	11.090	85.663
150	0.321	794.6	28.01	5.193	3.116	12.500	96.937
175	0.275	924.4	28.81	5.193	3.116	13.850	107.679
200	0.241	1,054	29.51	5.193	3.116	15.140	117.982
225	0.214	1,184	30.12	5.193	3.116	16.390	127.917
250	0.193	1,314	30.66	5.193	3.116	17.600	137.535
275	0.175	1,444	31.16	5.193	3.116	18.780	146.877
300	0.160	1,574	31.61	5.193	3.116	19.930	155.973

Appendix A2.3 Pressure 0.2 MPa

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	148.50	1.374	0.016	0.104	0.104		
1.2	148.50	1.414	0.052	0.328	0.328		
1.4	148.50	1.522	0.134	0.797	0.796		
1.6	148.60	1.757	0.290	1.631	1.628		
1.8	148.90	2.208	0.554	2.990	2.979		
2.0	149.30	3.015	0.977	5.323	5.285		
$T_\lambda = 2.158$	149.90	4.185	1.537	25.010	22.860		
2.2	149.90	4.375	1.625	3.419	3.406	2.846	14.135
2.4	149.30	4.885	1.847	2.195	2.097	3.260	15.048
2.6	148.30	5.306	2.016	2.153	1.972	3.471	15.860
2.8	147.10	5.738	2.175	2.209	1.918	3.613	16.590
3.0	145.70	6.192	2.332	2.387	1.966	3.733	17.247
3.2	143.90	6.695	2.494	2.653	2.087	3.834	17.830
3.4	141.90	7.255	2.664	2.943	2.209	3.881	18.337
3.6	139.70	7.874	2.841	3.246	2.310	3.809	18.710
3.8	137.10	8.555	3.025	3.570	2.390	3.675	19.053
4.0	134.10	9.305	3.217	3.940	2.451	3.557	19.304
4.2	130.70	10.140	3.420	4.395	2.499	3.432	19.459
4.4	126.60	11.070	3.638	5.014	2.540	3.298	19.512
4.6	121.60	12.160	3.880	5.984	2.579	3.147	19.470
4.8	114.80	13.530	4.170	7.942	2.623	2.964	19.352
5.0	102.80	15.680	4.608	16.580	2.696	2.683	19.294
$T_{svp} = 5.0356$	98.60	16.387	4.749	24.548	2.722	2.593	19.439
$T_{svp} = 5.0356$	40.36	27.842	7.023	34.804	3.040	1.721	14.136
5.2	32.030	31.140	7.669	14.290	3.081	1.670	12.791
6	21.260	38.840	9.057	7.737	3.096	1.734	12.768
7	16.260	45.850	10.140	6.519	3.095	1.882	13.834
8	13.450	52.110	10.980	6.064	3.100	2.036	15.040

(continued)

Appendix A2.3 (continued)

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
9	11.560	58.050	11.680	5.828	3.106	2.188	16.203
10	10.180	63.800	12.280	5.685	3.112	2.337	17.308
12	8.271	74.990	13.300	5.520	3.119	2.622	19.368
14	6.994	85.930	14.150	5.429	3.123	2.891	21.274
16	6.071	96.720	14.870	5.372	3.125	3.146	23.066
18	5.370	107.400	15.500	5.334	3.125	3.389	24.769
20	4.818	118.100	16.060	5.306	3.125	3.621	26.403
22	4.371	128.700	16.560	5.286	3.125	3.844	27.979
24	4.001	139.200	17.020	5.271	3.125	4.059	29.507
26	3.690	149.700	17.440	5.259	3.124	4.266	30.993
28	3.424	160.300	17.830	5.249	3.124	4.467	32.443
30	3.194	170.700	18.190	5.242	3.124	4.661	33.861
40	2.395	223.000	19.700	5.219	3.122	5.564	40.563
50	1.916	275.200	20.860	5.209	3.120	6.379	46.783
60	1.598	327.200	21.810	5.203	3.119	7.134	52.650
70	1.370	379.200	22.610	5.200	3.119	7.843	58.242
80	1.199	431.200	23.310	5.198	3.118	8.518	63.608
90	1.066	483.200	23.920	5.197	3.118	9.165	68.785
100	0.960	535.100	24.470	5.196	3.118	9.791	73.799
125	0.768	665.000	25.630	5.194	3.117	11.100	85.746
150	0.641	794.900	26.570	5.194	3.117	12.510	97.019
175	0.549	924.700	27.370	5.193	3.117	13.860	107.759
200	0.481	1,055.000	28.070	5.193	3.116	15.150	118.062
225	0.427	1,184.000	28.680	5.193	3.116	16.400	127.996
250	0.385	1,314.000	29.230	5.193	3.116	17.610	137.614
275	0.350	1,444.000	29.720	5.193	3.116	18.790	146.955
300	0.321	1,574.000	30.170	5.193	3.116	19.930	156.050

Appendix A2.4 Pressure 0.5 MPa

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	152.80	3.365	0.016	0.109	0.109		
1.2	152.80	3.407	0.054	0.346	0.346		
1.4	152.90	3.520	0.140	0.838	0.836		
1.6	153.10	3.767	0.304	1.705	1.697		
1.8	153.40	4.238	0.579	3.117	3.088		
2.0	154.00	5.081	1.021	5.604	5.510		
$T_\lambda = 2.127$	154.80	6.024	1.477	39.540	30.460		
2.2	154.80	6.301	1.605	2.696	2.681	3.308	15.561
2.4	154.20	6.743	1.798	1.985	1.900	3.685	16.538
2.6	153.50	7.125	1.951	1.976	1.830	3.852	17.424
2.8	152.50	7.513	2.095	1.993	1.774	3.962	18.236
3.0	151.40	7.920	2.235	2.151	1.839	4.075	18.982
3.2	150.10	8.373	2.381	2.385	1.972	4.209	19.665

Appendix A2.4 (continued)

