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THERMAL PROPERTIES OF SUPERHEATED RUBIDIUM VAPOR AT TEMPERATURES UP TO 2150 K AND PRESSURES UP TO 5 MPa

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Based on generalized experimental data, an equation of state is developed for superheated rubidium vapor, from which thermodynamic properties are calculated and tables that cover the parametric regions of 0.1-5.0 MPa pressure and 975-2150 K temperature are constructed.

The present work presents results of completed investigations of the thermal properties of superheated rubidium vapor that have been carried out at the Moscow Aeronautical Institute for the last six years.

A series of works [1–6] is devoted to experimental investigations of the *PVT* dependence of rubidium vapor. Experimental data at pressures of 0.05–0.2 MPa are obtained in [1] by the method of a constant volume piezometer with a null membrane in a hot zone. The results obtained, estimated by the authors of [1], are of the character of tentative experiments, and therefore these data were not among the calculations in a thermodynamic generalization. Measurements of specific volumes in 11 sets of experiments in the intervals of 1150-1494 K temperature and 0.42-1.5 MPa pressure are performed in [2] by the same method as in [1]. Using the procedure of [7], we estimated the measurement errors. Analysis showed that the measurement error amounted to about 5% in the 7th set of experiments and did not exceed 1.5% in the remaining sets. Thus, we excluded the data of the 7th set of experiments from processing. PVT data on rubidium vapor in the intervals of 1286–2088 K temperature and 0.74–5.18 MPa pressure with a 0.7–1.5% error in measuring the coefficient of compressibility are obtained in [3–6] by the method of a modified constant volume piezometer with a null membrane in a cold zone.

It is pertinent to note that the developed method, in which use is made of a null membrane taken out to the cold zone, permits reliable measurement of specific volumes at high temperatures while, when the piezometer with the null membrane is used in the hot zone, the membrane deforms and operates in an unstable manner, and measurement reproducibility is lost.

The design and technological features of the experimental installation, on which we performed the experiments are described in [4, 5] in detail.

Table 1 gives experimental data on the PVT dependence in four sets of experiments. The rubidium mass m in the piezometer is shown in the last column of the table for each set.

In the investigations use is made of rubidium that had, according to specifications of TU 48-3-55-75, the impurities 0.003% potassium, 0.003% sodium, and 0.030% cesium as its constituents.

We estimated the relative error from the coefficient of compressability $z = \mu PV/RT$. It is combined from the relative errors for the pressure ΔP, temperature $\Delta T/T$, and specific volume $\Delta V/V$:

$$\left(\frac{\Delta z}{z}\right)^2 = \left[\left(\frac{1}{z}\frac{\partial z}{\partial P}\right)_{V,T}\Delta P\right]^2 + \left[\left(\frac{1}{z}\frac{\partial z}{\partial T}\right)_{V,P}\Delta T\right]^2 + \left[\left(\frac{1}{z}\frac{\partial z}{\partial V}\right)_{T,P}\Delta V\right]^2 .$$

The relative error for the pressure $\Delta P/P$ was combined from errors obtained from the calibration characteristic of a membrane node together with an ICh-0.001 clock-type indicator of displacements and an IPD pressure

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TABLE 1. Experimental Data on the PVT Dependence of Superheated Rubidium Vapor

Set of the experiment	Experimental points	P, MPa	T, K	$V \cdot 10^3$, m^3/kg	$m \cdot 10^3$, kg
I	1	0.7003	1476	192.4	0.912
	2	0.7375	1505	185.9	
	3	0.7939	1552	178.3	
	4	0.9883	1695	157.0	
	5	1.469	1982	124.6	
	6	1.738	2152	114.8	
	7	1.688	2133	117.0	
	8	1.629	2092	118.9	
	9	1.423	1955	127.0	
II	1	1.813	1474	65.72	1.609
	2	1.975	1518	62.29	
	3	2.092	1555	60.44	
	4	2.353	1648	57.39	
	5	2.534	1698	54.89	
	6	2.860	1800	51.77	
	7	3.172	1885	48.95	
	8	3.749	2059	45.45	
	9	4.001	2140	44.37	
	10	3.893	2109	45.01	
	11	3.579	1998	46.13	
III	1	0.7372	1286	152.1	1.201
	2	0.8842	1354	133.6	
	3	1.017	1416	121.6	
	4	1.487	1594	94.42	
	5	2.034	1842	80.45	
	6	2.762	2164	69.82	
	7	2.609	2088	71.20	
IV	1	3.271	1607	35.29	2.192
	2	3.417	1634	34.57	
	3	3.583	1665	33.81	
	4	3.814	1708	32.80	
	5	3.919	1737	32.53	
	6	4.053	1774	32.11	
	7	4.172	1797	31.79	
	8	4.315	1828	31.41	
	9	4.465	1868	31.13	
	10	4.626	1907	30.70	
	11	4.758	1945	30.50	
	12	5.178	2062	29.94	

TABLE 2. Estimate of the Error of PVT Data for Superheated Rubidium Vapor, %

Set of the experiment	$\Delta P/P$	$\Delta V/V$	$\Delta T/T$	$\Delta z/z$
I	0.22–0.09	1.8–1.3	0.41–0.49	2.0–1.5
II	0.14–0.08	1.5–0.88	0.43–0.49	1.7–1.1
III	0.09–0.06	0.87–0.45	0.44–0.48	1.1–0.73
IV	0.22–0.12	–	0.41–0.49	to 2.0

