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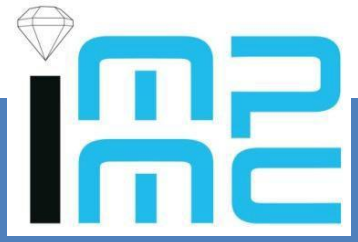
Thermodynamic and elastic data of solid and liquid Rb

(dec. 2020)



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General properties

Property		Value	Temp(°F)	Data Basis
Physical:				
Atomic Weight		85.48	--	Experimental
Melting Point, °F	39.4°C	102.9	--	Experimental
Boiling Point, °F	685.6°C	1266	--	Experimental
Critical Point, atm	19.05 MPa	188	3480 1915.6°C	Estimated
Density of Solid, lb/ft^3	1530 kg/m^3	95.518	68 20°C	Handbook
Density of Liquid, lb/ft^3	1511 kg/m^3	94.3	M.P. 39.4°C	Experimental
Density of Vapor, lb/ft^3		0.0708	B.P.	Theoretical
Viscosity of Liquid, lb/ft hr		1.64	M.P.	Experimental
Viscosity of Vapor, lb/ft hr		0.061	B.P.	Theoretical
Surface Tension, lb/ft		0.0053	M.P.	Experimental
Thermal:				
Thermal Conductivity of Liquid, BTU/hr ft °F		11.65	B.P.	Unknown
Thermal Conductivity of Vapor, BTU/hr ft °F		0.00482	B.P.	Estimated
Specific Heat of Liquid, BTU/lb°F		0.0877	B.P.	Estimated
Specific Heat of Vapor, BTU/lb °F		0.0578	B.P.	Theoretical
Latent Heat of Fusion, BTU/lb		11.79	M.P.	Survey
Latent Heat of Vaporization, BTU/lb		347.8	B.P.	Theoretical
Electrical and Magnetic:				
Resistivity, μ ohm-inch		9.1	M.P. liq	Experimental
Ionization Potential, volts		4.126		Experimental
Magnetic Susceptibility, fps electromagnetic units/unit mass		0.0379	64.4 sol	Handbook

W.D. Weatherford and R.K. Johnston, *Contamination Effects on Liquid Rubidium and Liquid Lithium Systems,* Southwest research in San Antonio (1963), p. 4

Table 4.1 Atomic properties of the alkali metals

Property	Li	Na	K	Rb	Cs	Fr
Atomic number	3	11	19	37	55	87
Number of naturally occurring isotopes	2	1	2 + 1[(a)]	1 + 1[(a)]	1	1[(a)]
Atomic weight	6.941(2)	22.989 768(6)	39.0983(1)	85.4678(3)	132.90543(5)	(223)
Electronic configuration	[He]$2s^1$	[Ne]$3s^1$	[Ar]$4s^1$	[Kr]$5s^1$	[Xe]$6s^1$	[Rn]$7s^1$
Ionization energy/kJ mol^{-1}	520.2	495.8	418.8	403.0	375.7	~375
Electron affinity/kJ mol^{-1}	59.8	52.9	46.36	46.88	45.5	(44.0)
ΔH_{dissoc}/kJ mol^{-1} (M_2)	106.5	73.6	57.3	45.6	44.77	—
Metal radius/pm	152	186	227	248	265	—
Ionic radius (6-coordinate)/pm	76	102	138	152	167	(180)
E°/V for $M^+(aq) + e^- \longrightarrow M(s)$	−3.045	−2.714	−2.925	−2.925	−2.923	—

[(a)]Radioactive: ^{40}K $t_{1/2}$ 1.277×10^9 y; ^{87}Rb $t_{1/2}$ 4.75×10^{10} y; ^{223}Fr $t_{1/2}$ 21.8 min.

Table 4.2 Physical properties of the alkali metals

Property	Li	Na	K	Rb	Cs
MP/°C	180.6	97.8	63.7	39.5	28.4
BP/°C	1342	883	759	688	671
Density (20°C)/g cm^{-3}	0.534	0.968	0.856	1.532	1.90
ΔH_{fus}/kJ mol^{-1}	2.93	2.64	2.39	2.20	2.09
ΔH_{vap}/kJ mol^{-1}	148	99	79	76	67
ΔH_f (monatomic gas)/kJ mol^{-1}	162	108	89.6	82.0	78.2
Electrical resistivity (25°C)/μohm cm	9.47	4.89	7.39	13.1	20.8

N.N. Greenwood, A. Earnshaw, *Chemistry of the Elements*, Elsevier (2012)

TABLE 5.3. Temperature of fusion of Rb

Reference	Temperature, K	Comments
Original studies		
13REN, 14REN	312.15 ± 0.05	Enthalpy measurements
35LOS	311.93 ± 0.1	Thermal analysis
55DAU/MAR	311.88 ± 0.5	Thermal analysis
63WEA	312.52	Cooling curve method
65FIL/MAR	312.44	Thermal analysis (measured)
65FIL/MAR	312.475 ± 0.01	Corrected value
69BAS/VOL	312.30 ± 0.05	Density measurements
70MAR	312.45	Thermal analysis (measured)
70MAR	312.46 ± 0.02	Corrected value
71GOA/OTT	312.44 ± 0.1	Thermal analysis
73SIM	312.51 ± 0.01	Thermal analysis
Reviews		
73HUL	312.64 ± 0.05	Based on 65FIL/MAR
82GUR	312.47 ± 0.03	Based on 70MAR
85JAN	312.65 ± 0.1	Based on 85OHS/BAB
85OHS/BAB	312.65 ± 0.1	Based on 65FIL/MAR
Adopted	312.45 ± 0.1 K	Based on 65FIL/MAR, 70MAR, 71GOA/OTT

C.B. Alcock, M.W. Chase and V.P. Itkin, *Thermodynamic properties of the group IA elements,* Journal of physical and chemical reference data, **23(3)** 385-497 (1994)

Phase diagram

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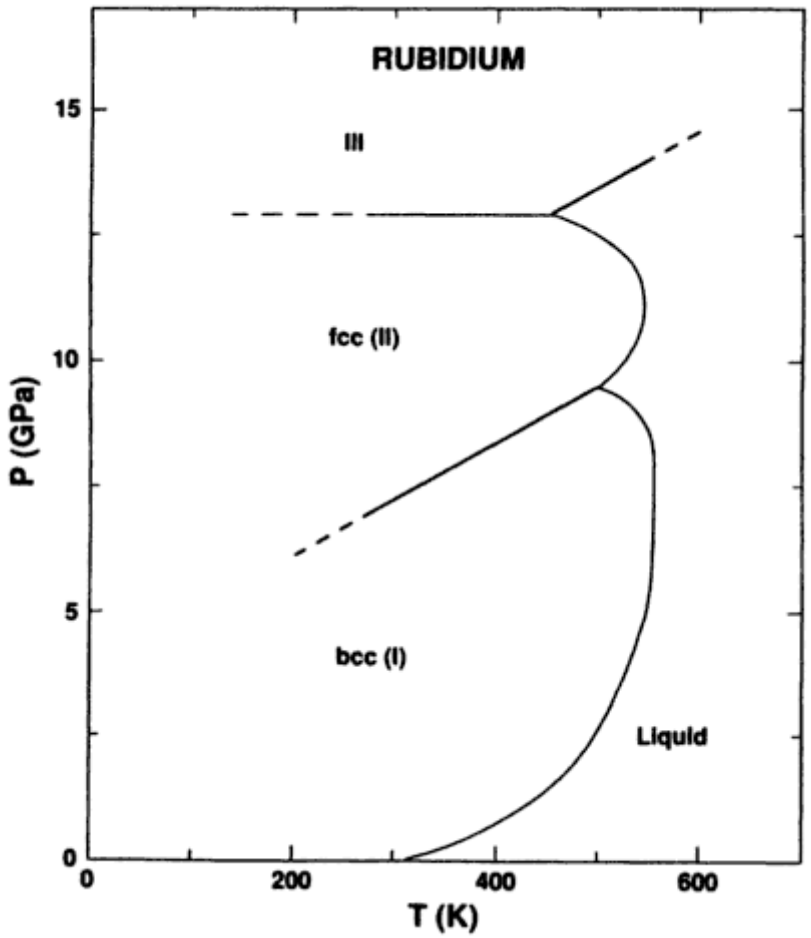
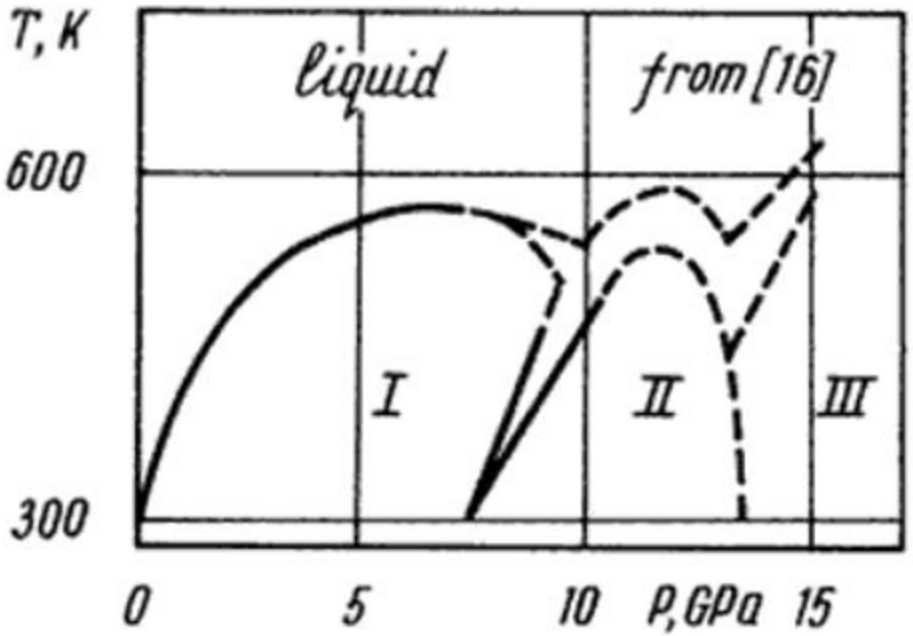
Young (1991)



D. A. Young, *Phase diagrams of the elements,* University of California Press (1991)

Tonkov (1992)



E.I.U. Tonkov, E.Y. Tonkov, *High Pressure Phase Transformations: A Handbook*, Gordon and Breach Science Publishers (1992)

Bridgman (1926)

TABLE I

Melting data for rubidium and caesium

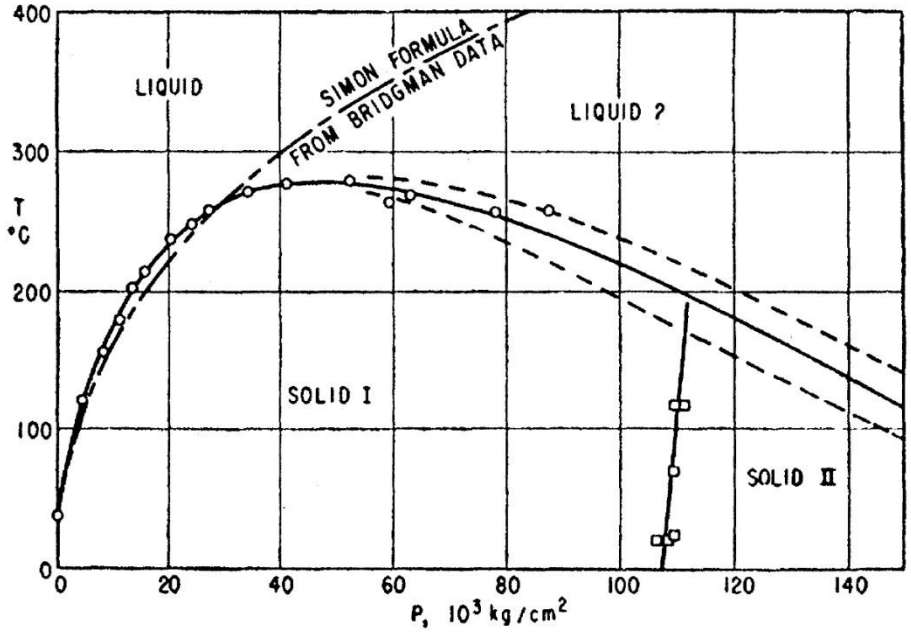
Pressure (kg/cm²)	Temp.	Rubidium ΔV (cm³/gm)	Rubidium Latent heat (kg · m/gm)	Temp.	Caesium ΔV (cm³/gm)	Caesium Latent heat (kg · m/gm)
1	38°.7	.0185	2.76	29°.7	.0136	1.65
500	48 .7	163	2.73	41 .4	118	1.68
1000	57 .9	145	2.70	51 .9	105	1.72
1500	66 .5	130	2.66	61 .4	96	1.76
2000	74 .5	119	2.67	70 .2	88	1.80
2500	82 .0	112	2.72	78 .3	83	1.88
3000	89 .1	106	2.76	85 .7	78	1.99
3500	95 .9	101	2.78	92 .4	75	2.14
4000				98 .5	72	2.29

« *Bridgman's [54, 57] data were taken only to about 8 kbar on a sample that was "evidently somewhat impure". Consequently, his data have been discarded also.* » J.F. Cannon, p. 788

[54] Bridgman, P. W., *Proc. Amer. Acad. Arts Sci.*, **56**, 61-154 (1921).

[57] Bridgman, P. W., *Phys. Rev.*, **27**, 68-86 (1926).

Bundy (1959)



Phase Diagram of Rubidium to 150 000 kg/cm² and 400°C
F. P. Bundy, Phys. Rev. **115**(2) 274 (1959)

P(GPa)	T(°C)
0.00124	37.348
0.42906	120.75
0.80213	155.44
1.0951	178.75
1.3217	201.51
1.5479	213.44
2.0003	236.23
2.3725	247.64
2.6784	257.41
3.3695	270.49
4.0472	277.06
5.1762	278.81
5.8797	263.74
6.2518	268.65
7.7523	256.38
8.6955	257.57
10.922	117.64
11.082	118.2
10.894	70.546
10.906	24.54
10.786	20.737
10.587	20.172

« For undetermined reasons Bundy's data, even after pressure calibration correction, deviate drastically from the melting curve data of others. » J.F. Cannon

"In 1959 Bundy[75], while investigating the melting curve of rubidium, discovered that under pressures of >40,000 kg/cm2 the originally positive slope of the melting curve became negative. Bundy's astonishment was so great that he placed a question mark on the plot of the melting curve of rubidium. Now that G. C. Kennedy et al. have published their studies we can state that the question mark on Bundy's plot was quite logical. As it turned out, Bundy's findings were erroneous, but nevertheless, as shown in [!], the melting curve of rubidium does have a maximum, though at much higher pressures. In 1959, however, Bundy's study had acted as a major stimulus to research." (Stishov, 1968)

Newton (1962)

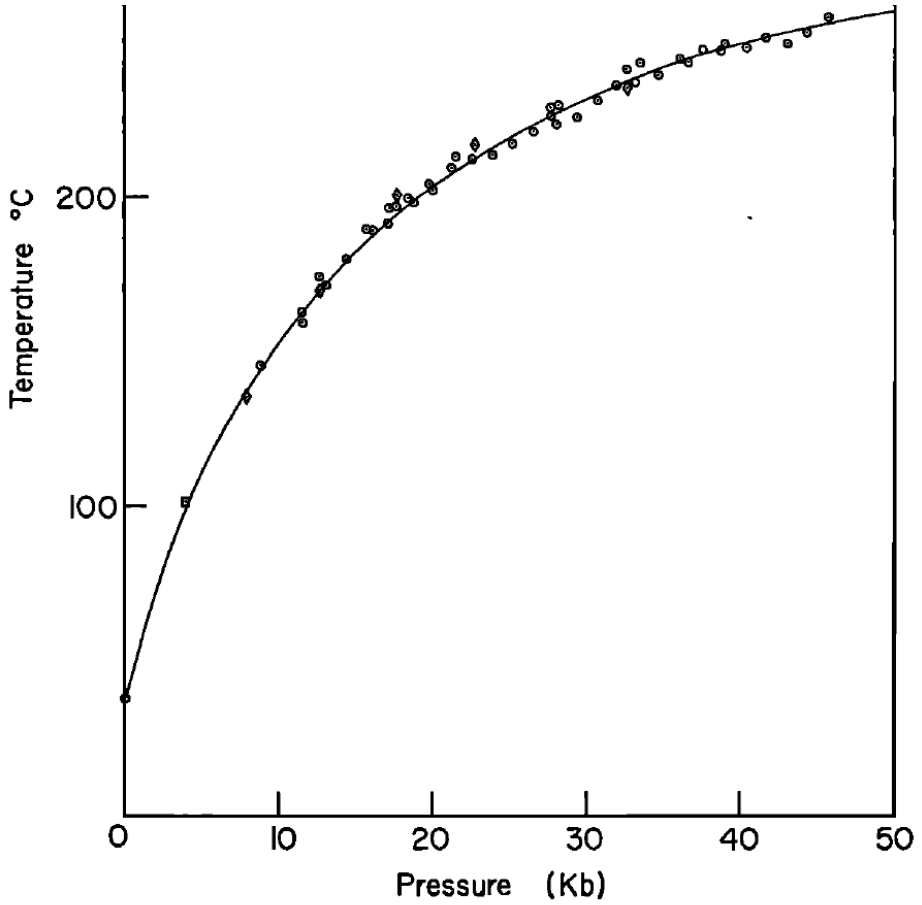


Fig. 4. Fusion curve for Rb.