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
3.4	148.50	8.874	2.533	2.629	2.101	4.338	20.283
3.6	146.80	9.424	2.690	2.864	2.208	4.387	19.937
3.8	145.00	10.020	2.851	3.093	2.291	4.244	20.421
4.0	142.90	10.660	3.016	3.321	2.354	4.133	20.836
4.2	140.60	11.350	3.183	3.558	2.402	4.020	21.180
4.4	138.10	12.090	3.355	3.815	2.439	3.909	21.453
4.6	135.40	12.880	3.531	4.104	2.470	3.797	21.655
4.8	132.40	13.730	3.712	4.440	2.497	3.685	21.789
5.0	129.00	14.660	3.901	4.846	2.523	3.573	21.861
5.2	125.20	15.680	4.101	5.354	2.548	3.458	21.879
6	102.10	21.420	5.121	10.040	2.689	2.942	21.179
7	59.44	33.930	7.047	11.650	2.946	2.443	17.870
8	41.34	43.780	8.366	8.505	3.031	2.412	17.670
9	32.87	51.560	9.285	7.241	3.068	2.488	18.308
10	27.76	58.470	10.010	6.635	3.090	2.592	19.111
12	21.60	71.080	11.160	6.065	3.116	2.824	20.810
14	17.89	82.920	12.080	5.796	3.129	3.061	22.495
16	15.35	94.340	12.840	5.641	3.135	3.294	24.131
18	13.49	105.500	13.500	5.541	3.137	3.520	25.717
20	12.05	116.500	14.080	5.472	3.138	3.740	27.259
22	10.90	127.400	14.600	5.422	3.138	3.952	28.762
24	9.957	138.200	15.070	5.384	3.137	4.159	30.229
26	9.171	149.000	15.500	5.354	3.137	4.359	31.664
28	8.503	159.600	15.890	5.331	3.136	4.554	33.071
30	7.929	170.300	16.260	5.312	3.135	4.744	34.452
40	5.940	223.100	17.780	5.257	3.130	5.631	41.030
50	4.756	275.500	18.950	5.231	3.127	6.437	47.180
60	3.968	327.800	19.900	5.218	3.125	7.185	53.005
70	3.405	379.900	20.710	5.210	3.123	7.890	58.568
80	2.982	432.000	21.400	5.205	3.122	8.561	63.914
90	2.653	484.000	22.010	5.202	3.121	9.206	69.077
100	2.390	536.000	22.560	5.199	3.120	9.829	74.080
125	1.914	665.900	23.720	5.196	3.119	11.130	86.010
150	1.597	795.800	24.670	5.195	3.118	12.540	97.272
175	1.370	925.700	25.470	5.194	3.118	13.880	108.005
200	1.199	1,056.000	26.160	5.193	3.117	15.170	118.303
225	1.066	1,185.000	26.780	5.193	3.117	16.420	128.233
250	0.960	1,315.000	27.320	5.193	3.117	17.620	137.847
275	0.873	1,445.000	27.820	5.193	3.117	18.800	147.184
300	0.801	1,575.000	28.270	5.193	3.117	19.940	0.156

Appendix A2.5 Pressure 1.0 MPa

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	158.70	6.578	0.020	0.133	0.133		
1.2	158.80	6.627	0.064	0.393	0.391		
1.4	159.00	6.753	0.160	0.919	0.911		
1.6	159.30	7.021	0.338	1.842	1.820		
1.8	159.80	7.530	0.636	3.384	3.320		
2.0	160.80	8.471	1.128	6.538	6.243		
$T_\lambda = 2.068$	161.40	9.020	1.398	39.200	25.520		
2.2	161.40	9.388	1.571	2.026	2.003	4.215	15.604
2.4	160.80	9.753	1.730	1.730	1.652	4.497	16.671
2.6	160.20	10.09	1.868	1.777	1.661	4.569	17.655
2.8	159.60	10.44	1.997	1.761	1.602	4.607	18.574
3.0	158.70	10.80	2.121	1.900	1.683	4.689	19.433
3.2	157.70	11.20	2.250	2.115	1.829	4.842	20.234
3.4	156.50	11.64	2.385	2.331	1.967	5.039	20.978
3.6	155.30	12.13	2.524	2.530	2.082	5.217	21.508
3.8	153.90	12.65	2.665	2.712	2.171	5.090	22.134
4.0	152.40	13.21	2.809	2.882	2.238	4.962	22.698
4.2	150.80	13.81	2.954	3.045	2.290	4.837	23.203
4.4	149.10	14.43	3.099	3.206	2.330	4.716	23.648
4.6	147.30	15.09	3.245	3.369	2.363	4.599	24.033
4.8	145.40	15.78	3.392	3.539	2.391	4.487	24.360
5.0	143.30	16.51	3.540	3.718	2.416	4.379	24.631
5.2	141.10	17.27	3.690	3.909	2.439	4.276	24.848
6	130.90	20.75	4.311	4.849	2.531	3.901	25.217
7	114.10	26.41	5.180	6.584	2.659	3.506	24.643
8	93.31	33.93	6.181	8.248	2.806	3.215	23.462
9	74.62	42.33	7.170	8.341	2.932	3.083	22.862
10	61.35	50.42	8.023	7.819	3.013	3.066	22.888
12	45.58	65.06	9.361	6.898	3.094	3.172	23.747
14	36.76	78.28	10.38	6.370	3.128	3.345	24.974
16	31.07	90.68	11.21	6.060	3.145	3.537	26.308
18	27.04	102.6	11.91	5.863	3.153	3.735	27.671
20	24.02	114.2	12.52	5.728	3.156	3.933	29.039
22	21.65	125.5	13.06	5.631	3.157	4.129	30.399
24	19.73	136.7	13.55	5.558	3.156	4.322	31.747
26	18.14	147.8	13.99	5.502	3.155	4.512	33.081
28	16.81	158.7	14.40	5.458	3.153	4.698	34.401
30	15.66	169.6	14.77	5.422	3.152	4.880	35.706
40	11.72	223.2	16.32	5.316	3.143	5.740	42.014
50	9.397	276.1	17.50	5.268	3.137	6.531	48.003
60	7.850	328.7	18.45	5.242	3.133	7.269	53.721
70	6.743	381.0	19.26	5.226	3.130	7.967	59.211
80	5.912	433.2	19.96	5.217	3.128	8.633	64.504
90	5.264	485.3	20.57	5.210	3.126	9.273	69.627
100	4.745	537.4	21.12	5.206	3.125	9.892	74.600
125	3.806	667.5	22.28	5.199	3.122	11.190	86.478

(continued)

Appendix A2.5 (continued)

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
150	3.178	797.4	23.23	5.196	3.121	12.590	97.709
175	2.728	927.3	24.03	5.195	3.120	13.930	108.421
200	2.390	1,057.0	24.72	5.194	3.119	15.210	118.704
225	2.126	1,187.0	25.34	5.193	3.119	16.450	128.623
250	1.915	1,317.0	25.88	5.193	3.118	17.650	138.228
275	1.742	1,447.0	26.38	5.192	3.118	18.820	147.558
300	1.597	1,576.0	26.83	5.192	3.118	19.960	156.645