TABLE 3. Change in the Error of Description of PVT Data upon Varying *i* and *j* in the Equation of State (1)

i	*j*							
	0–2	0–3	0–4	0–5	0–6	0–7	0–8	0–9
1–4	1.04	0.98	0.92	0.90	0.92	1.02	0.92	0.92
1–5	1.05	0.99	0.94	0.92	0.95	1.05	0.95	0.96
1–6	1.06	1.00	0.96	0.94	0.97	1.08	0.99	1.01
1–7	1.07	1.02	0.97	0.96	1.00	1.12	1.03	1.05
1–8	1.08	1.03	0.99	0.99	1.03	1.16	1.07	1.11
1–9	1.09	1.05	1.01	1.01	1.06	1.21	1.13	1.18
1–10	1.11	1.06	1.03	1.04	1.10	1.26	1.19	1.26
1–11	1.12	1.08	1.06	1.07	1.14	1.32	1.26	1.37

TABLE 4. Constants B_{ij} of the Equation of State (1)

j	B_{1j}	$B_{2j}\cdot 10$	$B_{3j}\cdot 10$	$B_{4j}\cdot 10^2$	$B_{5j}\cdot 10^3$
0	−0.74463	−0.90770	−0.10946	−0.12459	−0.13742
1	−0.57586	−0.83932	−0.11174	−0.13142	−0.14744
2	−0.38530	−0.73875	−0.11288	−0.13946	−0.15927
3	−0.18818	−0.59809	−0.11217	−0.14773	−0.17251
4	−0.012655	−0.41121	−0.10870	−0.15590	−0.18721
5	0.098884	−0.17634	−0.10134	−0.16343	−0.20338
6	0.098560	0.098903	−0.088723	−0.16957	−0.22093
7	−0.033222	0.39032	−0.069294	−0.17322	−0.23963
8	−0.193360	0.64616	−0.041512	−0.17291	−0.25906
9	−0.072978	0.77430	−0.0041583	−0.16664	−0.27852

transducer whose measurement accuracy is ±0.006% which is an order of magnitude higher than in MO standard manometers. The membrane node sensitivity, taken from the calibration curve, amounted to 0.001 MPa/division, which corresponded to the same level as the IPD complex sensitivity.

The relative error for the temperature $\Delta T/T$ was combined from the errors of a Shch68002 voltmeter, VR5/20 tungsten-rhenium thermocouples, and calculation of the reference temperature $\Delta T_{\text{ref}}/T$, which depends on how close the curve of the specific volume as a function of temperature is to a linear one within the temperature spread along the piezometer chamber. The temperature field nonuniformity along the length of the piezometer chamber introduces the largest error in calculating $\Delta z/z$. The temperature gradient, along the chamber length attained 25 K at temperatures of 2100–2200 K. Additional shielding was ineffective due to powerful heat removal along the piezometer capillary. The relative error in determining the specific volume $\Delta V/V$ is combined from determination of the errors of the piezometer chamber volume, rubidium mass in it, and thermal expansion of the chamber material. We found the volume of the piezometer chamber from the weight difference of an empty piezometer and one filled with water. After multiple weighings on a T1-1 balance the relative error in determining the volume amounted to 0.01% with a confidence level of 0.95 and a Student coefficient $t = 2.13$.

We found the rubidium vapor mass in the piezometer m by the procedure of [4]. The error in its determination amounted to $\pm 4\cdot 10^{-6}$ kg.

Table 2 gives the estimaties of the relative measurement error for P, V, T and the coefficient of compressibility z. The table shows that $\Delta z/z$ decreases upon transition to a region of higher parameters, and $\Delta V/V$ becomes comparable with the error of measuring the temperature $\Delta T/T$.

To calculate tables of thermodynamic functions, use is made of a procedure, proposed in [8–11], that has been used to advantage by the authors of these works for describing properties of a series of gases. In accordance with this procedure, to generalize the experimental data on the *PVT* dependence of the gaseous phase of rubidium, we chose an empirical equation of state of the form

$$z = 1 + \sum_{i=1}^{r} \sum_{j=0}^{li} B_{ij} \frac{\omega^{i}}{\tau^{i}}, \tag{1}$$

where $\tau = T/T_{\rm cr}$ is the reduced temperature; $\omega = \rho/\rho_{\rm cr}$ is the reduced density; $T_{\rm cr}$ and $\rho_{\rm cr}$ are the temperature and density at the critical point; B_{ij} are constants determined by the least-squares method.

Apart from our data, Achener's PVT data [2] were also among the array of experimental points for processing. The permissible approximation error was taken equal to 0.9–1.1%. As a result of calculations, we obtained 64 equations of state that describe 169 experimental points with an error of 0.9–1.4%. The change in the approximation error upon varying i and j is reflected in Table 3. Table 4 gives the values of the constants B_{ij} for the equation of state (1). The thermodynamic functions are calculated in the interval of the parameters T = 975–2150 K and P = 0.1–5.0 MPa; their values are given in Table 5, which includes values of the specific volume V, the coefficient of compressibility z, the enthalpy H, the entropy S, the specific heat at constant volume C_v and that at constant pressure C_p, the velocity of sound A, and the adiabatic exponent k. The calculation is performed with the use of well-known relations of thermodynamics [12, 13]. The values of the thermodynamic functions in an ideal gas state are calculated with the use of thermodynamic potentials [14]. The state of the solid phase at T = 0 K is taken as the origin of the vapor enthalpy.