The Fusion Curves of the Alkali Metals up to 50 Kilobars
R.C.Newton. A.Jayaraman. G.C.Kennedy
J. Geophys. Res. **67(6)** 2559 (1962)

P(GPa)	T(°C)
0.00671	37.667
0.88591	145.73
1.1611	159.08
1.1544	162.74
1.3154	171.42
1.443	179.76
1.5772	189.44
1.6107	189.11
1.7114	191.11
1.7248	196.45
1.7651	196.78
1.7718	200.45
1.8456	199.46
1.8792	198.13
1.9799	204.13
2.0067	202.13
2.1275	209.48
2.1544	212.81
2.2617	212.15
2.396	213.49
2.5235	217.17
2.6577	221.18
2.7718	228.85
2.7718	226.18
2.8121	223.52
2.8188	229.85
2.9463	225.86
3.0805	231.21
3.2013	236.21
3.2685	241.22
3.3221	236.89
3.3557	243.22
3.4698	239.56
3.6107	244.91
3.6644	243.91
3.7651	247.58
3.8792	247.26
3.8993	249.59
4.047	248.27
4.1745	251.61
4.3154	249.62
4.4362	253.3
4.5772	258.31

Newton (1962)

« *Of the three melting curves from Kennedy's laboratory [227, 261, 299], the most recent [261] appears to be superior in terms of sample purity, pressure determination, and method of determining the melting point. For these reasons, data from the earlier works [227, 299] have not been used in determining the best melting curves for any of the alkali metals.* » J.F. Cannon, p. 788

[227] Kennedy, G. C., Newton, R. C., in "Solids Under Pressure," W. Paul and D. M. Warschauer, Eds., McGraw-Hill Book Co., New York, 1963, pp.163-178
[261] Luedemann, H. D., Kennedy, G. C, J. Geophys. Res., 13, 2795-2805 (1968).
[299] Newton, R. C., Jayaraman, A., Kennedy, G. C., J. Geophys. Res., 67, 2559-2566 (1962).

Behavior of the Elements at High Pressures
John Francis Cannon, J. Phys. Chem. Ref. Data **3**, 781 (1974)

Luedemann & Kennedy (1968)

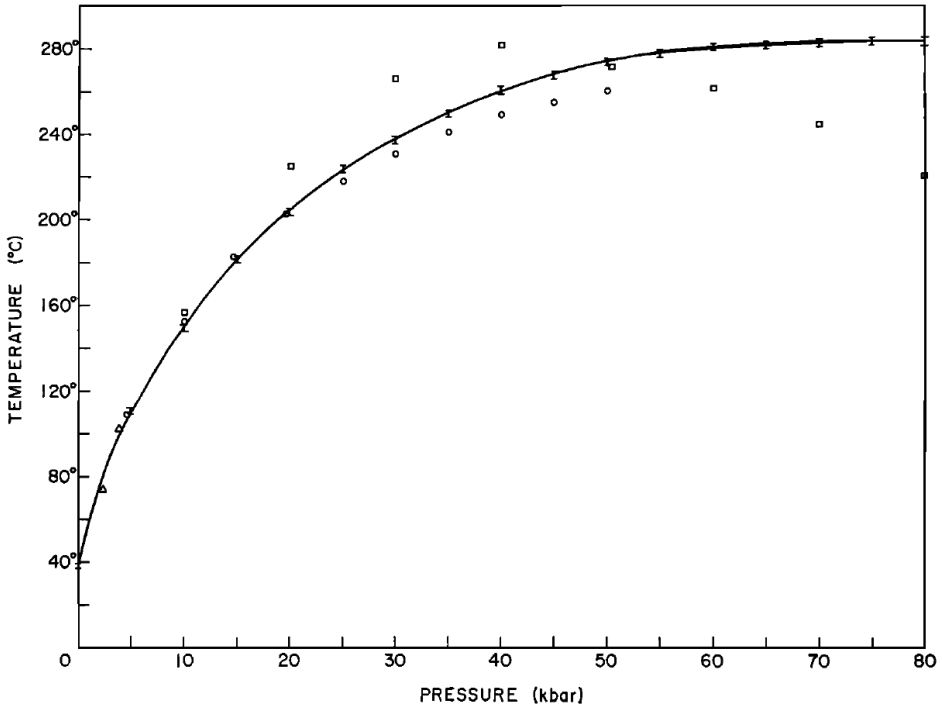


Fig. 4. The melting curve of rubidium. Symbols: *open triangle*, Bridgman; *open square*, Ponyatowskii; *open circle*, Newton et al.; *bar*, this work.

TABLE 1. Melting Points of the Alkali Metals

Pressure, kb	Temperature (°C) ± 2			
	Lithium	Sodium	Potassium	Rubidium
5	197	139	128	111
10	208	167	162	150
15	217	189	191	182
20	223	209	212	204
25	229	226	230	224
30	235	241	243	238
35	239	255	254	250
40	243	268	262	261
45	246	280	268	268
50	248	290	272	274
55	250	298	276	278
60	251	307	277	281
65	252	315	278	282
70	253	322	279	283
75	253	329	280	284
80	254	335	280	284

P (GPa)	T (°C)
0.5	111
1	150
1.5	182
2	204
2.5	224
3	238
3.5	250
4	261
4.5	268
5	274
5.5	278
6	281
6.5	282
7	283
7.5	284
8	284

Melting curves of lithium. sodium. potassium. and rubidium to 80 kilobars
H.D.Luedemann. G.C. Kennedy
Journal of Geophysical Research **73(8)** 2795 (1968)

Anderson (1969-1971)

[7] Anderson, D. R., Unpublished Dissertation, Brigham Young, University, Provo, Utah, 156 pp., (1969).
[8] Anderson, D. R., Ott, J. B., Goates, J. R., Hall, H. T., Report COO-1707-9, Nat. Tech. Information Serv., Springfield, Va. 22151, 15 pp. (1970).
[9] Anderson, D. R., Ott, J. B., Goates, J. R., Hall, H. T., J. Chem.Phys., 54, 234-238 (1971).

« *Anderson, et al. [9] based the pressure calibration for their tetrahedral press on the Hg melting curve reported by Klement, et al [235]. The temperature of the Na melting curve lies on the order of 100°C above the Hg melting curve. This means that the pressure calibration used by Anderson, et al is probably a little low.* » J. F. Cannon, p.788

Behavior of the Elements at High Pressures John Francis Cannon, J. Phys. Chem. Ref. Data **3**, 781 (1974)

Cannon (1970)

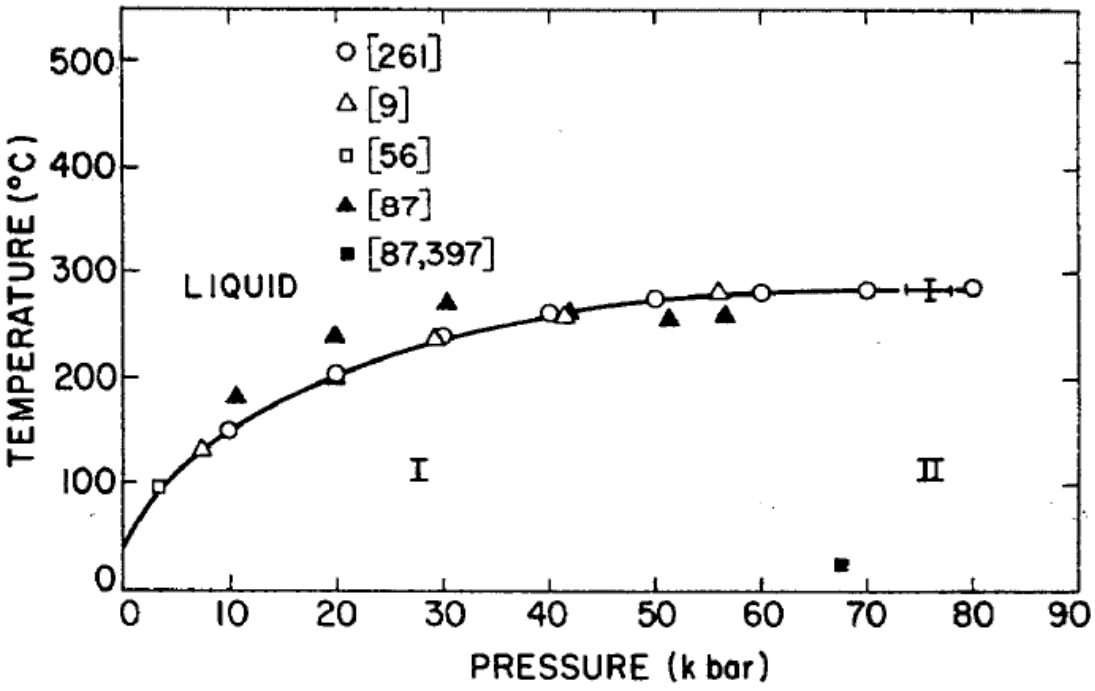


FIGURE 5. Phase diagram for rubidium.

[261] Luedemann, H. D., Kennedy, G. C, J. Geophys. Res., **13**, 2795-2805 (1968).
[9] Anderson, D. R., Ott, J. B., Goates, J. R., Hall, H. T., J. Chem. Phys., **54**, 234-238 (1971).
[56] Bridgman, P. W., Proc. Amer. Acad. Arts Sci., **60**, 385-421 (1925).
[87] Bundy,F. P.,Phys. Rev., **115**,274-277 (1959).
[397] Vereshchagin, L. F., Sernerchan, A. *A., Kuzin, N. N., Sadlov,* Yu. *A., SOY. Phys. Dokl., 14, 557-559 (1969); Engl. Transl.* Of Dokl. Akad. Nauk SSSR, **186**, 1045-1047 (1969).

Behavior of the Elements at High Pressures
John Francis Cannon, J. Phys. Chem. Ref. Data **3**, 781 (1974)

Young (1975)

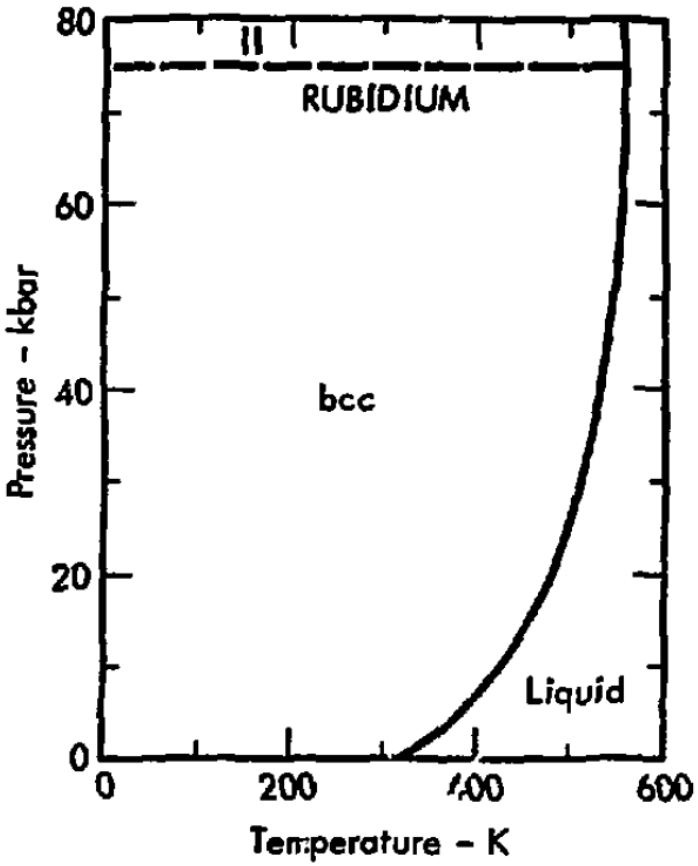


Fig. 39. The phase diagram of rubidium.

D.A. Young, *Phase diagrams of the elements*, No. UCRL—51902, California Univ. (1975)

Nikolaenko (1978)

Table 1. Thermodynamics of melting of lithium, potassium and rubidium (experimental data)

	T K	P kbar	ΔV $\frac{cm^3}{mole}$	V_s $\frac{cm^3}{mole}$	$\Delta S/R$	ΔU $\frac{cal}{mole}$
	312.12*	0.001	1.450*	56.380*	0.828	513.5
	313.65	0.074	1.435	56.225	0.831	515.3
	332.78	1.077	1.190	54.250	0.815	507.9
	352.67	2.310	1.000	52.210	0.809	511.7
Rb	372.65	3.773	0.840	50.200	0 803	518.6
	392.80	5.518	0.705	48.175	0.799	530.5
	412.70	7.566	0.584	46.203	0.788	540.4
	432.61	10.016	0.482	44.225	0.781	556.0
	452.64	12.995	0.395	42.250	0.778	576.7

*Extrapolated values.

A.M.Nikolaenko, I.N.Makarenko, S.M.Stishov, *Thermodynamics of melting of lithium, potassium and rubidium at high pressures,* Solid State Communications, **27**(4) 475-477 (1978)

Boehler (1984)

TABLE 1. Melting temperature T_m of Li, Na, K, Rb, and Cs at high pressures.