Appendix A2.6 Pressure 1.5 MPa

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	163.80	9.685	0.028	0.169	0.168		
1.2	164.00	9.744	0.080	0.448	0.445		
1.4	164.20	9.883	0.187	1.007	0.996		
1.6	164.60	10.18	0.380	2.012	1.973		
1.8	165.30	10.74	0.710	3.818	3.669		
2.0	166.80	11.89	1.310	10.310	8.875		
$T_\lambda = 2.003$	166.90	11.92	1.326	31.620	18.990		
2.2	166.80	12.36	1.536	1.654	1.624	5.198	16.101
2.4	166.30	12.67	1.673	1.586	1.515	5.335	17.249
2.6	165.70	12.99	1.803	1.634	1.540	5.276	18.317
2.8	165.20	13.31	1.924	1.593	1.471	5.228	19.324
3.0	164.40	13.64	2.037	1.730	1.565	5.277	20.275
3.2	163.60	14.01	2.155	1.935	1.718	5.448	21.172
3.4	162.70	14.42	2.279	2.138	1.862	5.702	22.012
3.6	161.70	14.86	2.406	2.322	1.981	5.993	22.792
3.8	160.50	15.34	2.536	2.486	2.074	5.903	23.519
4.0	159.40	15.85	2.668	2.634	2.146	5.748	24.188
4.2	158.10	16.40	2.800	2.773	2.201	5.600	24.800
4.4	156.70	16.96	2.932	2.905	2.245	5.457	25.354
4.6	155.30	17.56	3.064	3.035	2.281	5.321	25.852
4.8	153.80	18.18	3.196	3.166	2.311	5.192	26.295
5.0	152.20	18.82	3.328	3.299	2.339	5.070	26.685
5.2	150.50	19.50	3.460	3.436	2.365	4.953	27.023
6	143.00	22.48	3.992	4.040	2.462	4.548	27.904
7	131.70	26.96	4.681	4.952	2.584	4.152	28.124
8	118.50	32.44	5.411	6.006	2.706	3.858	27.677
9	103.90	38.93	6.175	6.925	2.821	3.655	27.024
10	89.98	46.11	6.930	7.337	2.922	3.546	26.587
12	68.77	60.71	8.262	7.145	3.054	3.524	26.683
14	55.39	74.56	9.330	6.713	3.117	3.626	27.478
16	46.58	87.62	10.20	6.369	3.148	3.776	28.535
18	40.37	100.10	10.94	6.121	3.163	3.945	29.698
20	35.75	112.20	11.57	5.943	3.170	4.122	30.909
22	32.15	123.90	12.13	5.812	3.172	4.302	32.140

Appendix A2.6 (continued)

T(K)	$\rho(kg/m^3)$	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	$\mu(\mu Pa\ s)$	k(mW/m K)
24	29.26	135.40	12.63	5.711	3.172	4.482	33.378
26	26.88	146.80	13.09	5.634	3.171	4.661	34.618
28	24.88	158.00	13.50	5.572	3.169	4.838	35.854
30	23.18	169.10	13.89	5.522	3.167	5.012	37.085
40	17.36	223.40	15.45	5.372	3.156	5.847	43.119
50	13.93	276.80	16.64	5.303	3.148	6.624	48.930
60	11.65	329.60	17.60	5.265	3.141	7.352	54.526
70	10.02	382.10	18.41	5.242	3.137	8.043	59.928
80	8.792	434.50	19.11	5.228	3.133	8.704	65.156
90	7.834	486.70	19.73	5.219	3.131	9.339	70.228
100	7.066	538.80	20.28	5.212	3.129	9.955	75.161
125	5.677	669.00	21.44	5.203	3.125	11.240	86.971
150	4.745	799.00	22.39	5.198	3.123	12.640	98.159
175	4.076	928.90	23.19	5.195	3.122	13.970	108.842
200	3.572	1,059.00	23.88	5.194	3.121	15.250	119.105
225	3.179	1,189.00	24.49	5.193	3.120	16.480	129.009
250	2.864	1,318.00	25.04	5.192	3.119	17.680	138.602
275	2.606	1,448.00	25.54	5.192	3.119	18.840	147.923
300	2.391	1,578.00	25.99	5.192	3.119	19.980	157.003

Appendix A2.7 Pressure 2.0 MPa

T(K)	$\rho(kg/m^3)$	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	$\mu(\mu Pa\ s)$	k(mW/m K)
1.0	168.40	12.70	0.035	0.198	0.197		
1.2	168.50	12.77	0.095	0.503	0.500		
1.4	168.70	12.92	0.214	1.126	1.112		
1.6	169.20	13.25	0.433	2.290	2.218		
1.8	170.20	13.91	0.817	4.570	4.216		
$T_\lambda = 1.932$	171.60	14.74	1.258	31.000	15.730		
2.0	171.80	14.92	1.351	1.926	1.926	5.664E-06	15.358
2.2	171.50	15.24	1.502	1.429	1.394	6.172E-06	16.654
2.4	171.00	15.52	1.624	1.511	1.447	6.111E-06	17.875
2.6	170.40	15.83	1.751	1.525	1.446	5.904E-06	19.021
2.8	169.90	16.14	1.867	1.463	1.367	5.776E-06	20.107
3.0	169.30	16.44	1.972	1.602	1.471	5.817E-06	21.139
3.2	168.50	16.78	2.082	1.799	1.627	6.035E-06	22.118
3.4	167.80	17.16	2.197	1.993	1.774	6.364E-06	23.043
3.6	166.90	17.58	2.316	2.167	1.895	6.774E-06	23.911
3.8	166.00	18.03	2.437	2.321	1.991	6.720E-06	24.723
4.0	164.90	18.51	2.560	2.459	2.065	6.534E-06	25.478
4.2	163.90	19.01	2.683	2.585	2.123	6.355E-06	26.176
4.4	162.70	19.54	2.806	2.704	2.170	6.186E-06	26.817
4.6	161.50	20.09	2.929	2.819	2.209	6.025E-06	27.403
4.8	160.20	20.67	3.051	2.933	2.242	5.874E-06	27.934
5.0	158.90	21.26	3.173	3.047	2.273	5.730E-06	28.412

Appendix A2.7 (continued)