According to data of [14], the heat of sublimation for rubidium at $T = 0$ K amounts to $H^0 = 82.192$ kJ/mole. Table 6 shows the root-mean-square deviations of the estimates for the thermodynamic functions.

In connection with the fact that at present there are no experimental data in the literature on direct measurement of individual properties of rubidium vapor, for example, specific heat, there are only data on measuring the *PVT* dependence, and we cannot check the reliability of the developed tables by comparing them with experiment.

Results of a comparison with existing calculations [14–17] are given below.

An injustifiably large correction for nonideality for the value of the specific volume, whose accuracy is estimated at 50%, is given, in our opinion, in calculations of [15]. Results of calculations of [14, 17] on the specific volume are in agreement with ours within 1–1.5% at temperatures up to 2000 K. As the pressure increases, the discrepancy with [14] increases to 2.5%.

Deviations for the coefficient of compressibility from results of [16] amount to 1.5–2.0%. They decrease to 1% at pressures higher than 2.0 MPa. On the 0.1 MPa isobar near the saturation line the discrepancies for the velocity of sound amount to about 2% in comparison with the data of [17].

In contrast to potassium and cesium vapors, the specific heat at constant pressure for rubidium on the 0.1 MPa isobar is smaller in our calculations than C_p of [17]. As the pressure increases, the deviations between C_p in the compared calculations decrease to 5%. Values of C_p that are systematically 5–10% smaller than the calculations of [16] are given in the developed tables. At pressures above 2 MPa the discrepancies for the specific heat decrease to 4%.

The reliability of the developed tables is ensured by their being calculated from generalized experimental data whose selection is made in careful analysis of the measurement error. The basis for the array of processed experimental data is formed by the data on the PVT dependence that were obtained at the Moscow Aeronautical Institute by a modified method of a constant volume piezometer with a null membrane in a cold zone. Only this method currently permits reliable measurement of specific volumes at high temperatures and pressures. As compared to other available tables, those developed by us cover a wide interval of state parameters and involve numerous temperature- and pressure-dependent thermodynamic functions (specific volume, enthalpy, specific heats at constant volume and at constant pressure, velocity of sound, adiabatic exponent).

The tables are recommended for practical use in thermal calculations and can also be of use in theoretical developments.