	T_m (°C)				
P(kbar)	Li	Na	K	Rb	Cs
0	180.0	97.8	63.7	39.4	28.4
5	194.8	136.5	128	115.0	113.0
10	205.9	167.5	167	161.5	160.0
15	215.2	192.5	195	193.0	188.0
20	223.0	214.0	214	216.5	197.0
25	229.3	232.5	229	234.0	197.5*
30	234.8	249.0		248.0	197.0

*triple point Cs_I - Cs_{II} - liquid at 22.8 kbar, 193°C

R. Boehler and D. A. Young, *Melting and adiabats of the alkali metals at high compressions, Journal of non-crystalline solids* **61**, 141 (1984)

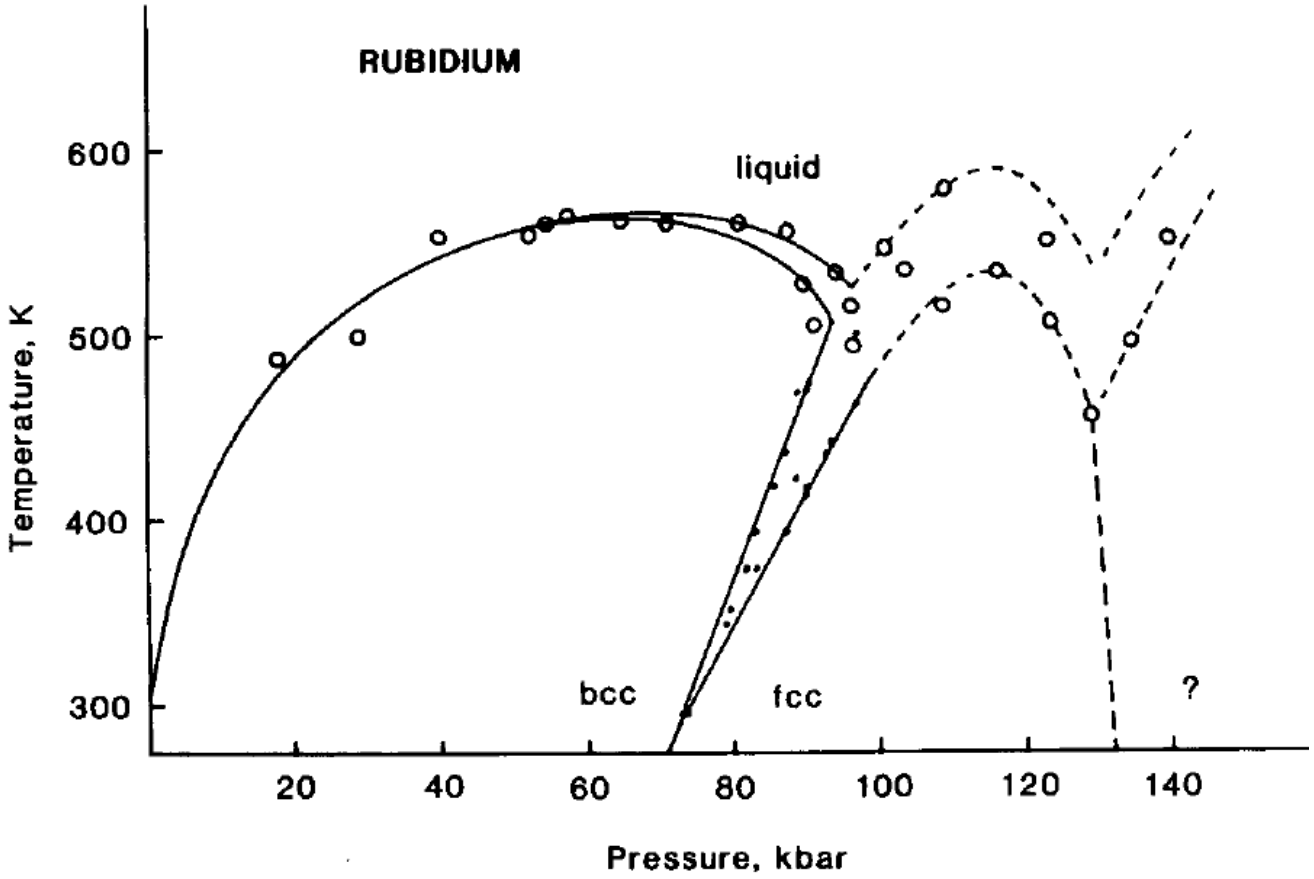
Shaw (1985)

From Table III, p. 7940

T(°C)	P (GPa)
60.1	0.120
78.8	0.225
108.3	0.450
130.9	0.600
150.1	0.700

G.H. Shaw and D. A. Caldwell, *Sound-wave velocities in liquid alkali metals studied at temperatures up to 150°C and pressures up to 0.7 Gpa*, Phys. Rev. B, **32** 7937 (1985)

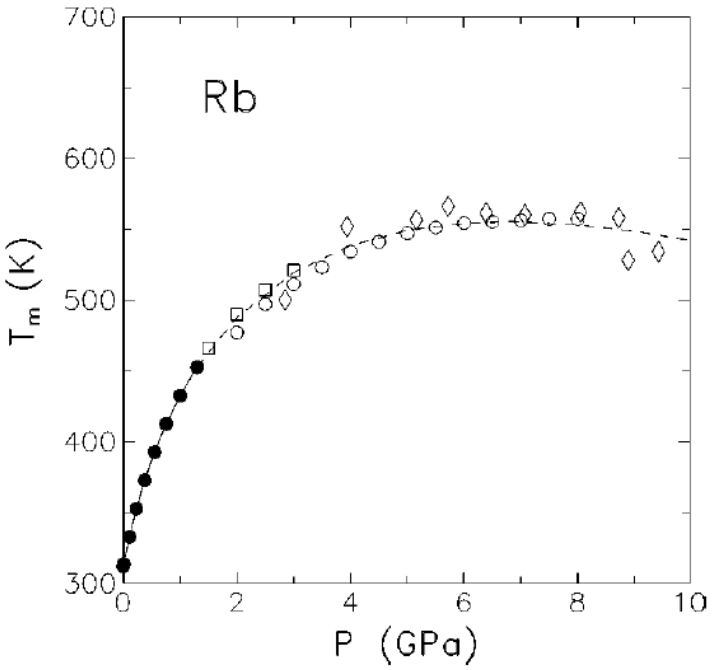
Boehler (1986)



P(GPa)	T (K)
7.3166	296.85
7.8839	344.58
7.9499	352.45
8.1609	374.48
8.2665	394.93
8.2929	375
8.5303	420.1
8.6887	437.94
8.7018	394.93
8.8338	423.25
8.847	469.93
8.9657	414.86
8.9657	470.98
8.9921	419.06
9.0053	475.7
9.2427	436.36
9.3219	443.71
9.6517	502.45
9.6517	464.69

R. Boehler and C.-S. Zha , *Systematics in the melting behavior of the alkali metals from DAC measurements*, Physica B+C, **139–140** 233-236 (1986)

Kechin (2001)



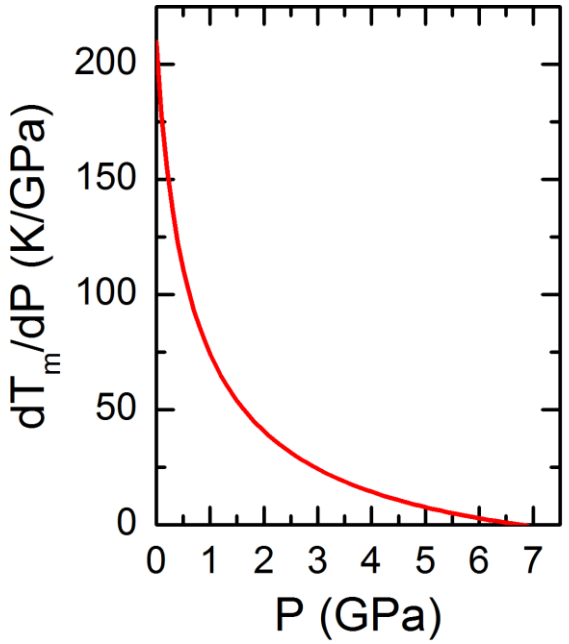


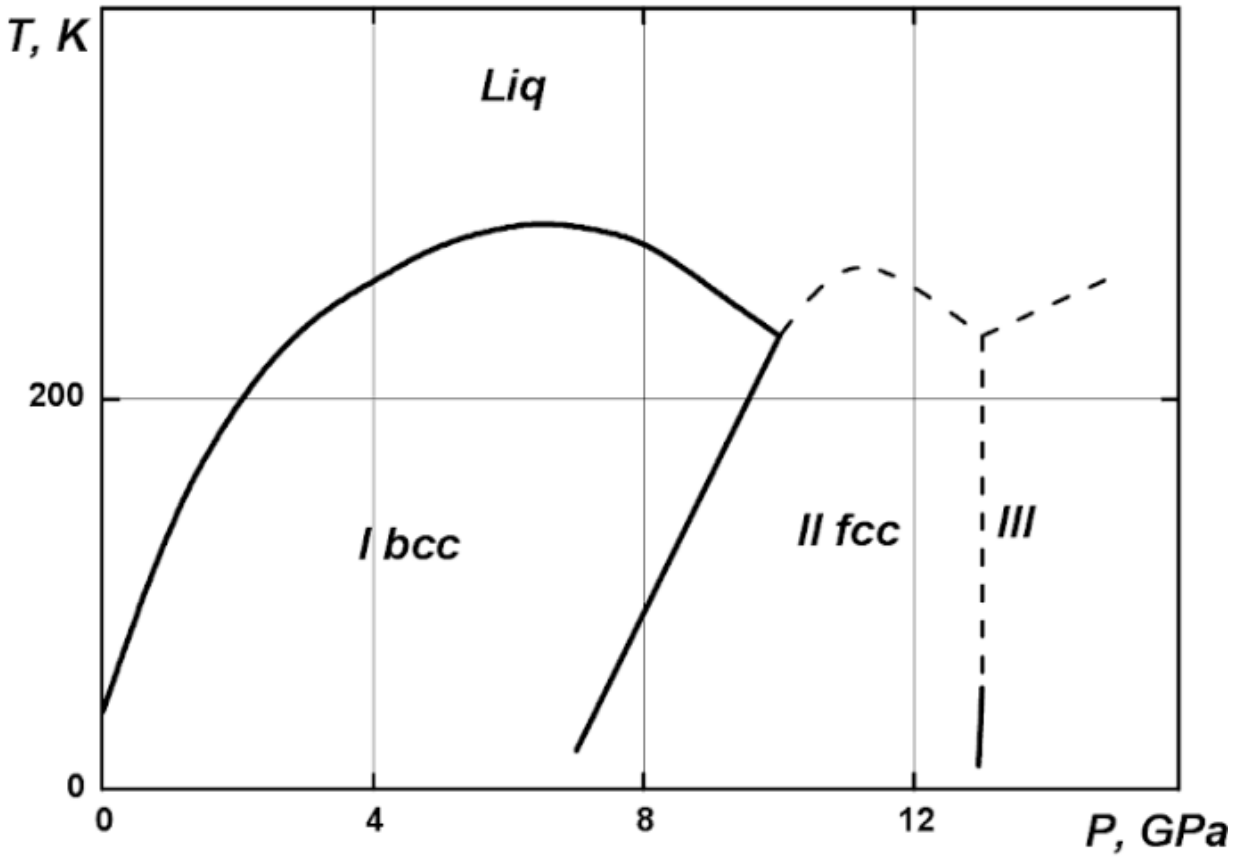
FIG. 2. Melting curve of Rb. The dashed line is extrapolation of Eq. (13) based on the data up to 1.3 GPa, solid circles (Ref. 37): $T_m = 312.12(1 + P/0.4287)^{0.3064} \exp(-0.04258P)$; open circles (Ref. 44), open squares (Ref. 45), and open diamonds (Ref. 46).

[37] Nikolaenko (1978)
[44] Luedemann (1968)
[45] Boehler (1984)
[46] Boehler (1986)

T_m=312.12*(1+P/0.4287)^(0.3064)*exp(-0.04258*P) (in K)

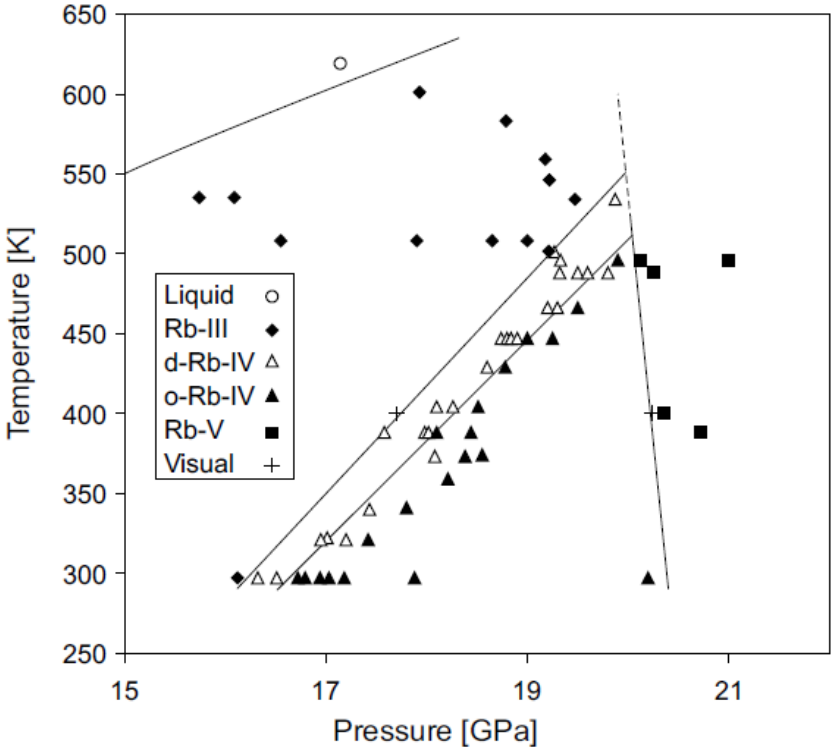
V. V. Kechin, *Melting curve equations at high pressure,*
Phys. Rev. B, **65** 052102 (2001)

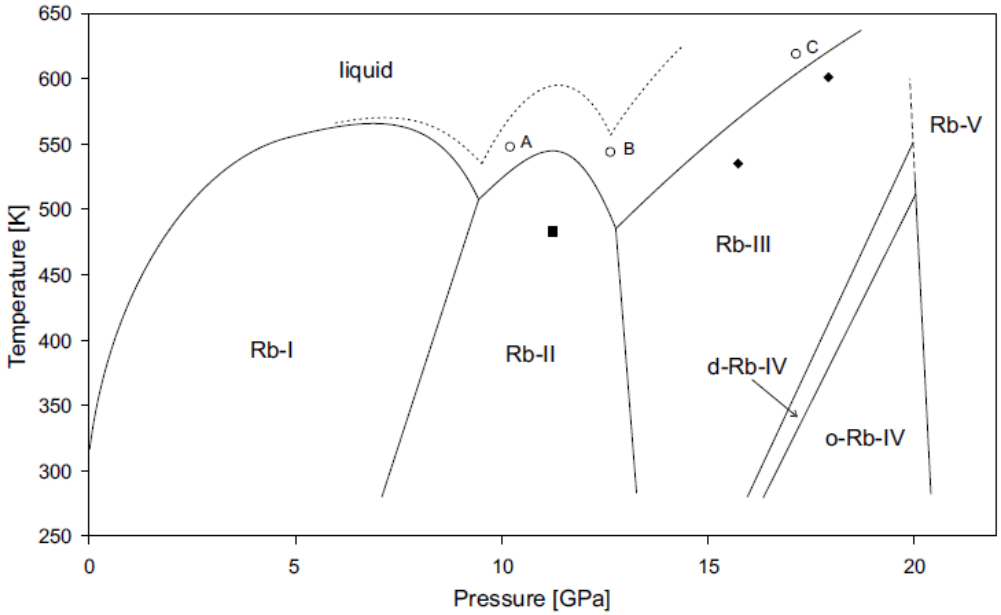
Tonkov (2004)



E. Yu Tonkov, E.G. Ponyatovsky, *Phase Transformations of Elements Under High Pressure*, CRC Press (2004)

Lundegaard (2007)





Lars F. Lundegaard, *High-Pressure Diffraction Studies of Rubidium Phase IV,* Ph.D. thesis, University of Edinburgh (2007)

Arafin (2016)