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
5.2	157.50	21.89	3.295	3.163	2.301	5.596E-06	28.839
6	151.30	24.61	3.781	3.652	2.408	5.131E-06	30.080
7	142.30	28.59	4.394	4.333	2.539	4.690E-06	30.754
8	132.10	33.29	5.021	5.074	2.662	4.367E-06	30.738
9	120.90	38.74	5.662	5.814	2.773	4.137E-06	30.345
10	109.30	44.88	6.307	6.420	2.870	3.985E-06	29.875
12	88.17	58.35	7.534	6.892	3.016	3.866E-06	29.463
14	72.39	72.05	8.590	6.766	3.101	3.902E-06	29.847
16	61.22	85.34	9.478	6.517	3.146	4.010E-06	30.649
18	53.13	98.14	10.230	6.288	3.169	4.150E-06	31.639
20	47.04	110.50	10.880	6.101	3.180	4.307E-06	32.717
22	42.29	122.60	11.460	5.954	3.185	4.471E-06	33.841
24	38.48	134.40	11.970	5.838	3.186	4.638E-06	34.989
26	35.34	145.90	12.430	5.745	3.186	4.807E-06	36.148
28	32.71	157.30	12.860	5.671	3.184	4.975E-06	37.313
30	30.47	168.60	13.250	5.609	3.181	5.142E-06	38.480
40	22.84	223.70	14.830	5.424	3.168	5.953E-06	44.265
50	18.35	277.40	16.030	5.335	3.157	6.715E-06	49.905
60	15.37	330.50	17.000	5.287	3.149	7.435E-06	55.378
70	13.23	383.20	17.810	5.258	3.143	8.119E-06	60.687
80	11.62	435.70	18.510	5.239	3.139	8.774E-06	65.844
90	10.36	488.00	19.130	5.227	3.136	9.405E-06	70.860
100	9.355	540.30	19.680	5.218	3.133	1.002E-05	75.749
125	7.526	670.50	20.840	5.206	3.128	1.129E-05	87.480
150	6.296	800.60	21.790	5.199	3.126	1.268E-05	98.618
175	5.412	930.50	22.590	5.196	3.124	1.401E-05	109.267
200	4.746	1,060.0	23.290	5.194	3.122	1.528E-05	119.505
225	4.226	1,190.0	23.900	5.193	3.121	1.651E-05	129.391
250	3.809	1,320.0	24.440	5.192	3.120	1.770E-05	138.971
275	3.466	1,450.0	24.940	5.192	3.120	1.886E-05	148.281
300	3.180	1,580.0	25.390	5.192	3.119	2.000E-05	157.352

Appendix A2.8 Pressure 2.5 MPa

T(K)	ρ(kg/m³)	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	μ(μPa s)	k(mW/m K)
1.0	172.50	15.640	0.041	0.220	0.220		
1.2	172.60	15.720	0.107	0.569	0.566		
1.4	172.80	15.890	0.244	1.304	1.280		
1.6	173.50	16.280	0.501	2.734	2.583		
1.8	175.00	17.090	0.976	5.937	5.042		
$T_\lambda = 1.855$	175.90	17.500	1.195	29.960	12.640		
2.0	176.00	17.780	1.342	1.412	1.404	6.878	15.783
2.2	175.70	18.040	1.468	1.287	1.248	7.050	17.147
2.4	175.10	18.300	1.582	1.465	1.405	6.757	18.438
2.6	174.60	18.620	1.708	1.441	1.373	6.412	19.656

(continued)

Appendix A2.8 (continued)

T(K)	$\rho(kg/m^3)$	h(kJ/kg)	s(kJ/kg K)	C_p(kJ/kg K)	C_v(kJ/kg K)	$\mu(\mu Pa\ s)$	k(mW/m K)
2.8	174.00	18.920	1.821	1.365	1.287	6.243	20.816
3.0	173.50	19.200	1.919	1.501	1.393	6.329	21.923
3.2	172.80	19.520	2.022	1.690	1.549	6.645	22.977
3.4	172.10	19.880	2.130	1.877	1.696	7.088	23.977
3.6	171.40	20.270	2.242	2.044	1.818	7.608	24.921
3.8	170.60	20.690	2.357	2.191	1.915	7.557	25.808
4.0	169.70	21.140	2.473	2.321	1.992	7.334	26.639
4.2	168.70	21.620	2.589	2.440	2.052	7.122	27.412
4.4	167.70	22.120	2.705	2.551	2.102	6.922	28.128
4.6	166.70	22.640	2.821	2.657	2.143	6.733	28.788
4.8	165.60	23.180	2.936	2.762	2.179	6.555	29.393
5.0	164.40	23.740	3.051	2.866	2.213	6.387	29.945
5.2	163.20	24.330	3.165	2.971	2.244	6.230	30.445
6	157.80	26.880	3.620	3.405	2.361	5.693	31.974
7	150.10	30.570	4.188	3.984	2.501	5.189	32.991
8	141.60	34.850	4.759	4.588	2.631	4.824	33.280
9	132.30	39.740	5.335	5.189	2.746	4.562	33.115
10	122.50	45.210	5.911	5.740	2.843	4.379	32.743
12	103.30	57.520	7.030	6.461	2.992	4.194	32.111
14	87.03	70.680	8.044	6.627	3.087	4.171	32.122
16	74.51	83.850	8.924	6.528	3.142	4.239	32.657
18	65.02	96.750	9.684	6.362	3.173	4.351	33.473
20	57.72	109.30	10.35	6.198	3.189	4.487	34.430
22	51.97	121.60	10.93	6.055	3.196	4.636	35.461
24	47.32	133.50	11.45	5.935	3.199	4.791	36.531
26	43.49	145.30	11.92	5.836	3.199	4.950	37.624
28	40.27	156.90	12.35	5.753	3.197	5.110	38.730
30	37.52	168.30	12.75	5.685	3.195	5.270	39.843
40	28.16	224.00	14.35	5.471	3.179	6.057	45.413
50	22.66	278.10	15.56	5.366	3.167	6.806	50.897
60	19.00	331.40	16.53	5.308	3.157	7.516	56.251
70	16.38	384.30	17.34	5.273	3.150	8.193	61.469
80	14.40	436.90	18.05	5.250	3.145	8.843	66.553
90	12.86	489.40	18.66	5.235	3.140	9.470	71.512
100	11.61	541.70	19.22	5.224	3.137	10.080	76.354
125	9.353	672.10	20.38	5.209	3.132	11.350	88.000
150	7.832	802.20	21.33	5.201	3.128	12.730	99.083
175	6.738	932.10	22.13	5.197	3.126	14.050	109.694
200	5.911	1,062.00	22.82	5.194	3.124	15.320	119.905
225	5.266	1,192.00	23.43	5.193	3.123	16.540	129.770
250	4.747	1,322.00	23.98	5.192	3.122	17.730	139.334
275	4.322	1,451.00	24.48	5.192	3.121	18.880	148.633
300	3.966	1,581.00	24.93	5.191	3.120	20.010	157.693

Appendix 3
He II Heat Conductivity Function

Appendix A3 Turbulent He II heat conductivity function, $f^{-1}(T,p)$, kW^3/m^5 K