TABLE 5. Thermal Properties of Superheated Rubidium Vapor

T	V	z	H	S	C_v	C_p	A	k
Pressure 0.100 MPa								
975	0,8925	0,9410	1165	2,295	0,2831	0,4517	366,8	1,508
1000	0,9238	0,9496	1176	2,298	0,2602	0,4148	374,5	1,519
1025	0,9539	0,9567	1186	2,302	0,2416	0,3856	382,1	1,531
1050	0,983$_1$	0,9624	1195	2,306	0,2265	0,3623	389,3	1,542
1075	1,011	0,9672	1204	2,310	0,2141	0,3435	396,4	1,553
1100	1,039	0,9712	1213	2,314	0,2039	0,3281	403,2	1,564
1125	1,066	0,9745	1221	2,319	0,1954	0,3155	409,7	1,574
1150	1,093	0,9773	1228	2,323	0,1883	0,3050	416,1	1,584
1175	1,120	0,9797	1236	2,328	0,1823	0,2963	422,2	1,592
1200	1,146	0,9817	1243	2,332	0,1773	0,2890	428,2	1,600
1225	1,172	0,9834	1250	2,337	0,1731	0,2828	433,9	1,607
1250	1,198	0,9849	1257	2,341	0,1695	0,2776	439,5	1,613
1275	1,223	0,9862	1264	2,345	0,1665	0,2732	444,9	1,618
1300	1,249	0,9873	1271	2,350	0,1639	0,2695	450,2	1,623
1325	1,274	0,9883	1278	2,354	0,1617	0,2663	455,3	1,628
1350	1,299	0,9892	1284	2,358	0,1598	0,2635	460,4	1,631
1375	1,324	0,9899	1291	2,363	0,1581	0,2611	465,3	1,635
1400	1,349	0,9906	1297	2,367	0,1567	0,2591	470,1	1,638
1425	1,374	0,9912	1304	2,371	0,1555	0,2573	474,7	1,640
1450	1,399	0,9917	1310	2,375	0,1545	0,2558	479,4	1,643
1475	1,424	0,9922	1317	2,379	0,1535	0,2545	483,9	1,645
1500	1,448	0,9926	1323	2,383	0,1513	0,2519	489,3	1,653
1525	1,473	0,9930	1329	2,387	0,1511	0,2513	493,3	1,652
1550	1,498	0,9934	1335	2,391	0,1509	0,2509	497,4	1,652
1575	1,522	0,9937	1342	2,395	0,1507	0,2505	501,4	1,651
1600	1,547	0,9940	1348	2,399	0,1506	0,2501	505,4	1,651
1625	1,572	0,9942	1354	2,402	0,1505	0,2498	509,3	1,651
1650	1,596	0,9945	1360	2,406	0,1504	0,2495	513,2	1,650
1675	1,621	0,9947	1367	2,410	0,1503	0,2493	517,1	1,650
1700	1,645	0,9949	1373	2,413	0,1502	0,2490	521,0	1,650
1725	1,670	0,9951	1379	2,417	0,1501	0,2489	524,8	1,650
1750	1,694	0,9953	1385	2,420	0,1501	0,2487	528,6	1,649
1775	1,719	0,9954	1392	2,424	0,1500	0,2485	532,4	1,649
1800	1,743	0,9956	1398	2,427	0,1500	0,2484	536,2	1,649
1825	1,768	0,9957	1404	2,431	0,1500	0,2483	539,9	1,649
1850	1,792	0,9958	1410	2,434	0,1499	0,2482	543,6	1,649
1875	1,817	0,9960	1416	2,437	0,1500	0,2482	547,2	1,648
1900	1,841	0,9961	1423	2,440	0,1500	0,2481	550,8	1,648
1925	1,865	0,9962	1429	2,444	0,1500	0,2481	554,4	1,648
1950	1,890	0,9963	1435	2,447	0,1501	0,2481	558,0	1,647
1975	1,914	0,9964	1441	2,450	0,1501	0,2481	561,5	1,647
2000	1,939	0,9965	1447	2,453	0,1502	0,2482	564,9	1,646
2025	1,963	0,9966	1454	2,456	0,1503	0,2483	568,4	1,646
2050	1,988	0,9966	1460	2,459	0,1505	0,2483	571,8	1,645
2075	2,012	0,9967	1466	2,462	0,1506	0,2485	575,2	1,644
2100	2,036	0,9968	1472	2,465	0,1508	0,2486	578,5	1,643
2125	2,061	0,9969	1479	2,468	0,1510	0,2488	581,8	1,643
2150	2,085	0,9969	1485	2,471	0,1512	0,2489	585,1	1,642
Pressure 1.000 MPa								
1300	0,1086	0,8590	1202	2,140	0,3448	0,5741	390,2	1,402
1325	0,1123	0,8713	1215	2,142	0,3180	0,5255	398,8	1,416
1350	0,1158	0,8818	1228	2,144	0,2956	0,4859	407,0	1,430
1375	0,1192	0,8909	1240	2,146	0,2766	0,4534	414,8	1,444
1400	0,1224	0,8988	1251	2,149	0,2604	0,4262	422,3	1,457
1425	0,1256	0,9057	1261	2,152	0,2466	0,4034	429,6	1,470
1450	0,1286	0,9118	1271	2,155	0,2347	0,3841	436,5	1,482
1475	0,1316	0,9172	1280	2,158	0,2245	0,3676	443,3	1,493
1500	0,1345	0,9220	1289	2,161	0,2141	0,3520	450,4	1,508
1525	0,1374	0,9263	1298	2,164	0,2069	0,3404	456,5	1,516
1550	0,1403	0,9301	1306	2,167	0,2006	0,3302	462,4	1,525
1575	0,1430	0,9336	1314	2,170	0,1951	0,3215	468,1	1,532
1600	0,1458	0,9368	1322	2,174	0,1903	0,3138	473,7	1,539
1625	0,1485	0,9396	1330	2,177	0,1861	0,3071	479,1	1,546
1650	0,1512	0,9422	1338	2,180	0,1824	0,3012	484,4	1,552