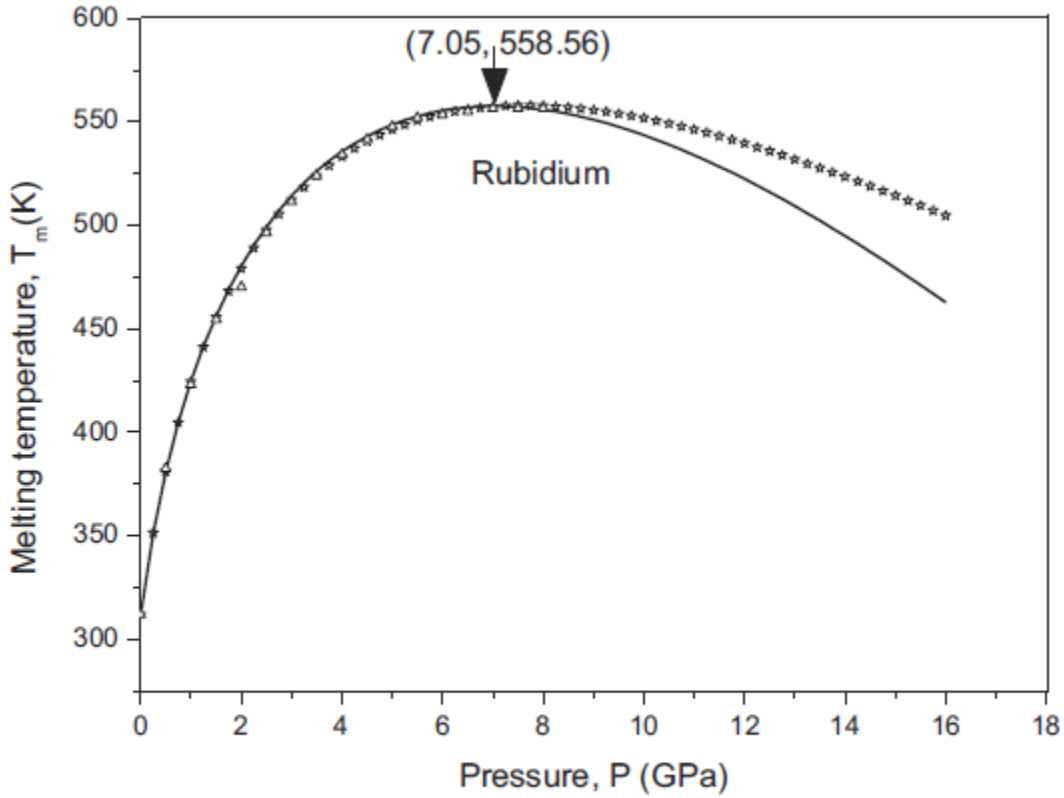
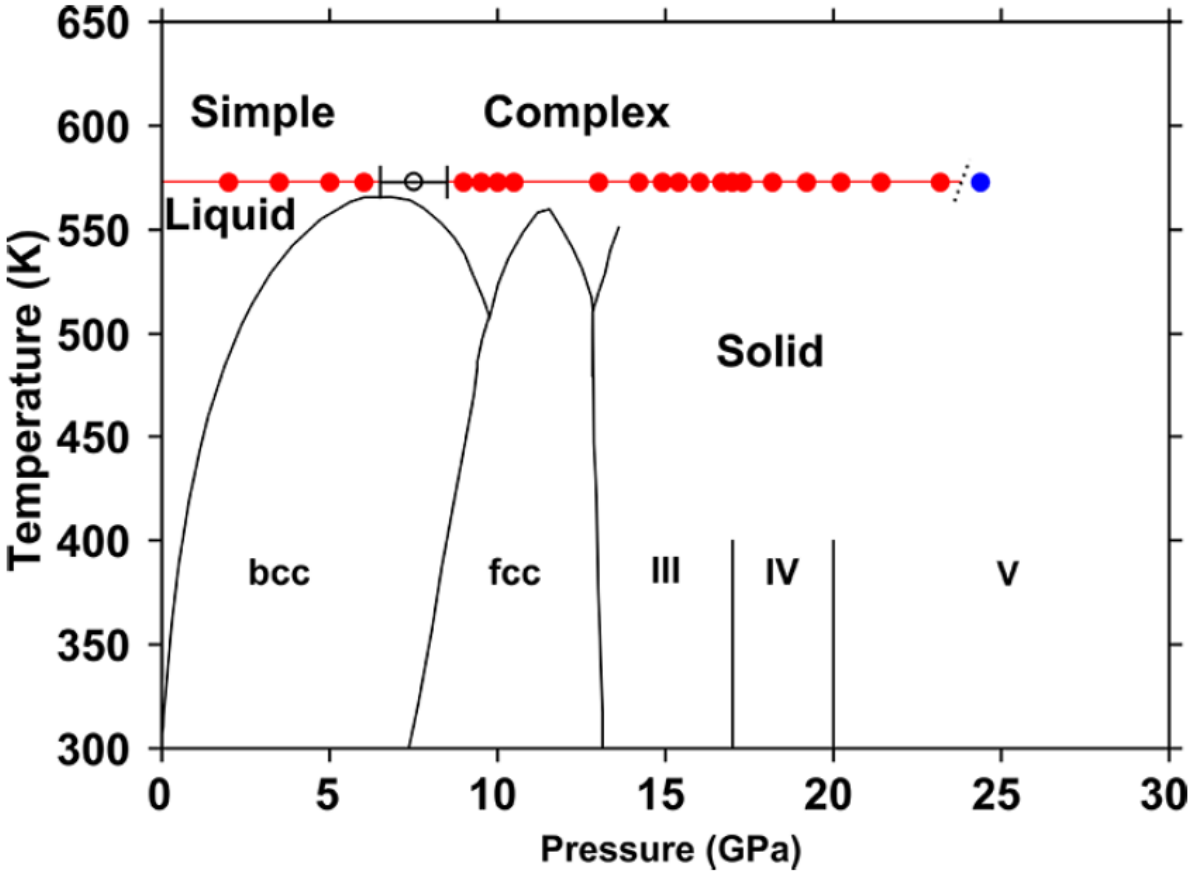


Fig. 3. T_m–P variation from Rb. open star represents values computed from Eq. (6); solid line represents values obtained from Eq. (29); upward triangles are the experimental values Ref. [13].

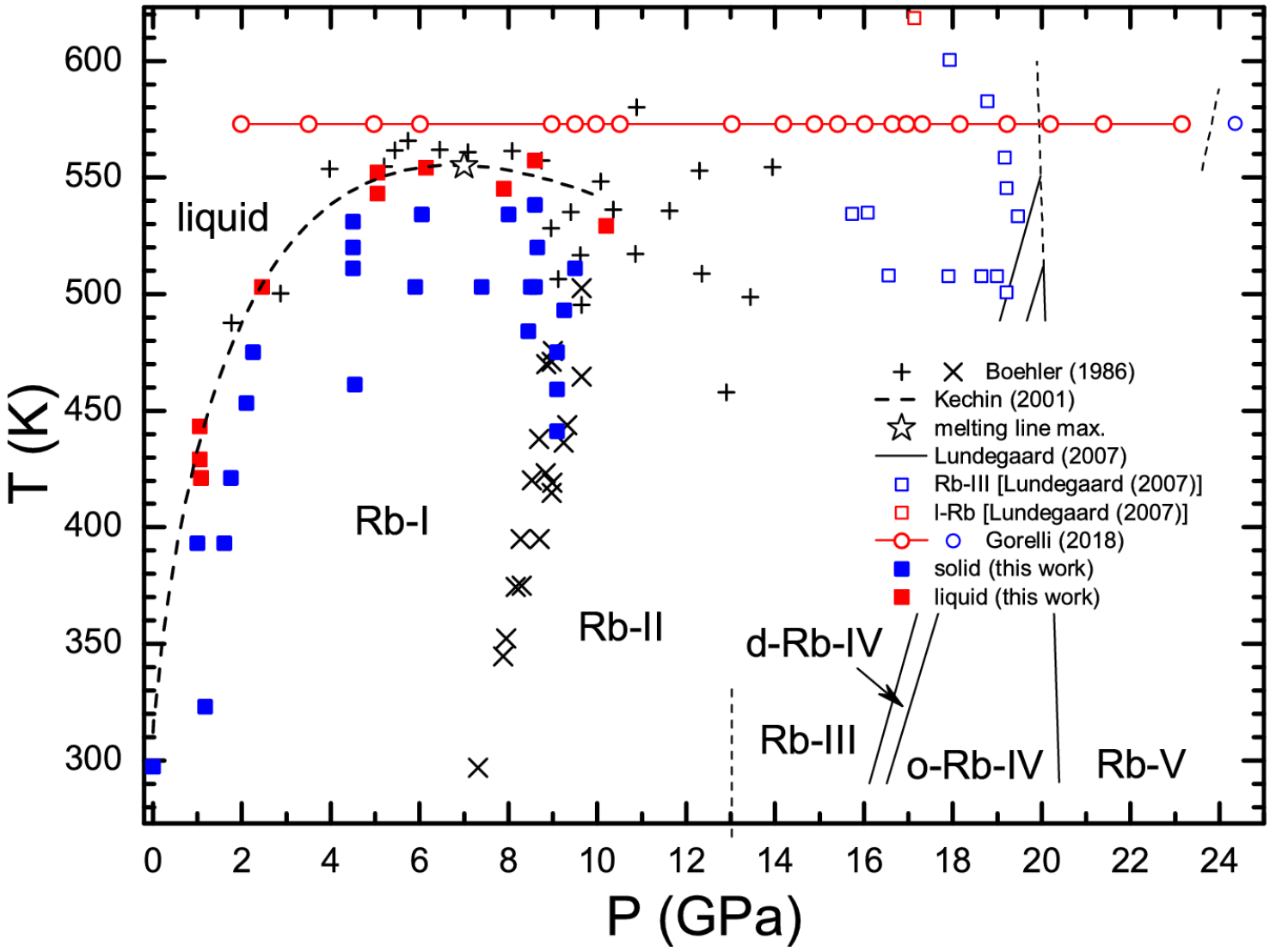
Sayyadul Arafin, Ram N.Singh,
An equation of state for alkali metals,
Journal of Physics and Chemistry of Solids, **91**, 101-105 (2016)

Gorelli (2018)



F.A. Gorelli *et al*, *Simple-to-Complex Transformation in Liquid Rubidium,* J. Phys. Chem. Lett., **9** 2909 (2018)

Ayrinhac (2020)



S. Ayrinhac, V.N. Robinson, F. Decremps, M. Gauthier, D. Antonangeli, S. Scandolo, and M.Morand, *Phys. Rev. Materials* **4**, 113611 (2020)

Comparison with other alkali metals

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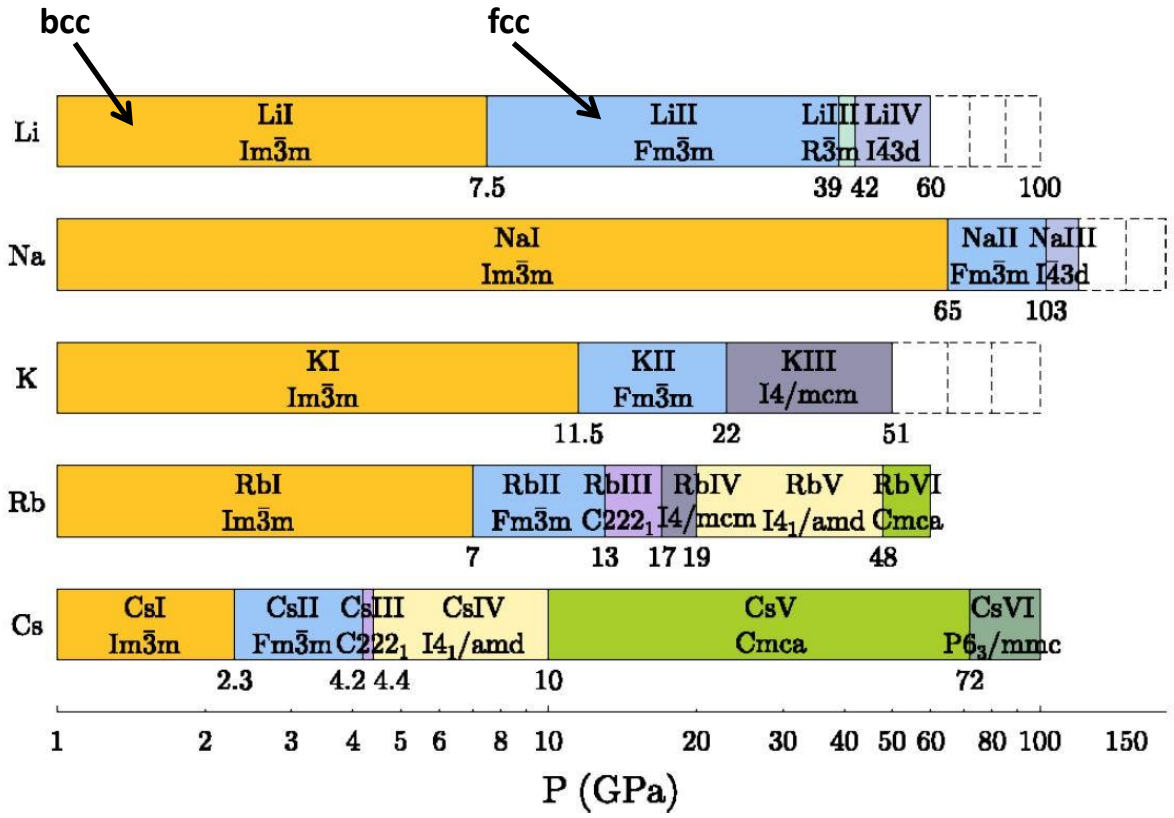

FIG. 1. (Color online) Phase sequences for the alkali metals as a function of pressure (Refs. 2–7, 11, and 13–15).