TEMP (K)	SVP	0.1 MPa	0.25 MPa	0.5 MPa	1 MPa	1.5 MPa	2 MPa	2.5 MPa
1.4	396.88	389.91	374.74	356.23	343.23	322.94	291.98	279.18
1.42	492.09	483.16	464.00	440.23	421.71	394.09	352.60	331.46
1.44	607.04	595.63	571.54	541.13	515.08	477.78	422.59	389.82
1.46	745.02	730.50	700.32	661.55	625.36	575.38	502.50	453.88
1.48	909.64	891.23	853.58	804.33	754.62	688.14	592.62	522.84
1.5	1,104.84	1,081.57	1,034.78	972.45	904.87	817.11	692.86	595.36
1.52	1,334.81	1,305.52	1,247.60	1,169.02	1,078.03	963.05	802.68	669.54
1.54	1,603.96	1,567.21	1,495.81	1,397.13	1,275.74	1,126.23	920.88	742.74
1.56	1,916.77	1,870.84	1,783.17	1,659.73	1,499.25	1,306.30	1,045.52	811.63
1.58	2,277.66	2,220.49	2,113.27	1,959.50	1,749.17	1,502.09	1,173.75	872.13
1.6	2,690.81	2,619.91	2,489.35	2,298.61	2,025.27	1,711.38	1,301.68	919.55
1.62	3,159.86	3,072.31	2,914.01	2,678.47	2,326.23	1,930.69	1,424.35	948.79
1.64	3,687.69	3,580.03	3,388.95	3,099.42	2,649.33	2,155.11	1,535.63	954.68
1.66	4,275.95	4,144.16	3,914.56	3,560.40	2,990.12	2,378.07	1,628.42	932.58
1.68	4,924.68	4,764.10	4,489.55	4,058.54	3,342.20	2,591.24	1,694.78	879.06
1.7	5,631.79	5,437.10	5,110.43	4,588.75	3,696.87	2,784.58	1,726.45	792.94
1.72	6,392.53	6,157.71	5,771.08	5,143.29	4,042.96	2,946.41	1,715.47	676.33
1.74	7,198.86	6,917.20	6,462.18	5,711.32	4,366.75	3,063.84	1,655.15	535.73
1.76	8,038.89	7,703.03	7,170.71	6,278.62	4,652.08	3,123.42	1,541.29	382.86
1.78	8,896.31	8,498.36	7,879.58	6,827.27	4,880.66	3,112.10	1,373.74	234.57
1.8	9,749.90	9,281.59	8,567.29	7,335.65	5,032.79	3,018.70	1,157.98	111.09
1.82	10,573.23	10,026.21	9,207.86	7,778.62	5,088.44	2,835.73	906.67	31.12
1.84	11,334.63	10,700.85	9,771.03	8,128.11	5,028.94	2,561.60	640.58	1.49
1.86	11,997.49	11,269.75	10,222.94	8,354.22	4,839.10	2,203.13	388.07	
1.88	12,521.14	11,693.80	10,527.32	8,426.88	4,510.05	1,777.95	181.76	
1.9	12,862.33	11,932.24	10,647.41	8,318.24	4,042.50	1,316.21	50.37	
1.92	12,977.62	11,945.21	10,548.69	8,005.91	3,450.25	860.57	2.39	
1.94	12,826.67	11,697.28	10,202.53	7,476.91	2,763.44	462.82		
1.96	12,376.63	11,161.98	9,590.84	6,732.33	2,030.59	174.52		

Appendix A3 (continued)

TEMP (K)	SVP	0.1 MPa	0.25 MPa	0.5 MPa	1 MPa	1.5 MPa	2 MPa	2.5 MPa
1.98	11,607.65	10,327.35	8,711.42	5,792.32	1,317.94	27.72		
2	10,519.24	9,202.22	7,583.96	4,700.74	703.69	0.00		
2.02	9,137.17	7,822.67	6,255.61	3,528.19	263.46			
2.04	7,520.03	6,257.67	4,805.26	2,371.58	41.55			
2.06	5,763.86	4,612.16	3,344.14	1,347.17	0.00			
2.08	4,002.59	3,024.66	2,009.69	572.35				
2.1	2,400.26	1,655.30	947.80	129.50				
2.12	1,129.61	657.73	276.12	1.99				
2.14	328.41	125.60	18.18					
2.16	21.57	0.35						

Appendix 4
Temperature-Entropy Diagrams for Helium

Appendix A4 Normal fluid viscosity and laminar flow heat conductivity function

T(K)	$\mu_n(10^{-7}$ Pa.s)	g(T) (W/m^3 K) $\times 10^{-13}$
1.20	21.35	3.08
1.22	20.35	4.03
1.26	18.67	6.77
1.28	17.97	8.67
1.30	17.35	11.03
1.32	16.80	13.94
1.34	16.33	17.47
1.36	15.91	21.77
1.38	15.54	26.96
1.40	15.22	33.18
1.44	14.70	49.30
1.46	14.48	59.71
1.48	14.30	71.88
1.50	14.13	86.16
1.52	13.99	102.85
1.54	13.86	122.20
1.56	13.74	144.94
1.60	13.54	201.08
1.62	13.45	235.78
1.64	13.37	275.56
1.66	13.29	321.19
1.68	13.22	373.07
1.70	13.16	432.22
1.72	13.11	499.82
1.74	13.06	576.22
1.76	13.03	661.50
1.78	13.00	758.24
1.80	13.00	865.32
1.82	13.02	984.22
1.84	13.05	1,118.40

(continued)

Appendix A4 (continued)

T(K)	$\mu_n(10^{-7}$ Pa.s)	g(T) (W/m^3 K) $\times 10^{-13}$
1.86	13.12	1,263.00
1.88	13.22	1,420.90
1.90	13.36	1,591.30
1.92	13.54	1,775.30
1.94	13.78	1,972.20
1.96	14.07	2,178.60
1.98	14.44	2,391.80
2.00	14.88	2,617.60
2.02	15.40	2,846.10
2.04	16.03	3,075.70
2.06	16.77	3,310.70
2.10	18.67	3,777.20
2.12	19.87	3,999.40
2.14	21.29	4,229.60
2.16	23.03	4,456.50
2.18	25.25	4,677.10