Continued Table 5

T	V	z	H	S	C_v	C_p	A	k
1675	0,1539	0,9446	1345	2,184	0,1791	0,2960	489,5	1,557
1700	0,1566	0,9468	1353	2,187	0,1762	0,2914	494,6	1,562
1725	0,1592	0,9488	1360	2,190	0,1736	0,2873	499,5	1,567
1750	0,1618	0,9507	1367	2,194	0,1713	0,2837	504,2	1,571
1775	0,1645	0,9524	1374	2,197	0,1693	0,2805	508,9	1,575
1800	0,1671	0,9540	1381	2,200	0,1675	0,2776	513,5	1,578
1825	0,1696	0,9555	1388	2,204	0,1659	0,2751	518,0	1,582
1850	0,1722	0,9569	1395	2,207	0,1645	0,2728	522,4	1,585
1875	0,1748	0,9582	1401	2,210	0,1632	0,2708	526,7	1,587
1900	0,1773	0,9594	1408	2,213	0,1621	0,2690	530,9	1,590
1925	0,1799	0,9605	1415	2,216	0,1611	0,2673	535,1	1,592
1950	0,1824	0,9616	1422	2,220	0,1602	0,2659	539,2	1,594
1975	0,1849	0,9626	1428	2,223	0,1595	0,2646	543,2	1,595
2000	0,1875	0,9636	1435	2,226	0,1588	0,2635	547,1	1,597
2025	0,1900	0,9645	1441	2,229	0,1582	0,2624	551,0	1,598
2050	0,1925	0,9653	1448	2,232	0,1577	0,2616	554,8	1,599
2075	0,1950	0,9662	1454	2,235	0,1573	0,2608	558,6	1,600
2100	0,1975	0,9669	1461	2,238	0,1570	0,2601	562,3	1,601
2125	0,2000	0,9677	1467	2,241	0,1567	0,2595	565,9	1,601
2150	0,2025	0,9684	1474	2,244	0,1565	0,2590	569,5	1,601
Pressure 2.000 MPa								
1425	0,05475	0,7899	1204	2,088	0,3671	0,6460	379,6	1,316
1450	0,05680	0,8053	1219	2,090	0,3390	0,5877	389,3	1,334
1475	0,05874	0,8187	1233	2,092	0,3152	0,5407	398,5	1,352
1500	0,06058	0,8303	1246	2,094	0,2935	0,5006	407,6	1,371
1525	0,06235	0,8405	1258	2,096	0,2767	0,4691	415,7	1,386
1550	0,06405	0,8496	1269	2,099	0,2622	0,4426	423,4	1,400
1575	0,06570	0,8577	1280	2,101	0,2497	0,4201	430,8	1,413
1600	0,06731	0,8649	1291	2,104	0,2388	0,4009	438,0	1,425
1625	0,06888	0,8714	1300	2,107	0,2293	0,3844	444,8	1,437
1650	0,07041	0,8773	1310	2,110	0,2210	0,3701	451,4	1,447
1675	0,07191	0,8827	1319	2,113	0,2137	0,3577	457,8	1,457
1700	0,07339	0,8876	1328	2,116	0,2072	0,3468	464,0	1,467
1725	0,07485	0,8921	1336	2,120	0,2016	0,3372	470,0	1,476
1750	0,07628	0,8962	1345	2,123	0,1966	0,3288	475,8	1,484
1775	0,07770	0,9000	1353	2,126	0,1921	0,3214	481,4	1,491
1800	0,07910	0,9035	1361	2,129	0,1882	0,3149	486,9	1,499
1825	0,08049	0,9068	1368	2,132	0,1846	0,3090	492,2	1,505
1850	0,08187	0,9098	1376	2,135	0,1815	0,3038	497,4	1,511
1875	0,08323	0,9126	1384	2,139	0,1787	0,2992	502,4	1,517
1900	0,08458	0,9153	1391	2,142	0,1762	0,2950	507,3	1,522
1925	0,08593	0,9177	1398	2,145	0,1740	0,2913	512,1	1,526
1950	0,08726	0,9200	1406	2,148	0,1721	0,2880	516,8	1,531
1975	0,08859	0,9222	1413	2,151	0,1703	0,2850	521,4	1,535
2000	0,08991	0,9243	1420	2,154	0,1687	0,2824	525,9	1,538
2025	0,09123	0,9262	1427	2,157	0,1674	0,2800	530,3	1,541
2050	0,09254	0,9281	1434	2,160	0,1661	0,2779	534,6	1,544
2075	0,09384	0,9298	1441	2,163	0,1650	0,2759	538,8	1,547
2100	0,09514	0,9315	1448	2,166	0,1641	0,2742	542,9	1,549
2125	0,09644	0,9330	1454	2,169	0,1633	0,2727	547,0	1,551
2150	0,09773	0,9345	1461	2,172	0,1626	0,2713	550,9	1,553
Pressure 3.000 MPa								
1525	0,03621	0,7322	1209	2,054	0,3612	0,6768	365,7	1,232
1550	0,03769	0,7499	1225	2,056	0,3352	0,6138	376,8	1,256
1575	0,03909	0,7653	1239	2,059	0,3132	0,5638	387,0	1,278
1600	0,04040	0,7788	1253	2,061	0,2944	0,5233	396,5	1,297
1625	0,04166	0,7907	1266	2,064	0,2783	0,4898	405,4	1,316
1650	0,04287	0,8012	1277	2,067	0,2643	0,4617	413,9	1,332
1675	0,04403	0,8107	1289	2,069	0,2521	0,4379	421,9	1,348
1700	0,04516	0,8193	1299	2,072	0,2415	0,4176	429,6	1,362
1725	0,04626	0,8271	1310	2,075	0,2322	0,4001	436,9	1,376
1750	0,04734	0,8342	1319	2,078	0,2240	0,3850	443,9	1,388
1775	0,04839	0,8407	1329	2,082	0,2168	0,3717	450,7	1,400
1800	0,04942	0,8466	1338	2,085	0,2104	0,3601	457,2	1,411

Continued Table 5

T	V	z	H	S	c_v	c_p	A	k
1825	0,05043	0,8521	1347	2,088	0,2048	0,3499	463,5	1,421
1850	0,05142	0,8572	1356	2,091	0,1997	0,3409	469,6	1,430
1875	0,05240	0,8619	1364	2,094	0,1953	0,3329	475,5	1,439
1900	0,05337	0,8663	1372	2,097	0,1913	0,3258	481,2	1,447
1925	0,05433	0,8704	1380	2,100	0,1877	0,3195	486,8	1,454
1950	0,05528	0,8742	1388	2,103	0,1846	0,3139	492,2	1,461
1975	0,05622	0,8778	1396	2,107	0,1817	0,3088	497,4	1,468
2000	0,05715	0,8812	1404	2,110	0,1792	0,3043	502,5	1,473
2025	0,05807	0,8844	1411	2,113	0,1769	0,3002	507,5	1,479
2050	0,05899	0,8874	1419	2,116	0,1749	0,2966	512,3	1,484
2075	0,05990	0,8902	1426	2,119	0,1731	0,2933	517,1	1,488
2100	0,06080	0,8929	1433	2,122	0,1716	0,2904	521,7	1,492
2125	0,06170	0,8955	1441	2,125	0,1702	0,2877	526,2	1,496
2150	0,06260	0,8979	1448	2,128	0,1689	0,2854	530,6	1,499