H. Katzke, P. Tolédano, *Structural mechanisms and order-parameter symmetries for the high-pressure phase transitions in alkali metals,* Physical Review B, ***71*(18),** 184101 (2005)

« The known phase transition sequence is bcc Rb-I to fcc Rb-II at 7 Gpa [1], to unknown Rb-III at 13 GPa [1], to incommensurate Rb-IV at 17 GPa [4], to body-centered tetragonal Rb-V at 20 GPa [5] and finally to orthorhombic Rb-VI at 48 Gpa [6,7]. » R.J. Nelmes [Phys. Rev. Lett. (2002)]

Li	bcc $\xrightarrow{7.5}$ fcc $\xrightarrow{39}$ *hR*1 $\xrightarrow{42}$ *cI*16 $\xrightarrow{60}$ *oC*88 $\xrightarrow{70}$ *oC*40 $\xrightarrow{95}$ *oC*24 < 125
Na	bcc $\xrightarrow{65}$ fcc $\xrightarrow{104}$ *cI*16 $\xrightarrow{117}$ *oP*8 $\xrightarrow{125}$ h-g (*tI*19*) $\xrightarrow{180}$ *hP*4 < 200 GPa
K	bcc $\xrightarrow{11.6}$ fcc $\xrightarrow{20}$ h-g (*tI*19*) $\xrightarrow{54}$ *oP*8 $\xrightarrow{90}$ *tI*4 $\xrightarrow{96}$ *oC*16 < 112 GPa fcc $\xrightarrow{25}$ *hP*4 $\xrightarrow{35}$
Rb	bcc $\xrightarrow{7}$ fcc $\xrightarrow{13}$ *oC*52 $\xrightarrow{17}$ h-g (*tI*19*) $\xrightarrow{20}$ *tI*4 $\xrightarrow{48}$ *oC*16 < 70 GPa
Cs	bcc $\xrightarrow{2.4}$ fcc $\xrightarrow{4.2}$ *oC*84 $\xrightarrow{4.3}$ *tI*4 $\xrightarrow{12}$ *oC*16 $\xrightarrow{72}$ dhcp < 223 GPa

V.F. Degtyareva, *Potassium under pressure: Electronic origin of complex structures,* Solid State Sciences, **36** 62 (2014)

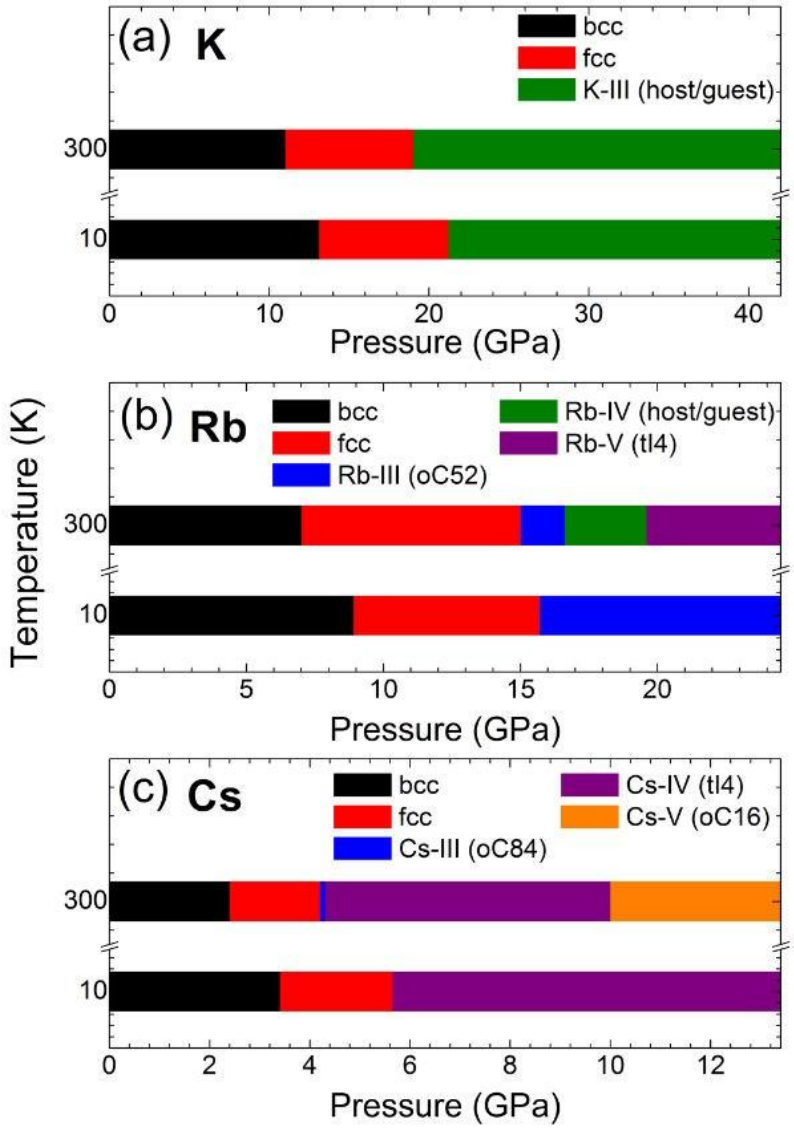

FIG. 7. (Color online) Phases of K, Rb, and Cs at 10 K and room temperature [4,19].

G. Fabbris. J. Lim. L. S. I. Veiga. D. Haskel. and J. S. Schilling, *Electronic and structural ground state of heavy alkali metals at high pressure*, Phys. Rev. B **91** 085111 (2015)

Crystal phases

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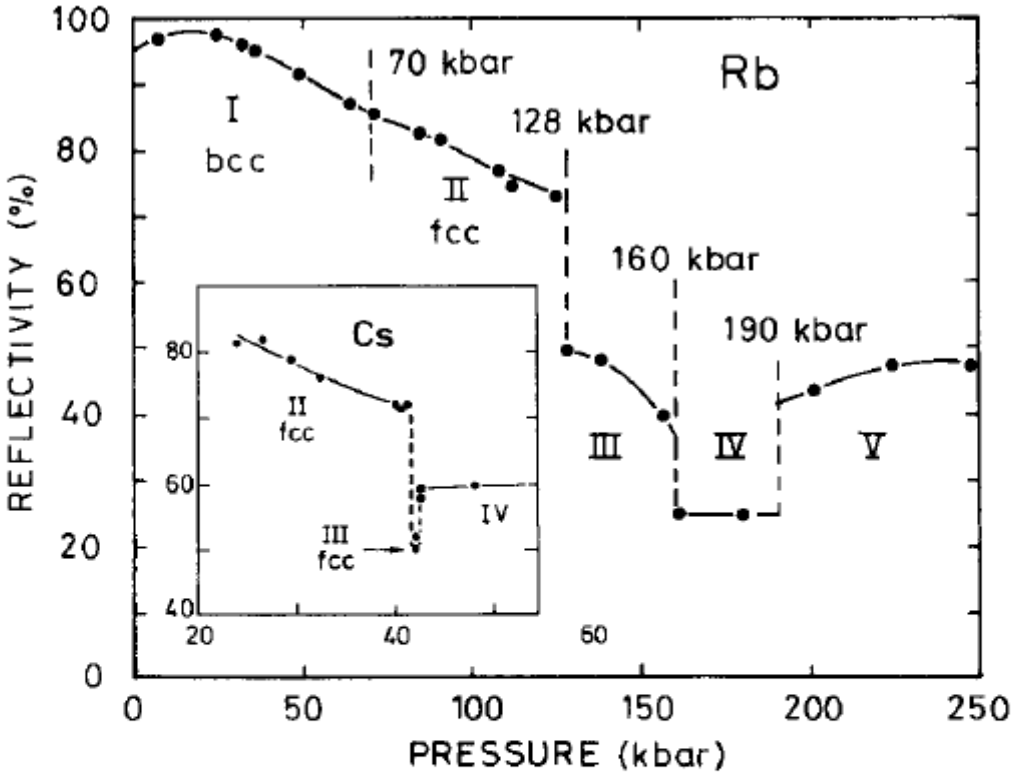


Figure 2

Pressure scan of the near-infrared reflectivity ($\hbar\omega$ = 0.7 eV) of polycrystalline Rb metal in the pressure range 0 - 250 kbar. A similar pressure scan ($\hbar\omega$ = 0.6 eV) for Cs metal /26/ is shown on a different pressure scale.

K. Takemura & K. Syassen, *Solid State Communications*, **44 (8)** 1161-1164 (1982)

Rb-III

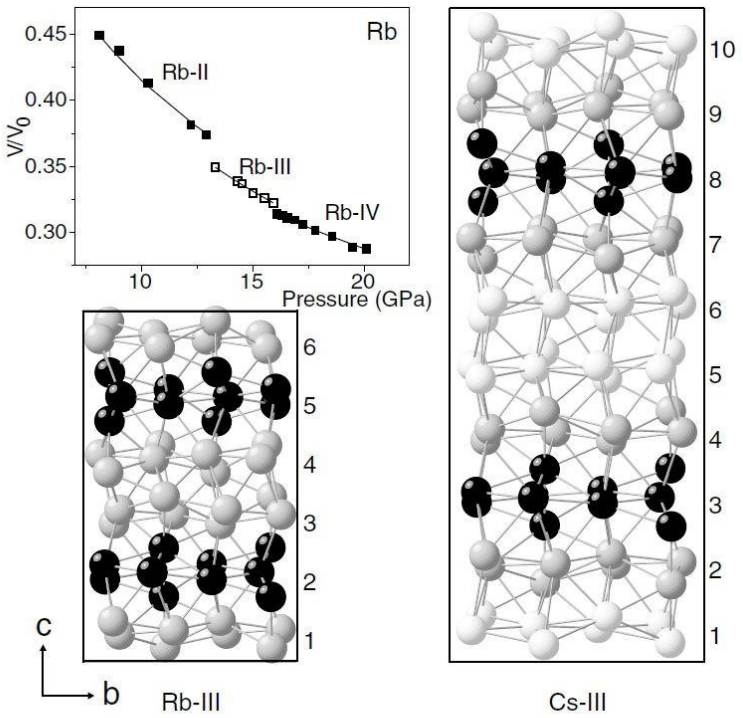


FIG. 2. Crystal structures of Rb-III and Cs-III, on the same scale, viewed along the *a* axis of the $C222_1$ unit cell. Rb-III is drawn with a nonstandard origin on a 2_1 screw axis along *a* to facilitate comparison with Cs-III which is drawn with the standard origin on a twofold axis (see text and note [20]). The 8- and 10-atom *a*-*b* layers in the two structures are numbered. Nonequivalent 8-atom layers in Cs-III are in two different shades of grey. Contact distances of up to 4.1 Å for Rb-III and 4.7 Å for Cs-III are shown as solid lines. Inset: equation of state of Rb-II, III, and IV. The lines are guides to the eye.

14-16 Gpa
*oC*52

R. J. Nelmes, M. I. McMahon, J. S. Loveday and S. Rekhi,
Phys. Rev. Lett. **88**, 155503 (2002)

Rb-IV

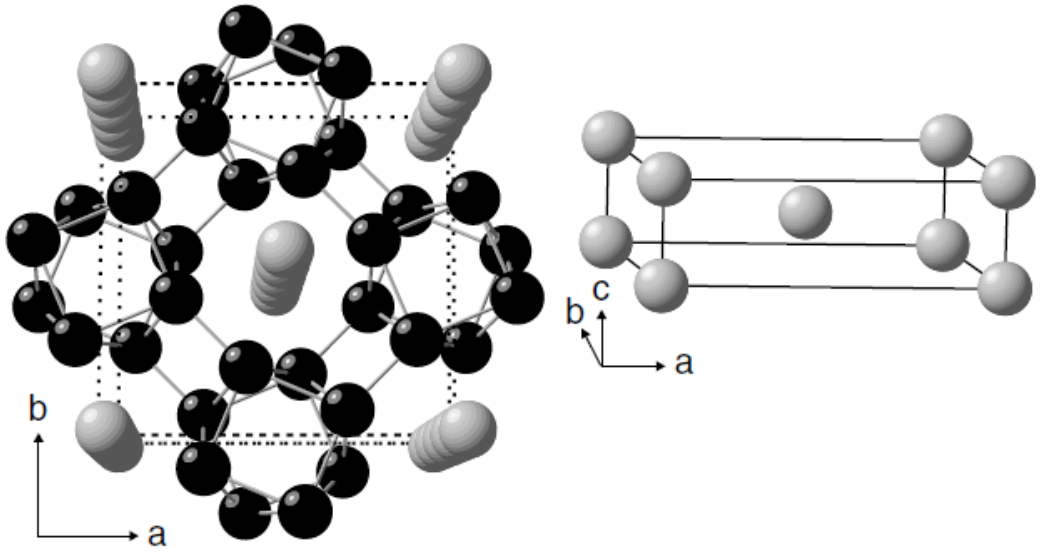
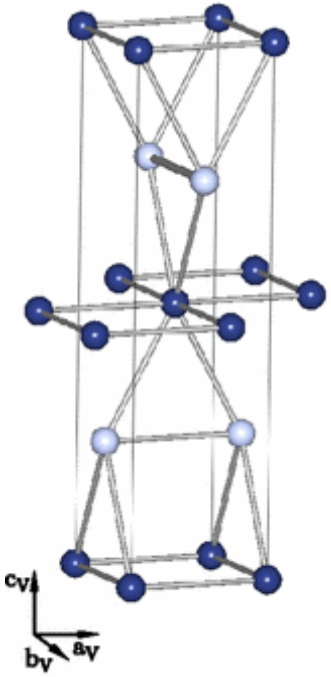


FIG. 3. Host-guest structure of Rb-IV. The host framework is shown in black, and the guest structure in grey.

16-20 GPa
Guest atoms : BCT lattice

M. I. McMahon. S. Rekhi. and R. J. Nelmes. Phys. Rev.Lett. **87**, 055501 (2001)
M. I. McMahon and R. J. Nelmes. Phys. Rev. Lett. **93**, 055501 (2004)
U. Schwarz *et al,* Phys. Rev. Lett. **83,** 4085 (2004)
I. Loa *et al*, Phys. Rev. Lett. **99**, 035501 (2007)

Rb-V



Tetragonal body-centered structure of Rb-V (*tI*4)

H. Olijnyk and W. B. Holzapfel, Phys. Lett. **99A**, 381 (1983)
H. Katzke, P. Tolédano, Phys. Rev. B, ***71*(18),** 184101 (2005)

Rb-VI

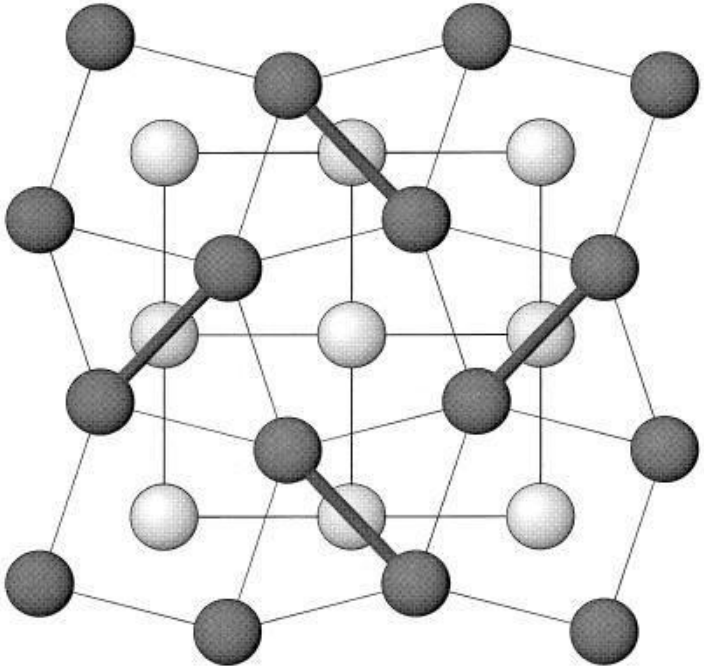


Fig. 3. Projection of the *oC*16 structure of Rb-VI along the orthorhombic *a*-axis. Only two successive layers of 8*f* and 8*d* atoms are shown. The short bond distances d_1 (see Table 1) between 8*f* atoms are indicated by thick lines.

Phase	Rb-VI
P (GPa)	48.1
a (Å)	9.3718(10)
b (Å)	5.5501(6)
c (Å)	5.5278(6)
a/c	1.6886
b/c	1.0040
y (8f)	0.1704(9)
z (8f)	0.3177(9)
x (8d)	0.2107(4)
$R(F^2)$	0.100
V_{atom} (Å^3)	17.970
V/V_0	0.194
d_1 (Å)	2.764(8)
d_3 (Å)	3.046(4)
d_{other} (Å)	2.81–2.90

U. Schwarz, K. Syassen, A. Grzechnik, M. Hanfland,
The crystal structure of rubidium-VI near 50 GPa,
Solid State Communications, **112** 319–322 (1999)

Critical point

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T_c =2017 K
Pc=1245 MPa
ρ_c=290 kg/m^3

F. Hensel., W.W. Warren Jr., Fluid Metals, *Liquid–Vapor Transition of Metals*, Princeton University Press, Princeton (1999)

Table 1. The results of theoretical calculations and experimental measurements of T_c (K).