Appendix 5
T-S Diagrams in He II Region
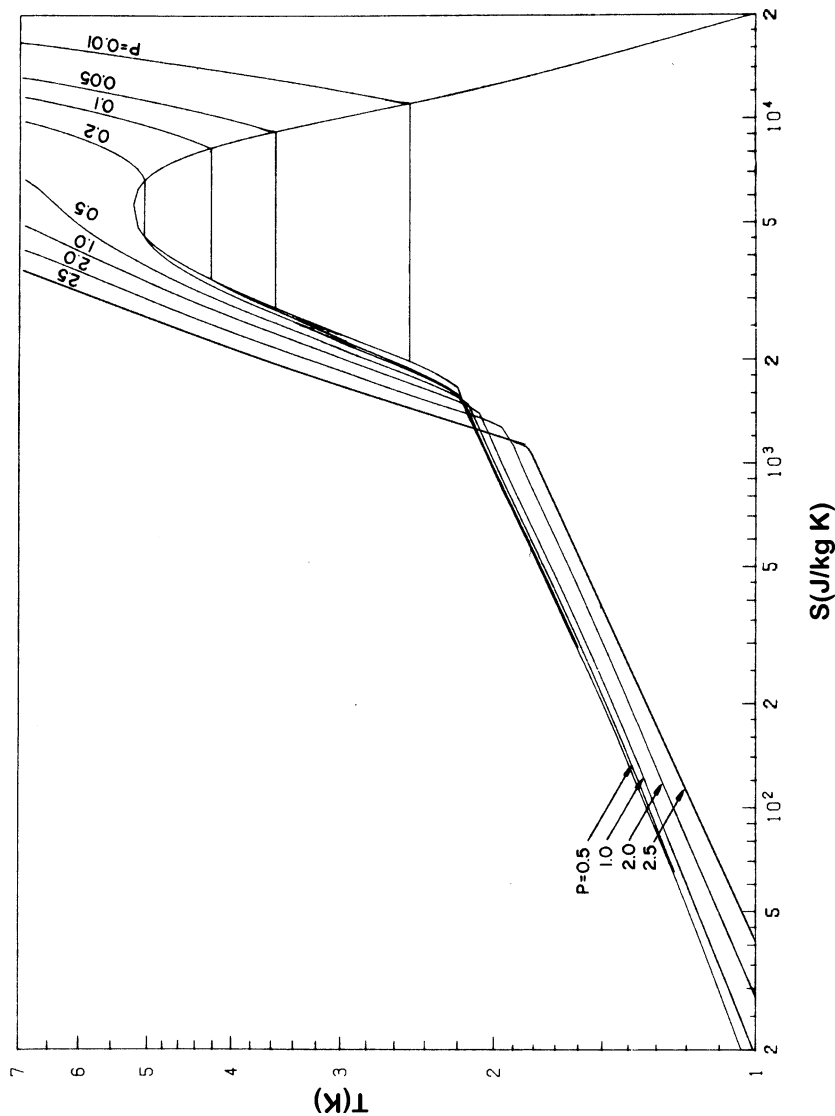
Helium $T-S$ diagram showing isobars. Pressure P is in MPa
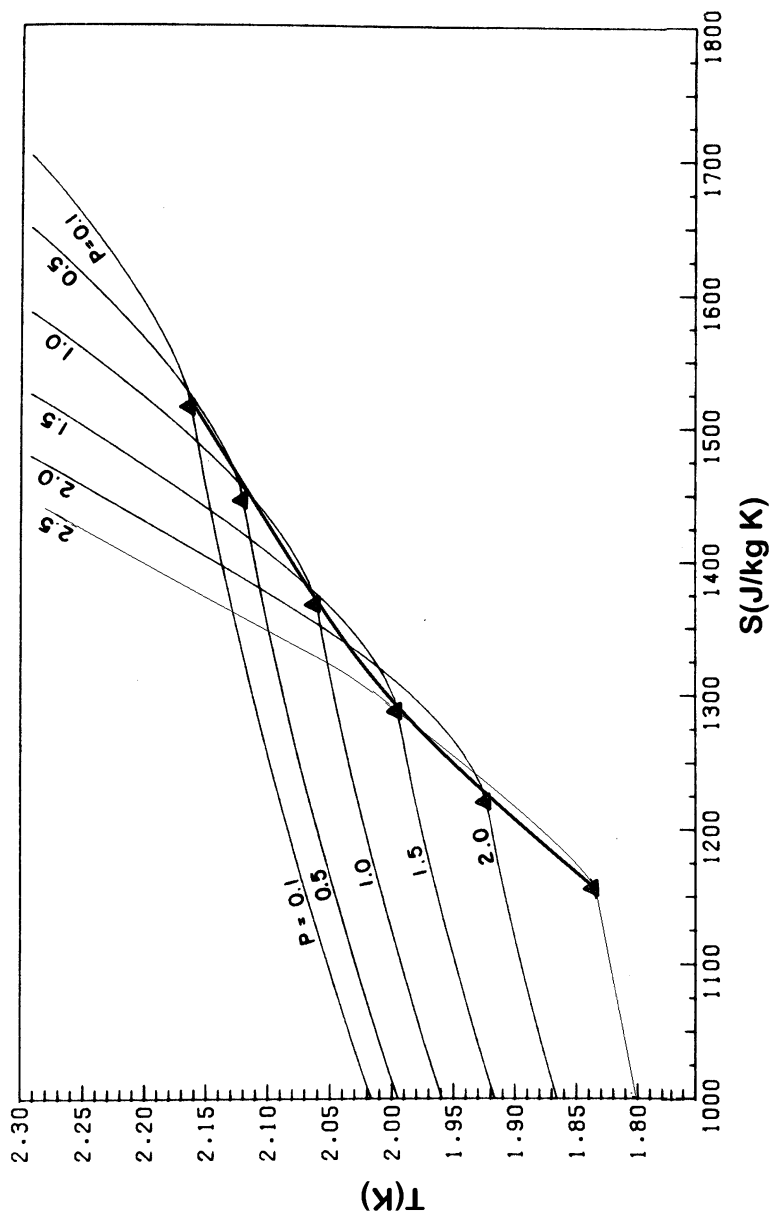
Helium T–S diagram showing isobars crossing λ-line; $\varDelta$ represent λ-point and pressure P is in MPa
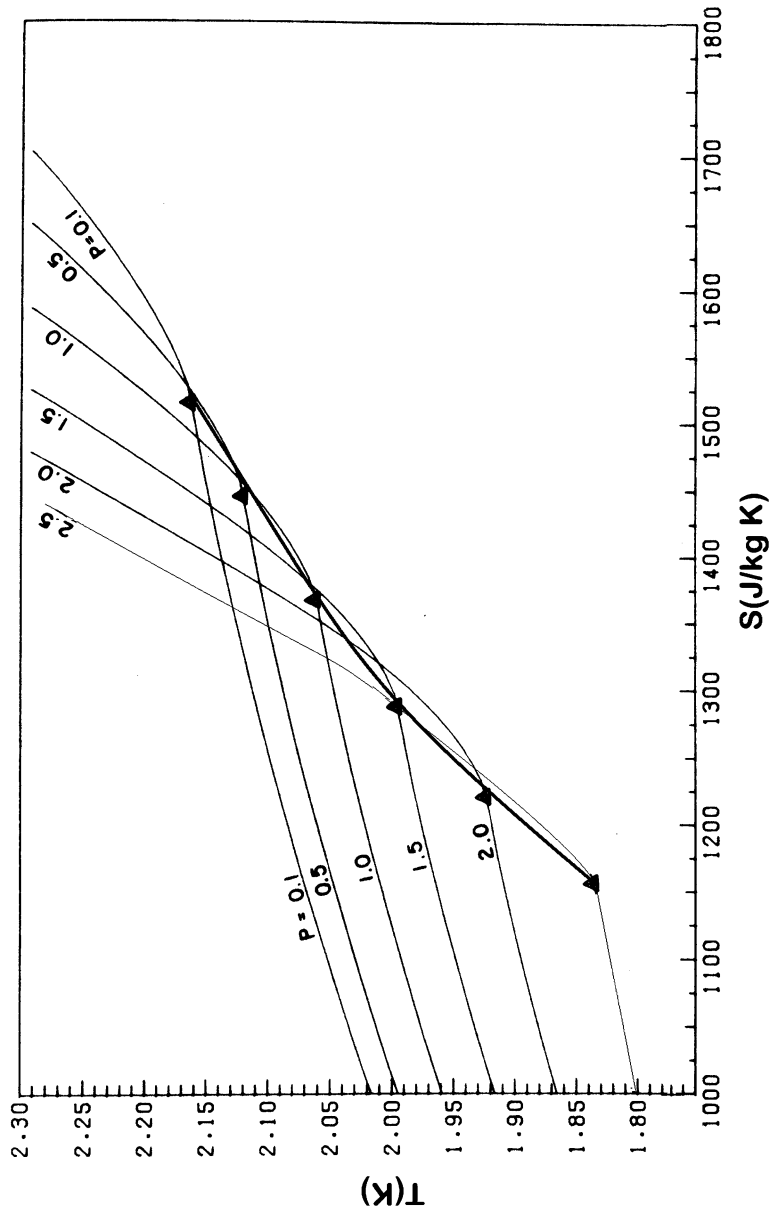
Helium T–S diagram showing isenthalps. Enthalpy H is in kJ/kg