Pressure 4.000 MPa

T	V	z	H	S	c_v	c_p	A	k
1600	0,02571	0,6607	1203	2,025	0,3654	0,7715	336,9	1,104
1625	0,02703	0,6840	1221	2,028	0,3387	0,6816	351,4	1,143
1650	0,02823	0,7036	1237	2,031	0,3165	0,6159	364,2	1,175
1675	0,02935	0,7204	1252	2,034	0,2976	0,5652	375,7	1,203
1700	0,03039	0,7352	1265	2,037	0,2814	0,5248	386,2	1,228
1725	0,03139	0,7482	1278	2,040	0,2674	0,4917	396,0	1,250
1750	0,03234	0,7598	1290	2,044	0,2552	0,4641	405,1	1,270
1775	0,03325	0,7703	1301	2,047	0,2446	0,4409	413,7	1,288
1800	0,03414	0,7798	1312	2,050	0,2353	0,4210	421,9	1,305
1825	0,03500	0,7885	1322	2,053	0,2270	0,4039	429,6	1,320
1850	0,03583	0,7964	1332	2,057	0,2198	0,3891	437,0	1,334
1875	0,03665	0,8037	1342	2,060	0,2133	0,3762	444,1	1,347
1900	0,03745	0,8104	1351	2,063	0,2076	0,3648	451,0	1,359
1925	0,03823	0,8167	1360	2,066	0,2026	0,3548	457,5	1,370
1950	0,03901	0,8225	1369	2,069	0,1980	0,3459	463,8	1,380
1975	0,03977	0,8279	1377	2,073	0,1940	0,3380	469,9	1,390
2000	0,04052	0,8330	1386	2,076	0,1904	0,3310	475,9	1,398
2025	0,04126	0,8377	1394	2,079	0,1872	0,3248	481,6	1,406
2050	0,04199	0,8422	1402	2,082	0,1843	0,3192	487,1	1,414
2075	0,04271	0,8464	1410	2,085	0,1817	0,3142	492,5	1,421
2100	0,04343	0,8503	1418	2,088	0,1795	0,3096	497,7	1,427
2125	0,04414	0,8541	1425	2,091	0,1774	0,3056	502,8	1,433
2150	0,04484	0,8576	1433	2,094	0,1756	0,3020	507,8	1,438

Pressure 5.000 MPa

T	V	z	H	S	c_v	c_p	A	k
1700	0,02008	0,6071	1215	2,001	0,3355	0,8464	313,3	0,981
1725	0,02134	0,6359	1234	2,006	0,3127	0,7070	332,8	1,041
1750	0,02243	0,6586	1251	2,010	0,2941	0,6257	348,5	1,086
1775	0,02340	0,6777	1266	2,014	0,2783	0,5688	362,0	1,123
1800	0,02431	0,6941	1279	2,018	0,2648	0,5258	374,0	1,154
1825	0,02516	0,7085	1292	2,022	0,2531	0,4918	384,9	1,181
1850	0,02596	0,7213	1304	2,026	0,2429	0,4641	395,0	1,204
1875	0,02673	0,7328	1315	2,029	0,2340	0,4410	404,3	1,226
1900	0,02747	0,7432	1326	2,033	0,2261	0,4215	413,1	1,245
1925	0,02819	0,7527	1336	2,036	0,2192	0,4048	421,4	1,262
1950	0,02889	0,7615	1346	2,040	0,2130	0,3904	429,2	1,278
1975	0,02957	0,7695	1356	2,043	0,2076	0,3779	436,7	1,292
2000	0,03023	0,7769	1365	2,047	0,2027	0,3669	443,9	1,305
2025	0,03088	0,7838	1374	2,050	0,1984	0,3572	450,7	1,318
2050	0,03152	0,7903	1383	2,053	0,1945	0,3486	457,3	1,329
2075	0,03215	0,7963	1392	2,057	0,1911	0,3410	463,6	1,339
2100	0,03277	0,8020	1400	2,060	0,1880	0,3342	469,7	1,349
2125	0,03338	0,8073	1408	2,063	0,1852	0,3282	475,6	1,357
2150	0,03398	0,8123	1416	2,066	0,1828	0,3228	481,3	1,365

TABLE 6. Root-Mean-Square Deviations of Estimates for Thermodynamic Functions of Superheated Rubidium Vapor, %