Me	Li	Na	K	Rb	Cs	Fr
[11]	3293	—	—	—	—	—
[12]	—	2800	2440	2190	2150	—
[13]	—	2880	2440	—	—	—
[14]	3223 ± 600	2573 ± 350	2223 ± 600	2093 ± 25	2057 ± 40	—
[15]	2938	—	—	—	—	—
[16]	3286	2573 ± 60	2173 ± 50	—	—	—
[5]	—	2136	1790	—	—	—
[17]	—	—	—	—	—	1550
[18]	3831	2635	2185	2061	1942	—
[19]	3223	2573	2223	2093	2057 ± 40	1810
[20]	—	2504	2281 ± 5	2106	2048 ± 4	—
[2]	—	2326	1924	—	—	—
[21, 22]	3680 ± 300	2503 ± 50	2281	2106 ± 15	2043 ± 15	1980 ± 50
[23]	—	2504 ± 50	2240 ± 40	2097 ± 10	2043 ± 6	—
[24]	—	—	2280	2090	2010	—
[25]	—	—	—	—	1924	—
[26]	3503 ± 10	2497 ± 18	2239 ± 49	2100 ± 15	2035 ± 23	—
[26]	3344 ± 42	—	—	—	—	—
[27]	3741	2429	2195	1995	2018	—
[28]	3474	2590	2195	—	—	—
[7]	3407	—	2050	—	—	—
[8]	3232	—	—	—	—	—
[29]	—	—	—	—	1938 ± 10	—
[30]	—	2485	2280	2017	1924	—
[4]	3285	2421	2106	1796	1736	—
[31]	3214	2908	2152	1912	1770	—
[32]	3350	2263	2111	1946	1884	—
[6]	3225	—	—	—	—	—
[33, 34]	3503 ± 10	2497 ± 18	2239	—	2035 ± 23	—
[35]	3210	2480	2230	2120	2020	—
[36]	—	—	—	—	—	1400
[37]	—	—	1987	1822	—	—
[38]	3940	2489	—	—	—	—
[39]	—	—	—	—	—	1690
[40]	2797	2180	2233	1836	1786	—
This work	3190	2420	2106	1930	1830	1690

Estimation of the critical temperatures of alkaline metals on the basis of specified data on surface tension polytherms
B B Alchagirov, B S Karamurzov, Kh Kh Kalazhokov, Z A Kokov and O Kh Kyasova
Journal of Physics: Conference Series**, 1147 (1)** 012004 (2019)

Elastic constants

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Roberts (1966)

THE ELASTIC CONSTANTS OF RUBIDIUM

Table 1. *Measured velocities in rubidium**

Propagation direction	V_L @ 293°K	V_L @ 80°K	V_S @ 80°K
[100]	1·255	1·360	1·000
[110]	1·460	1·645	1·000 Pol[001]
[111]	1·535	1·710	—

* Velocity units are in km/sec. The precision of these measurements is ±2·5%.

C.A. Roberts and R. Meister, *The elastic constants of rubidium,* J. Phys. Chem. Solids. **27** 1401 (1966)

Gutman (1966)

Table 1. *Values of the adiabatic elastic constants, the elastic anisotropy and the density of rubidium. The elastic constants are in units of* 10^{10} dyn/cm^2 *and the density in* g/cm^3

T (°K)	Sample	C_n	C_{44}	C'	C_{11}	C_{12}	B_s	A	ρ
4·2*	1	5·36	2·21	0·274	3·42	2·88	3·06	8·07	—
78	1	4·97	1·98	0·256	3·25	2·73	2·90	7·73	1·61
78	2	4·91	1·97	—	—	—	—	—	1·61
110	1	4·78	1·89	0·246	3·14	2·64	2·81	7·68	1·60
140	1	4·62	1·80	0·238	3·06	2·57	2·73	7·56	1·59
170	1	4·44	1·71	0·230	2·96	2·50	2·65	7·43	1·58

* Linearly extrapolated.

E.J. Gutman, J. Trivisonno, *Temperature dependence of the elastic constants of rubidium,* Journal of Physics and Chemistry of Solids **28(5)** 805 (1967)

Suzuki (1968)

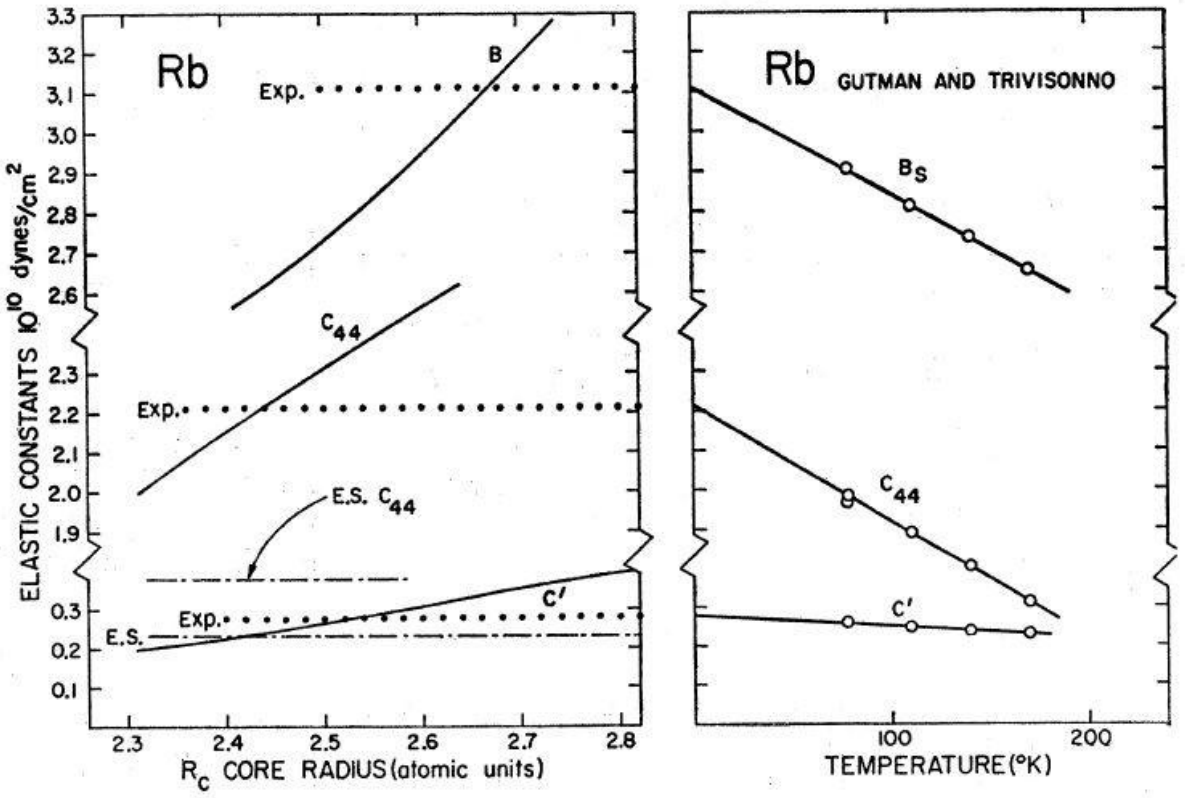

FIG. 4. Second-order elastic constants of rubidium. Notations are the same as Fig. 1.

Suzuki, T., Granato, A. V., & Thomas Jr, J. F., *Second-and third-order elastic constants of alkali metals,* Physical Review, **175**, 766 (1968)

TABLE II. Elastic constants at fusion and T_M, ρ, α, and M for eleven cubic elements.

Element	T_M (°K)	$c_{11}(T_M)$	$c_{12}(T_M)$ (10^{12} dyn/cm^2)	$c_{44}(T_M)$	$\rho(300)$ (g/cm^3)	α (10^{-4}°K^{-1})	M
fcc							
Li	459	0.1266[a]	0.1064[a]	0.0739[a]	0.534[b]	···	6.94
Na	370.7	0.0709[c]	0.0599[c]	0.0370[c]	0.971[d]	2.75[e]	23.00
K	335.2	0.0363[f]	0.0310[f]	0.0172[f]	0.851[f]	2.5[e]	39.10
Rb	311.7	0.0269[g]	0.0230[g]	0.0130[g]	1.53[b]	···	85.48
Cs	301.7	0.0218[h]	0.0186[h]	0.0107[h]	1.873[b]	···	132.91
bcc							
Al	932.7	0.683[i]	0.403[i]	0.188[i]	2.699[d]	0.99[e]	26.97
I		1.315[i]	1.053[i]	0.4833[i]			
Cu	1356				8.937[j]	0.70[e]	63.54
II		1.269[j]	1.018[j]	0.470[j]			
I		0.958[i]	0.791[i]	0.279[i]			
Ag	1233.8				10.50[j]	0.81[e]	107.88
II		0.916[j]	0.764[j]	0.287[j]			
I		1.538[i]	1.343[i]	0.294[i]			
Au	1336				19.30[j]	0.58[e]	197.00
II		1.572[j]	1.380[j]	0.281[j]			
Pb	600.4	0.419[i]	0.374[i]	0.100[i]	11.34[b]	1.2[e]	207.21
Ni	1728	1.52[i]	1.42[i]	0.66[i]	8.90[b]	0.57[e]	58.69

[a] T. Slotwinski and J. Trivisonno, J. Phys. Chem. Solids **30**, 1276 (1969).
[b] See Ref. 17.
[c] M. E. Diederich and J. Trivisonno, J. Phys. Chem. Solids **27**, 637 (1966).
[d] O. L. Anderson, in *Physical Acoustics* (Academic Press Inc., New York, 1965), Vol. III, Part B.
[e] O. Kubaschewski, Trans. Faraday Soc. **45**, 931 (1949).
[f] W. R. Marquardt and J. Trivisonno, J. Phys. Chem. Solids **26**, 273 (1965).
[g] See Ref. 18.
[h] F. J. Kollarits and J. Trivisonno, J. Phys. Chem. Solids **29**, 2133 (1968).
[i] See Ref. 10.
[j] See Ref. 11.

Rb : C_{11} = 2.69 GPa ; C_{12} = 2.30 GPa ; C_{44} = 1.30 GPa ; ρ = 1530 kg/m^3

J.N. Shapiro, *Lindemann law and lattice dynamics,*
Physical Review B, **1(10)** 3982 (1970)

Adiabatic sound velocity

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• Kim (1971)	liquid, v(T), up to 250°C
• Rosenbaum (1971)	*(published in Shaw'85)*
• Copley (1974)	dispersion curve
• Shaw (1985)	liquid, several isotherms
• Loa (2007)	solid (Rb-IV), longitudinal sound velocity
• Blairs (2007)	review at ambient P
• Bryk (2013)	exp. + simu.
• Belashchenko (2016)	simu.
• Ayrinhac (2020)	exp. + simu, 573 K

Kim (1971)

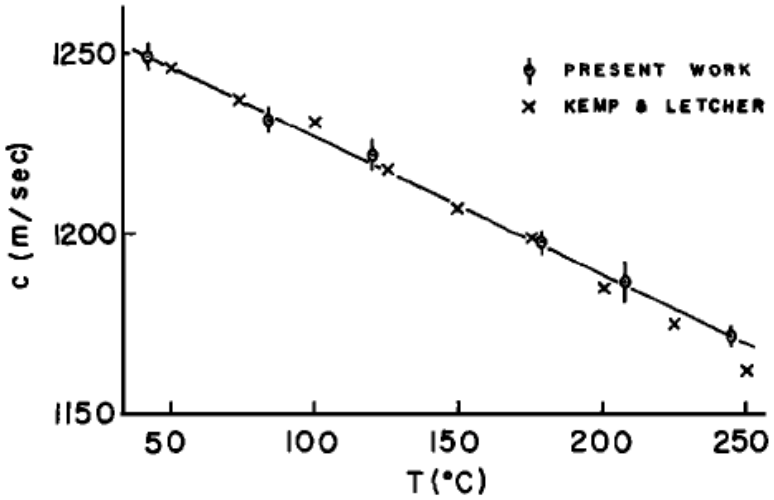


FIG. 3. Sound velocity versus temperature in liquid Rb.

$$\text{rubidium}: c = 1265.8 - 0.3823T,$$

M. G. Kim, K. A. Kemp, and S. V. Letcher,
Ultrasonic Measurement in Liquid Alkali Metals
J. Acoust. Soc. Am. **49**, 706 (1971)

Copley (1974)

Dispersion curve

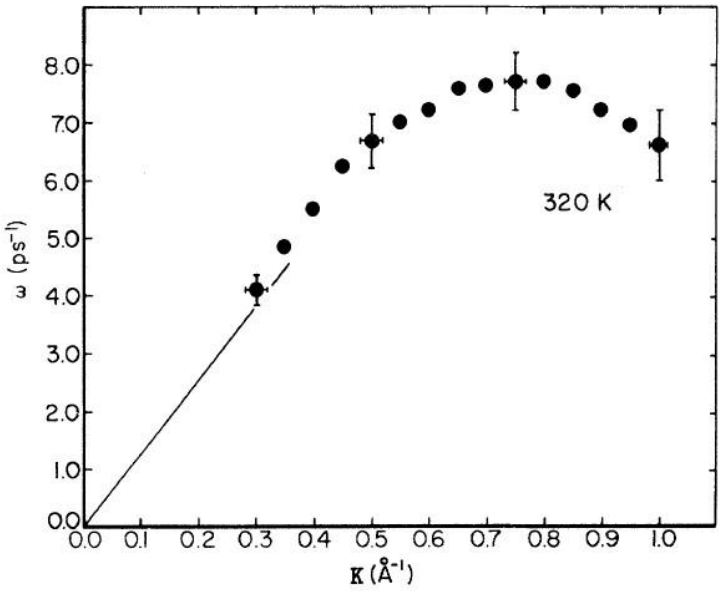


FIG. 2. "Dispersion curve" for liquid rubidium derived from the measured $\tilde{S}(\kappa,\omega)$. Error estimates reflect the width of the observed peaks and the resolution in κ. Solid line, derived from the measured sound velocity (Ref. 16).

J.R.D. Copley, J.M. Rowe, *Short-wavelength collective excitations in liquid rubidium observed by coherent neutron scattering*, *Phys. Rev. Lett.* **32(2)** 49 (1974)

Shaw (1985)

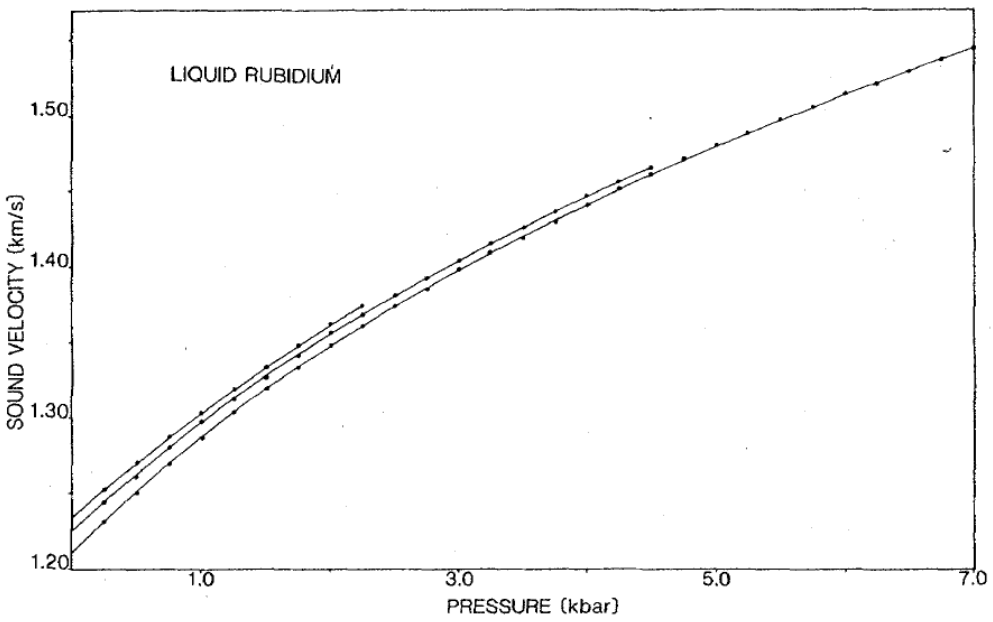


FIG. 4. Thermodynamic sound velocity in rubidium as a function of pressure. The dots are individual data points, and the curves are sketched in. The upper curve is for ~~60.1 °C~~, the middle curve is for 108.3 °C, and the lower curve is for 150.1 °C.