Appendix 6
Helium T-S Diagrams

p = 10, 9, 8, ...2, 1.5, 1, 0.9, 0.8, ...0.1 MPa

Temperature (K)

Entropy (kJ/kg-K)
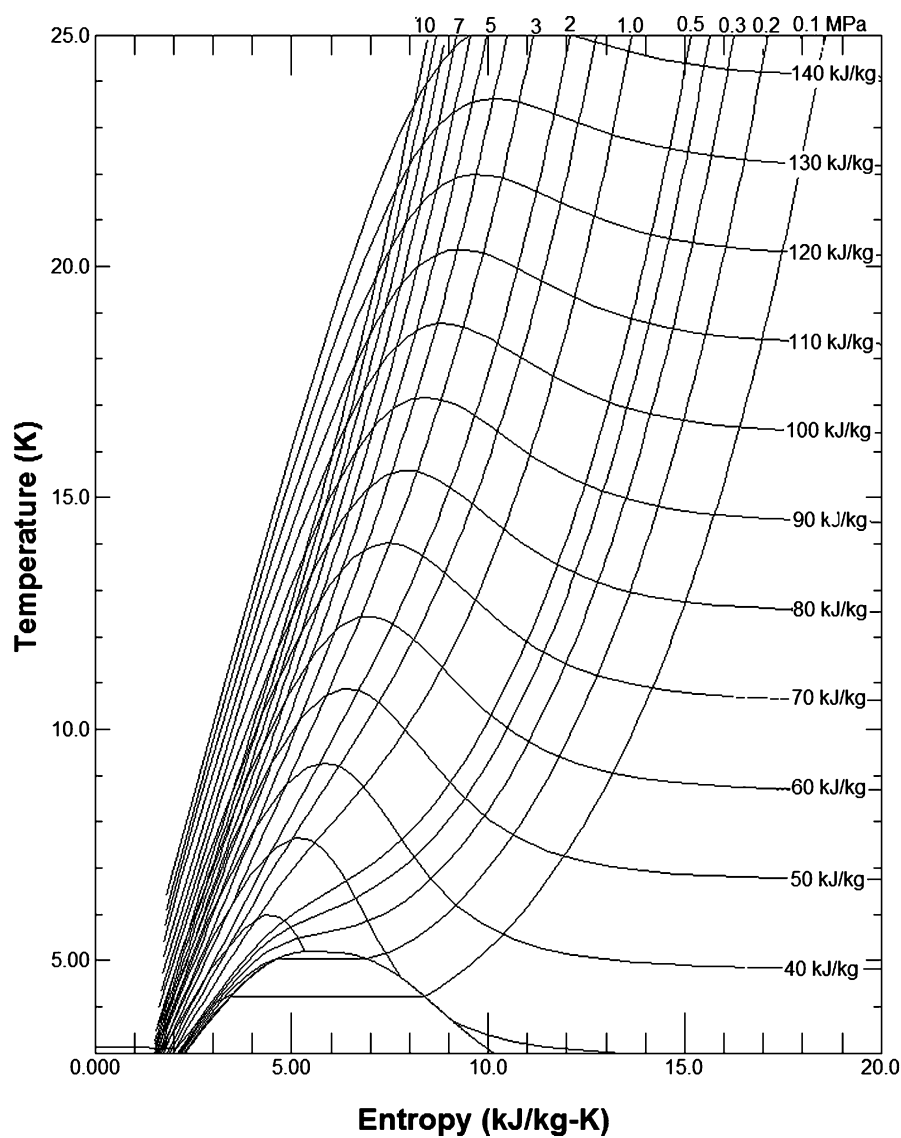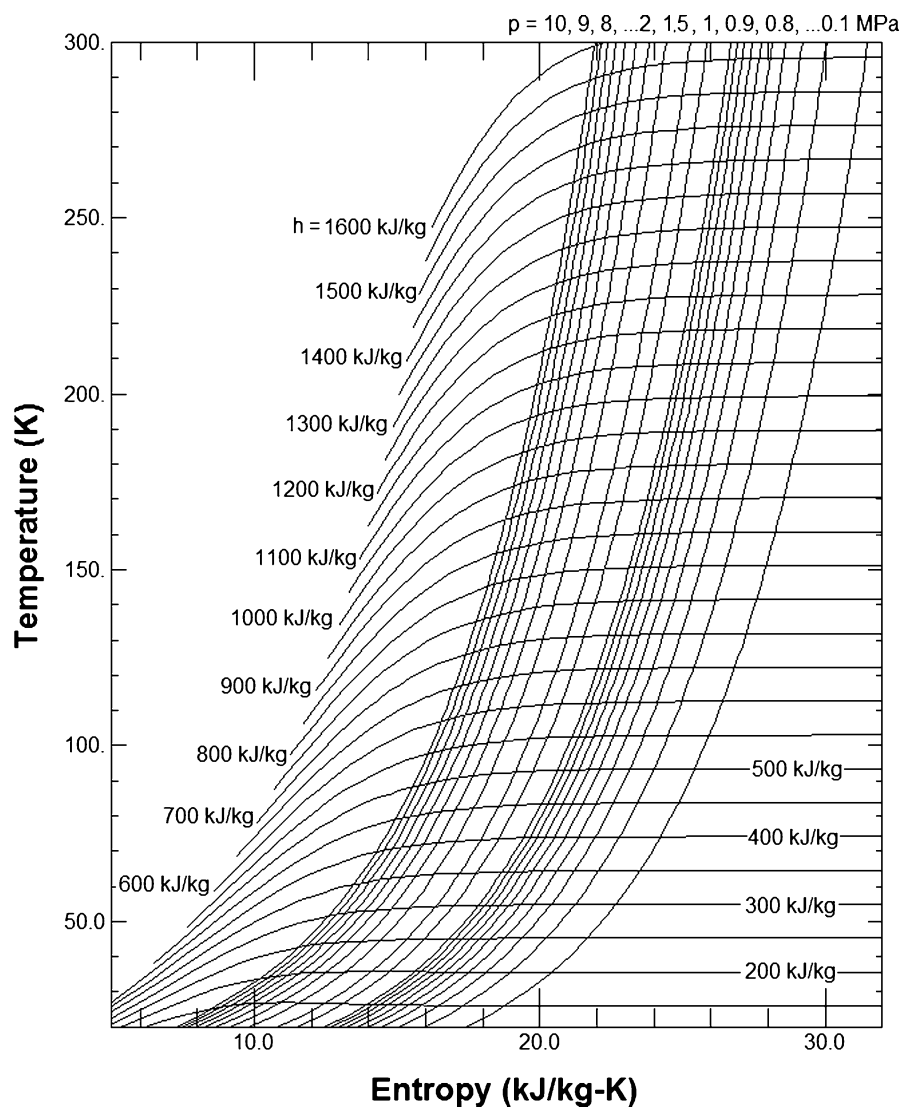
Conversion Factors