T, K	Δz	ΔH	ΔS	ΔC_v	ΔC_p	ΔA	Δk
Pressure 0.100 MPa							
1000	0,42	0,38	0,15	17	13	2,7	5,2
1100	0,11	0,15	0,06	7,6	5,7	1,1	2,0
1200	0,02	0,05	0,02	3,9	2,7	0,61	1,2
1300	0,01	0,01	0,004	1,9	1,2	0,34	0,69
1400	0,01	0,01	0,003	0,73	0,38	0,17	0,35
1500	0,01	0,01	0,005	0,14	0,07	0,07	0,13
1600	0,01	0,01	0,004	0,22	0,20	0,01	0,02
1700	0,01	0,01	0,003	0,35	0,25	0,04	0,08
1800	0,01	0,001	0,002	0,40	0,25	0,06	0,13
1900	0,01	0,004	0,001	0,40	0,23	0,07	0,16
2000	0,01	0,007	0,001	0,38	0,20	0,08	0,17
2100	0,01	0,01	0,002	0,35	0,16	0,09	0,18
2150	0,01	0,01	0,003	0,33	0,14	0,09	0,18
Pressure 0.200 MPa							
1050	0,51	0,51	0,19	18	14	2,5	4,6
1100	0,25	0,31	0,12	13	9,9	1,8	3,4
1200	0,04	0,10	0,04	6,9	5,0	1,1	2,1
1300	0,02	0,02	0,008	3,5	2,2	0,63	1,3
1400	0,01	0,02	0,006	1,4	0,74	0,33	0,66
1500	0,01	0,02	0,01	0,27	0,13	0,13	0,26
1600	0,02	0,02	0,01	0,42	0,39	0,02	0,04
1700	0,03	0,01	0,007	0,68	0,50	0,07	0,16
1800	0,03	0,002	0,004	0,78	0,50	0,11	0,25
1900	0,03	0,008	0,001	0,79	0,45	0,14	0,31
2000	0,02	0,02	0,002	0,75	0,39	0,16	0,34
2100	0,02	0,02	0,004	0,70	0,32	0,17	0,36
2150	0,01	0,02	0,005	0,67	0,29	0,18	0,37
Pressure 0.400 MPa							
1150	0,29	0,41	0,16	15	12	2,2	4,2
1200	0,10	0,22	0,09	12	8,5	1,8	3,5
1300	0,03	0,04	0,02	6,1	4,0	1,1	2,2
1400	0,02	0,04	0,01	2,6	1,4	0,61	1,2
1500	0,01	0,05	0,02	0,52	0,22	0,26	0,51
1600	0,04	0,04	0,02	0,77	0,73	0,04	0,07
1700	0,05	0,02	0,01	1,3	0,96	0,13	0,30
1800	0,06	0,003	0,01	1,5	0,97	0,22	0,49
1900	0,05	0,02	0,002	1,6	0,89	0,28	0,61
2000	0,04	0,03	0,004	1,5	0,76	0,32	0,68
2150	0,02	0,05	0,1	1,3	0,57	0,35	0,73
Pressure 0.600 MPa							
1200	0,21	0,37	0,15	14,9	11,4	2,4	4,6
1300	0,03	0,06	0,03	8,3	5,5	1,6	3,0
1400	0,03	0,05	0,02	3,6	2,0	0,85	1,7
1500	0,02	0,07	0,03	0,76	0,27	0,38	0,74
1600	0,05	0,06	0,03	1,1	1,0	0,06	0,10
1700	0,08	0,03	0,02	1,9	1,4	0,18	0,43
1800	0,08	0,01	0,01	2,2	1,4	0,32	0,72
1900	0,08	0,02	0,003	2,3	1,3	0,41	0,90
2000	0,06	0,05	0,006	2,2	1,1	0,47	1,0
2100	0,04	0,06	0,01	2,1	0,94	0,51	1,1
2150	0,03	0,07	0,01	2,0	0,85	0,53	1,1
Pressure 0.800 MPa							
1250	0,10	0,27	0,11	14	9,9	2,3	4,6
1300	0,02	0,09	0,04	10	6,8	1,8	3,7
1400	0,04	0,07	0,02	4,6	2,5	1,1	2,2