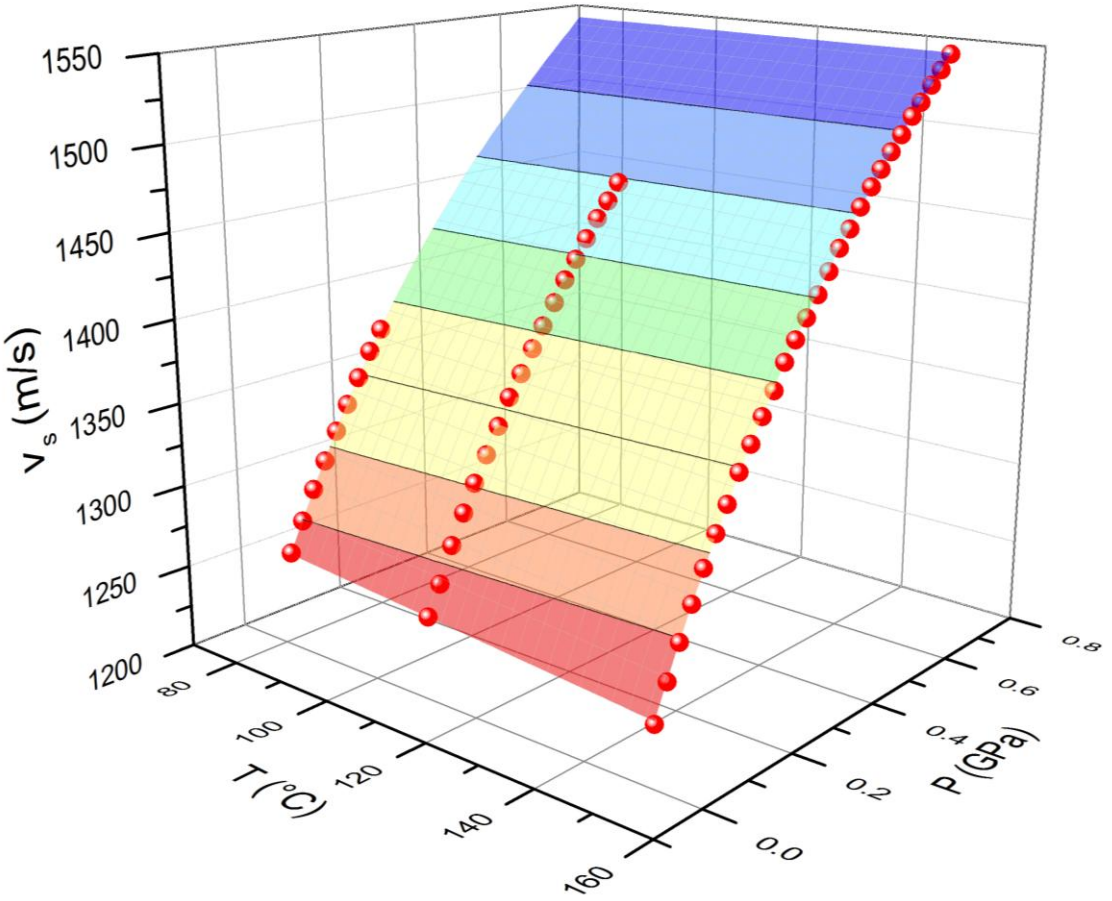
78.8°C

G.H. Shaw and D. A. Caldwell, *Sound-wave velocities in liquid alkali metals studied at temperatures up to 150°C and pressures up to 0.7 GPa*, Phys. Rev. B, **32** 7937 (1985)

From Shaw (1985)
Fig. 5

T (°C)	P(GPa)	v(m/s)
78.8	0.02565	1252.5
78.8	0.05109	1269.8
78.8	0.07587	1287.2
78.8	0.10065	1302.8
78.8	0.12609	1319
78.8	0.15087	1333.5
78.8	0.17565	1348
78.8	0.20043	1362.6
78.8	0.22522	1374.3
108.3	0.025	1243.6
108.3	0.04978	1260.3
108.3	0.07587	1280.4
108.3	0.1013	1297.2
108.3	0.12543	1312.3
108.3	0.15087	1326.8
108.3	0.1763	1341.3
108.3	0.20043	1356.4
108.3	0.22587	1368.2
108.3	0.2513	1381
108.3	0.27478	1392.7
108.3	0.30087	1404.5
108.3	0.325	1416.2
108.3	0.35043	1426.8
108.3	0.37457	1437.4
108.3	0.39935	1448
108.3	0.42348	1457
108.3	0.44891	1466.5

T (°C)	P(GPa)	v(m/s)
150.1	0.025	1230.2
150.1	0.05044	1250.3
150.1	0.07587	1268.7
150.1	0.1013	1286.6
150.1	0.12543	1303.4
150.1	0.15152	1319.6
150.1	0.17565	1333
150.1	0.20109	1348
150.1	0.22587	1360.9
150.1	0.25065	1373.7
150.1	0.27609	1385.5
150.1	0.30022	1398.9
150.1	0.32435	1409.5
150.1	0.34978	1419.6
150.1	0.37522	1430.2
150.1	0.4	1441.3
150.1	0.42478	1452.5
150.1	0.44891	1461.5
150.1	0.475	1472.1
150.1	0.49978	1481.6
150.1	0.52391	1489.9
150.1	0.54935	1498.3
150.1	0.57413	1506.7
150.1	0.60022	1515.6
150.1	0.6237	1522.3
150.1	0.64913	1530.7
150.1	0.67391	1538.5
150.1	0.7	1546.4



vS=v0+aT+bP+cT²+dP²+eP³+fTP			(m/s)
v0	1255.59297	0.99393	m/s
a	-0.28673	0.00825	m/s.°C
b	729.24498	6.39166	m/s.GPa
c	0	0	$m/s.°C^{-2}$
d	-662.85003	19.08553	$m/s.GPa^{-2}$
e	310.08802	17.90442	$m/s.GPa^{-3}$
f	0.40441	0.03674	m/s.°C.GPa

Shaw (1985)

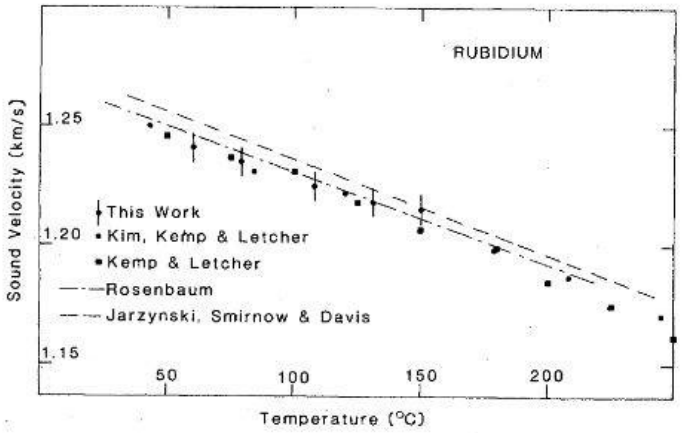


FIG. 8. Sound velocity in rubidium as a function of temperature at room pressure. The data of K. A. Kemp and S. V. Letcher [Office of Naval Research Technical Report No. 1 (1968)] are taken as reported in Kim *et al.* (Ref. 2).

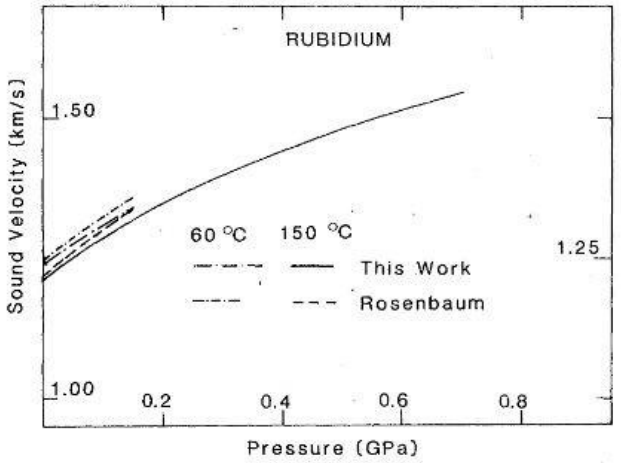
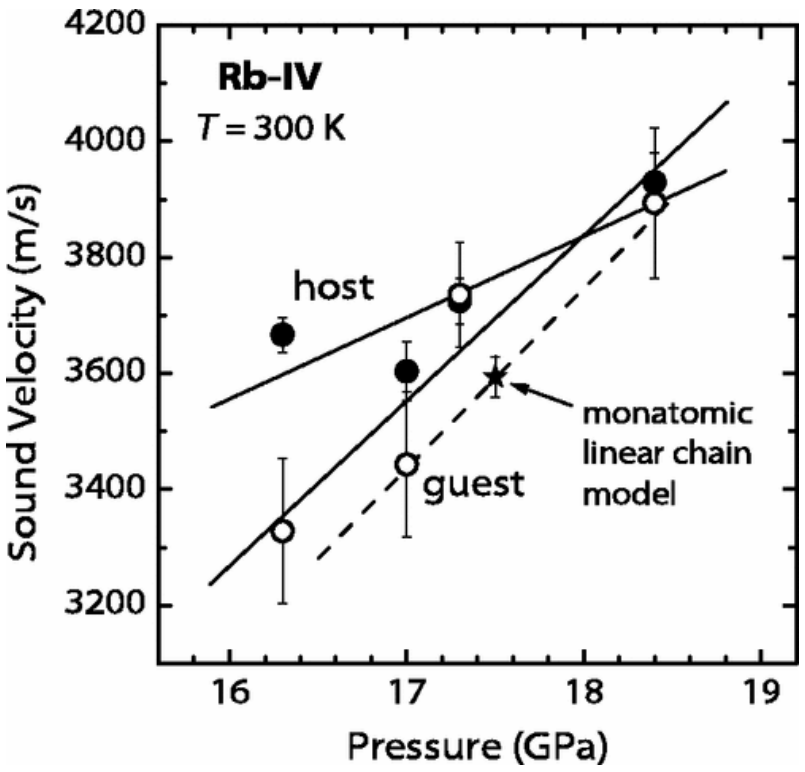


FIG. 10. Sound velocity in rubidium as a function of pressure compared with the results of Rosenbaum (Ref. 10). The upper two curves are for a temperature of 60.1 °C and the lower two curves are for a temperature of 150.1 °C.

$dv_S/dT = -0.40 \pm 0.01$ km/s.K

Sound-wave velocities in liquid alkali metals studied at temperatures up to 150 °C and pressures up to 0.7 GPa
George H. Shaw and D. A. Caldwell, Phys. Rev. B, **32** 7937 (1985)

Loa (2007)



I. Loa *et al*, *Phys. Rev. Lett.* **99**, 035501 (2007)

Blairs (2007)

Rubidium

Table 38 Rubidium*

A, m s^{-1}	B, m s^{-1} K^{-1}	C, m s^{-1} K^{-2}	Range, K	Reference
1370	−0·382		316–518	105
1370	−0·382		298–523	157
1340	−0·299		333–423	156
1385	−0·4		T_m–433	96
1351	−0·3101	$-5{\cdot}029\times10^{-5}$	303–1100	106
1298	−0·1525	$-1{\cdot}6114\times10^{-4}$	500–1500	159

*The suggested $c(T)$ relation for pure liquid rubidium is $c=1324{\cdot}5-0{\cdot}2313T-1{\cdot}057\times10^{-4}T^2$ (m s^{-1}).

[105] M. G. Kim, K. A. Kemp and S. V. Letcher: J. Acoust. Soc. Am., 1971, 49, 706
[157] M. G. Kim and S. V. Letcher: J. Chem. Phys., 1971, 55, 1164.
[156] G. H. Shaw and D. A. Caldwell: Phys. Rev. B, 1985, 32B, 7937.
[96] O. J. Kleppa: J. Chem. Phys., 1950, 18, 1331.
[106] I. I. Novikov, Y. S. Trellin and T. A. Tsyganova: High Temp., 1970, 8, 423.
[159] D. I. Arnold, O. I. Girney, E. V. Grodzinsky, V. F. Kozhevnikov and S. P. Naurzakov: J. Non-cryst. Solids, 1996, 205–207, 459.

$c(T_{MP}=39.3°C)=1241.91$ m/s
$c(T=300°C)=1157.21$ m/s

S. Blairs, *Review of data for velocity of sound in pure liquid metals and metalloids,* International Materials Reviews, **52(6)** 321-344 (2007)

Bryk (2013)

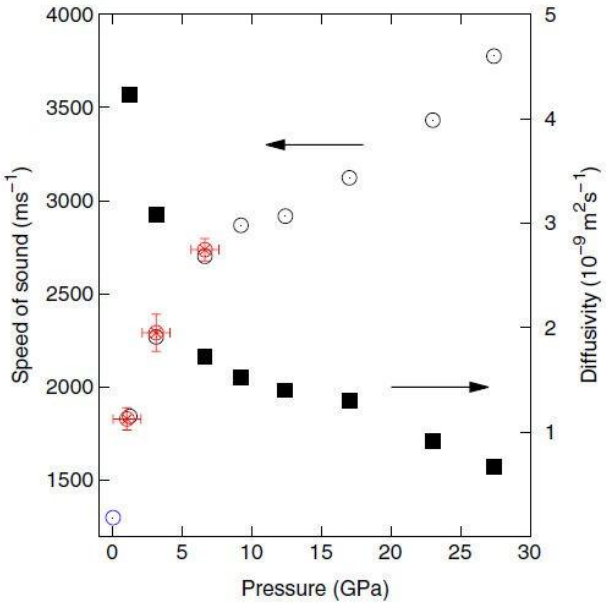


FIG. 4 (color online). Pressure dependence of dynamic properties. The diffusion coefficient D (filled symbols) and the apparent speed of sound c_{app} (open symbols) in liquid Rb at 573 K as a function of pressure. Red dots with error bars are experimental findings after IXS measurements. The ambient pressure point (blue symbol at 0 GPa) measured at 600 K by inelastic neutron scattering is from Ref. [41].