Unit/unit system	SI	CGS	English
Length	1 m	100 cm	3.281 ft
Area	1 m^2	10^4 cm^2	10.76 ft^2
Volume	1 m^3 (10^3 L)	10^6 cm^3	35.31 ft^3
Mass	1 kg	1,000 g	2.205 lb$_m$
Density	1 kg/m^3	10^{-3} g/cm^3	6.243 $\times$ 10^{-2} lb$_m$/ft^3
Velocity	1 m/s	100 cm/s	3.281 ft/s
Force	1 N	10^5 dynes	0.2248 lb$_F$
Pressure	1 Pa	10 dynes/cm^2	1.45 $\times$ 10^{-4} lb$_f$/in^2
	10^{-5} bar	9.869 $\times$ 10^{-6} atm	
		7.501 $\times$ 10^{-3} torr	
Temperature	1 K	1 K	9/5°R
Energy	1 J	10^7 erg	9.479 $\times$ 10^{-4} Btu
Heat transfer rate	1 W	10^7 erg/s	3.412 Btu/hr
Heat transfer coefficient	1 W/m^2 K	10^{-4} W/cm^2 K	0.176 Btu/hr ft^{2}°R
Viscosity	1 Pa s	10 poise	5.8 $\times$ 10^{-6} lb$_f$ hr/ft^2
Thermal conductivity	1 W/m K	10^{-2} W/cm K	0.578 Btu/hr ft°R

Physical Constants

Universal gas constant	$R = 0.0823$ L atm/mole K; 8.31 J/mole K
Speed of light in vacuum	$c = 2.998 \times 10^{8}$ m/s
Avogadro's number	$N_o = 6.024 \times 10^{23}$ molecules/mole
Boltzmann constant	$k_B = 1.38 \times 10^{-23}$ J/K molecule
Planck's constant	$h = 6.625 \times 10^{-34}$ J s/molecule
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}$ W/m^2 K^4
Electron mass	$m_e = 9.11 \times 10^{-31}$ kg
Proton mass	$m_p = 1.67 \times 10^{-27}$ kg
Permeability constant	$\mu_o = 1.26 \times 10^{-6}$ H/m
Permittivity constant	$\varepsilon_o = 8.85 \times 10^{-12}$ F/m
Bohr magneton	$\mu_e = 0.927 \times 10^{-23}$ J/T
Elementary charge	$e = 1.60 \times 10^{-19}$ Coul
Gravitational acceleration	$g = 9.807$ m/s^2

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About the Author

Dr. Van Sciver is a Distinguished Research Professor and John H. Gorrie Professor of Mechanical Engineering at Florida State University. He is also a Program Director at the National High Magnetic Field Laboratory (NHMFL). Dr. Van Sciver joined the FAMU-FSU College of Engineering and the NHMFL in 1991, initiating and teaching a graduate program in magnet and materials engineering and in cryogenic thermal sciences and heat transfer. He also led the NHMFL development efforts of the cryogenic systems for the NHMFL Hybrid and 900 MHz NMR superconducting magnets. Between 1997 and 2003, he served as Director of Magnet Science and Technology at the NHMFL. Dr. Van Sciver is a Fellow of the ASME and the Cryogenic Society of America and American Editor for the journal *Cryogenics*. He is the 2010 recipient of the Kurt Mendelssohn Award.

Prior to joining Florida State University, Dr. Van Sciver was Research Scientist and then Professor of Nuclear Engineering, Engineering Physics and Mechanical Engineering at the University of Wisconsin-Madison from 1976 to 1991. During that

time he also served as the Associate Director of the Applied Superconductivity Center. Dr. Van Sciver received his Ph.D. in Low Temperature Physics from the University of Washington-Seattle in 1976. He received his BS degree in Engineering Physics from Lehigh University in 1970.

Dr. Van Sciver is author of over 200 publications and patents in low temperature physics, liquid helium technology, cryogenic engineering and magnet technology. The first edition of *Helium Cryogenics* was published by Plenum Press (1986). The present work is an update and expansion of that original project.