Continued Table 6

T, K	Δz	ΔH	ΔS	ΔC_v	ΔC_p	ΔA	Δk
1500	0,02	0,10	0,04	1,0	0,30	0,50	0,96
1600	0,07	0,08	0,04	1,34	1,3	0,08	0,13
1700	0,10	0,04	0,03	2,4	1,8	0,23	0,51
1800	0,11	0,01	0,02	2,9	1,9	0,41	0,93
1900	0,10	0,03	0,003	3,0	1,7	0,54	1,2
2000	0,08	0,06	0,01	2,9	1,5	0,62	1,3
2100	0,06	0,08	0,02	2,7	1,2	0,68	1,4
2150	0,04	0,09	0,02	2,6	1,1	0,70	1,4
Pressure 1.000 MPa							
1300	0,04	0,13	0,06	12	8,0	2,2	4,3
1400	0,05	0,08	0,03	5,5	3,0	1,3	2,6
1500	0,02	0,12	0,05	1,2	0,31	0,59	1,2
1600	0,08	0,10	0,05	1,6	1,5	0,11	0,16
1700	0,12	0,05	0,03	2,9	2,2	0,27	0,67
1800	0,13	0,01	0,02	3,6	2,3	0,51	1,1
1900	0,12	0,04	0,004	3,7	2,1	0,67	1,4
2000	0,10	0,08	0,01	3,6	1,8	0,77	1,6
2100	0,07	0,11	0,02	3,4	1,5	0,85	1,7
2150	0,05	0,12	0,03	3,3	1,4	0,88	1,8
Pressure 1.500 MPa							
1400	0,10	0,11	0,04	7,5	4,2	1,7	8,6
1500	0,02	0,18	0,07	1,9	0,42	0,83	1,7
1600	0,12	0,14	0,07	2,0	2,0	0,16	0,24
1700	0,17	0,08	0,05	4,0	2,9	0,38	0,92
1800	0,19	0,01	0,03	5,0	3,2	0,73	1,6
1900	0,18	0,06	0,01	5,4	3,0	0,97	2,1
2000	0,14	0,12	0,02	5,3	2,7	1,1	2,4
2100	0,08	0,16	0,04	5,0	2,2	1,3	2,6
2150	0,06	0,18	0,05	4,8	2,0	1,3	2,7
Pressure 2.000 MPa							
1425	0,18	0,19	0,06	7,6	4,0	1,9	3,9
1500	0,04	0,24	0,10	2,6	0,84	1,0	2,1
1600	0,14	0,20	0,09	2,2	2,4	0,20	0,32
1700	0,22	0,10	0,07	5,0	3,6	0,48	1,1
1800	0,24	0,02	0,04	6,4	4,0	0,95	2,1
1900	0,22	0,09	0,01	6,9	3,8	1,3	2,3
2000	0,16	0,16	0,03	6,9	3,4	1,5	3,2
2100	0,10	0,22	0,06	6,6	2,9	1,7	3,4
2150	0,05	0,24	0,07	6,4	2,6	1,8	3,5
Pressure 2.500 MPa							
1500	0,14	0,32	0,12	3,6	1,7	1,2	2,5
1600	0,14	0,25	0,12	2,4	2,6	0,21	0,37
1700	0,25	0,13	0,08	5,7	4,1	0,61	1,5
1800	0,28	0,20	0,04	7,6	4,7	1,2	2,6
1900	0,25	0,11	0,01	8,4	4,6	1,6	3,4
2000	0,18	0,20	0,04	8,5	4,1	1,9	4,0
2100	0,08	0,27	0,08	8,1	3,5	2,1	4,3
2150	0,04	0,30	0,09	7,9	3,2	2,2	4,4
Pressure 3.000 MPa							
1525	0,29	0,41	0,14	3,0	2,5	0,87	2,0
1600	0,90	0,32	0,14	2,4	2,9	0,18	0,40
1700	0,25	0,16	0,10	6,4	4,5	0,81	1,9
1800	0,29	0,02	0,05	8,7	5,2	1,5	3,2
1900	0,25	0,13	0,01	9,7	5,2	2,0	4,2
2000	0,17	0,24	0,06	10,0	4,8	2,4	4,8
2100	0,06	0,33	0,10	9,7	4,1	2,6	5,2
2150	0,04	0,37	0,12	9,4	3,8	2,8	5,4

Continued Table 6

T, K	Δz	ΔH	ΔS	ΔC_v	ΔC_p	ΔA	Δk
Pressure 3.500 MPa							
1600	0,19	0,42	0,15	2,6	3,9	0,42	0,75
1700	0,19	0,20	0,11	6,9	4,9	1,1	2,5
1800	0,27	0,03	0,05	9,7	5,7	1,9	3,9
1900	0,23	0,16	0,02	11	5,8	2,4	5,0
2000	0,13	0,29	0,07	11	5,3	2,9	5,8
2100	0,04	0,39	0,12	11	4,6	3,2	6,3
2150	0,10	0,43	0,14	11	4,3	3,3	6,4
Pressure 4.000 MPa							
1700	0,07	0,27	0,11	7,5	5,6	1,9	3,7
1800	0,18	0,04	0,04	11	6,1	2,4	5,0
1900	0,16	0,18	0,03	12	6,3	3,0	6,1
2000	0,05	0,33	0,09	13	5,8	3,5	6,9
2150	0,22	0,50	0,18	12	4,7	4,0	7,6
Pressure 4.500 MPa							
1700	1,2	0,49	0,08	8,6	12	4,6	7,8
1800	0,14	0,06	0,03	12	6,8	3,5	6,8
1900	0,05	0,20	0,05	14	6,7	3,9	7,6
2000	0,11	0,38	0,12	14	6,3	4,3	8,3
2100	0,28	0,51	0,19	14	5,6	4,6	8,8
2150	0,39	0,57	0,22	14	5,2	4,8	8,9
Pressure 5.000 MPa							
1800	1,1	0,19	0,03	13	10	6,3	11
1900	0,41	0,20	0,09	15	7,4	5,3	9,9
2000	0,40	0,41	0,16	16	6,8	5,4	10
2100	0,55	0,57	0,23	16	6,0	5,7	10
2150	0,65	0,64	0,27	16	5,6	5,8	11

NOTATION

P, pressure, Pa; V, specific volume, m^3/kg; T, temperature, K; H, enthalpy, kJ/kg; H^0, heat of sublimation at 0 K, kJ/kg; S, entropy, kJ/(kg· K); A, velocity of sound, m/sec; k, adiabatic exponent; z, coefficient of compressibility; T_{cr}, critical temperature, K; ρ_{cr}, critical density, kg/m^3; B_{ij}, constants of the equation of state; m, mass, kg.

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