T.Bryk *et al, Phys. Rev. Lett.* **111** 077801 (2013)

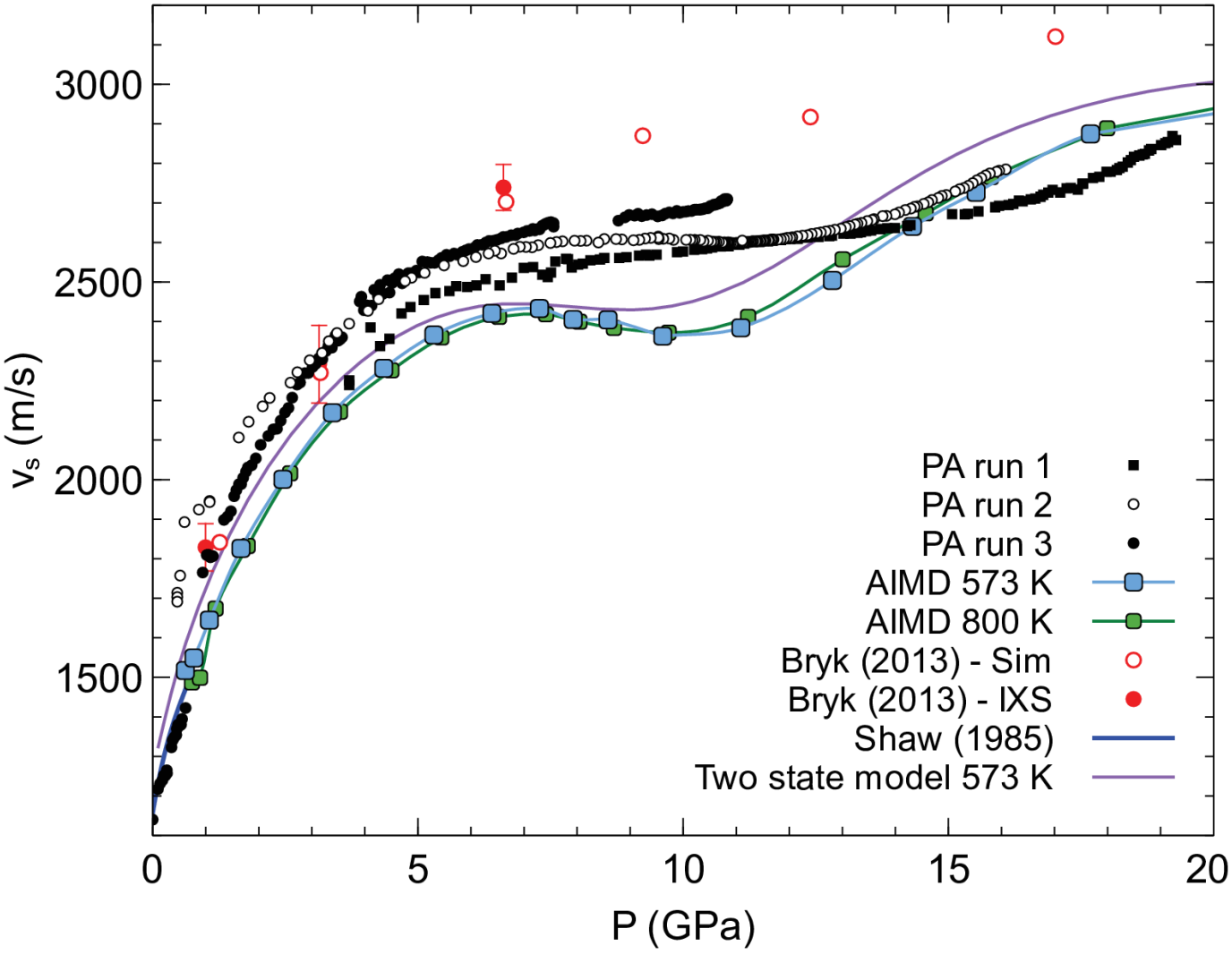
Belashchenko (2016)

Table 7. Adiabatic sound velocity in rubidium models u_s, m/s

T, K	$Y = V/V_0$							
	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4
300	1239	1239	1459	1565	1725	1964	2341	2940
500	1159	1229	1436	1571	1755	2017	2405	2993
700	1204	1244	1446	1591	1787	2058	2449	3034
1000	1192	1264	1473	1629	1834	2111	2502	3082
1500	1254	1310	1530	1698	1910	2188	2568	3143
2000	1358	1381	1589	1758	1971	2247	2623	3198
2500	1426	1464	1655	1816	2024	2297	2671	3251
3000	1466	1513	1717	1877	2080	2349	2720	3295
3500	1471	1562	1781	1957	2159	2409	2760	3303

D. K. Belashchenko, *Russian Journal of Physical Chemistry A* **90**(9), 1707 (2016)

Ayrinhac (2020)



S. Ayrinhac, V.N. Robinson, F. Decremps, M. Gauthier, D. Antonangeli, S. Scandolo, and M.Morand, *Phys. Rev. Materials* **4**, 113611 (2020)

Thermal expansion coefficient

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Solid Rb

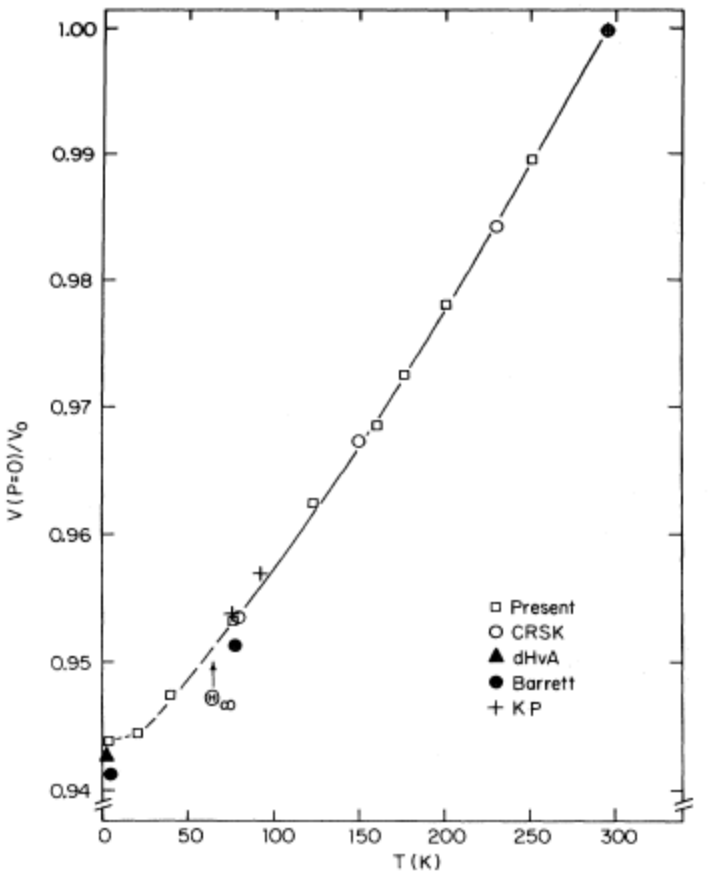


FIG. 15. $P=0$ thermal expansion for rubidium. The symbols refer to published results as follows: CRSK, Ref. 80; dHvA, Ref. 29; Barrett, Ref. 57; KP, Ref. 79.

M. S. Anderson and C. A. Swenson, *Experimental compressions for sodium, potassium, and rubidium metals to 20 kbar from 4.2 to 300 K*, Phys. Rev. B **28**. 5395 (1983)

Jarzynski (1975)

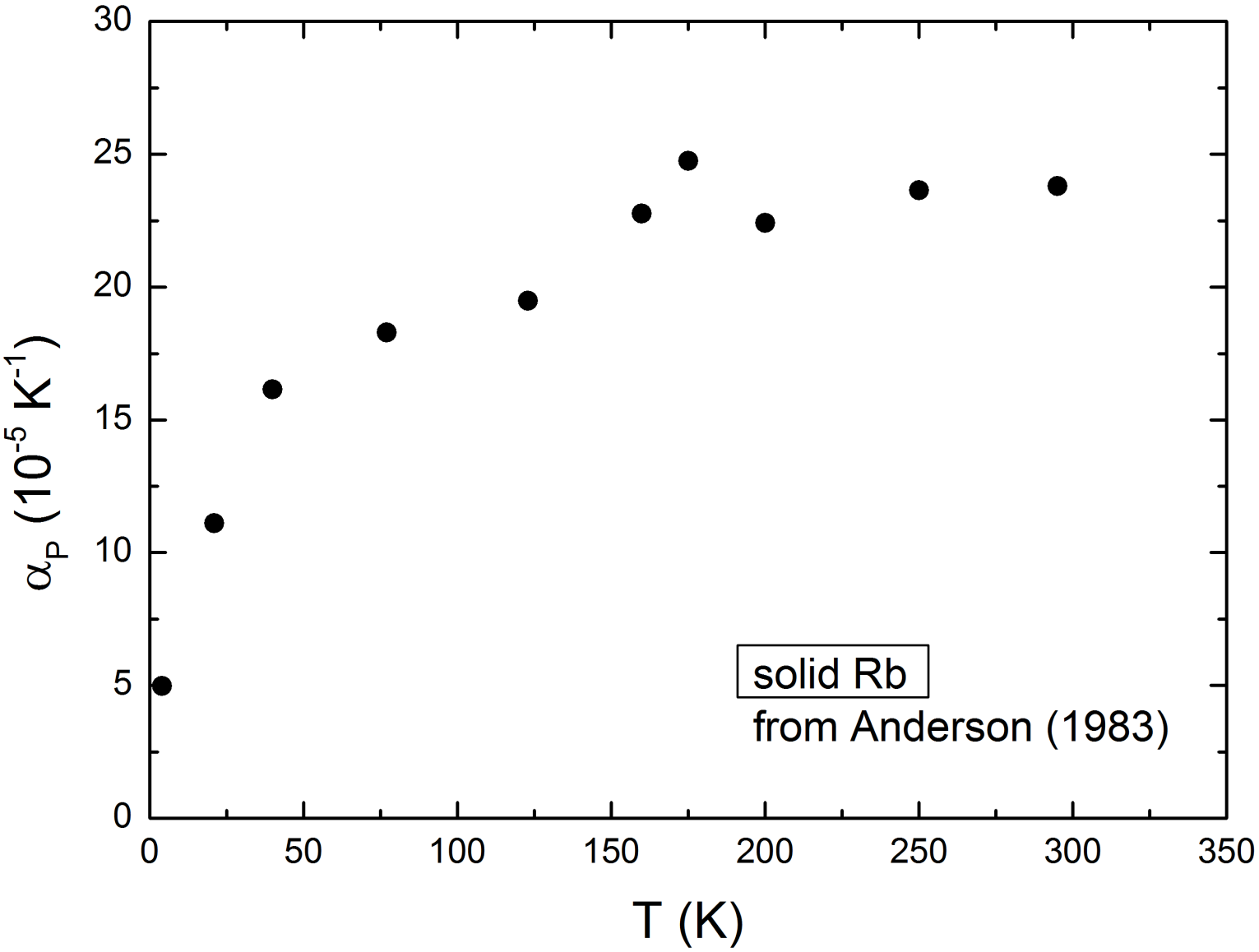
Liquid Rb

Table 2. Comparison with previous data of expansivities, α, and isothermal compressibilities, κ_T, calculated from the equation of state given in table 1. The expansivities are in units of $°C^{-1} \times 10^{-4}$ and compressibilities are in units of $bar^{-1} \times 10^{-6}$.

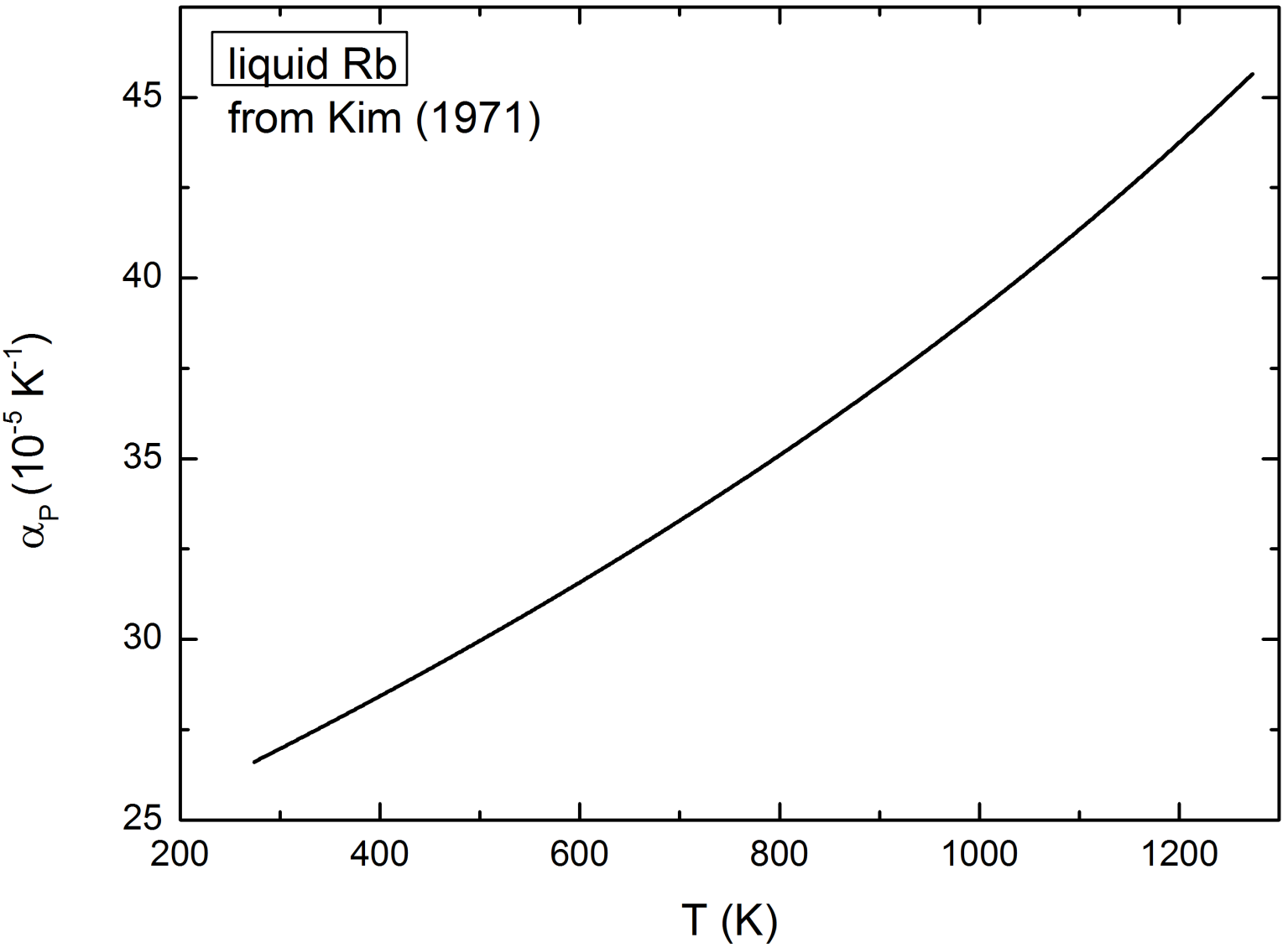
Thermodynamic parameter	T(°C)	p(bar)	Present investigation	Previous data
α	40	1	3·35	2·72†
α	40	1380	2·68	2·13‡
κ_T	40	1	50·1	47·0‡
κ_T	40	1380	40·1	37·0‡
κ_T	200	1	60·2	57·8‡

† Kim, Kemp and Letcher (1971).
‡ Rosenbaum (1971).

J. Jarzynski,
Equation of state of liquid rubidium,
Philosophical Magazine, **31(6)** 1253-1261 (1975)



M. S. Anderson and C. A. Swenson,
Experimental compressions for sodium, potassium, and rubidium metals to 20 kbar from 4.2 to 300 K,
Phys. Rev. B **28** 5395 (1983)



M. G. Kim, K. A. Kemp, and S. V. Letcher,
Ultrasonic Measurement in Liquid Alkali Metals
J. Acoust. Soc. Am. **49**, 706 (1971)

Density (EOS)

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• Bardeen (1938)	solid, calculations
• Grover (1969)	
• Kim (1971)	liquid, ρ(T), up to 1000°C
• Vaidya (1971)	solid, up to 4.5 GPa
• Copley (1974)	solid, neutron-scattering
• Jarzynski (1975)	liquid, up to 0.138 GPa and 178°C
• Vargaftik (1978)	liquid, 500-1000 K, up to 750 atm
• Takemura (1982)	solid, X-ray difraction, up to 13 GPa
• Anderson (1983)	V/V_0, solid, up to 2.3 GPa, low T, 0-295 K
• Shaw (1985)	liquid, calculated from sound velocities, T=150.1°C
• Winzenick (1994)	solid, up to 50 GPa
• Nelmes (2002)	solid, 10 to 20 Gpa, exp. : X-ray diff.
• Xie (2008)	solid, up to 10 GPa, simulations
• Bryk (2013)	liquid, up to 30 GPa, T=300°C, simulations & exp.
• Fabbris (2015)	solid, up to 25 GPa, T=10 K
• Santoro (2018)	simulations
• Gorelli (2018)	liquid, up to 25 GPa, T=573 K
• Ayrinhac (2020)	liquid, T=573 K

Bardeen (1938)

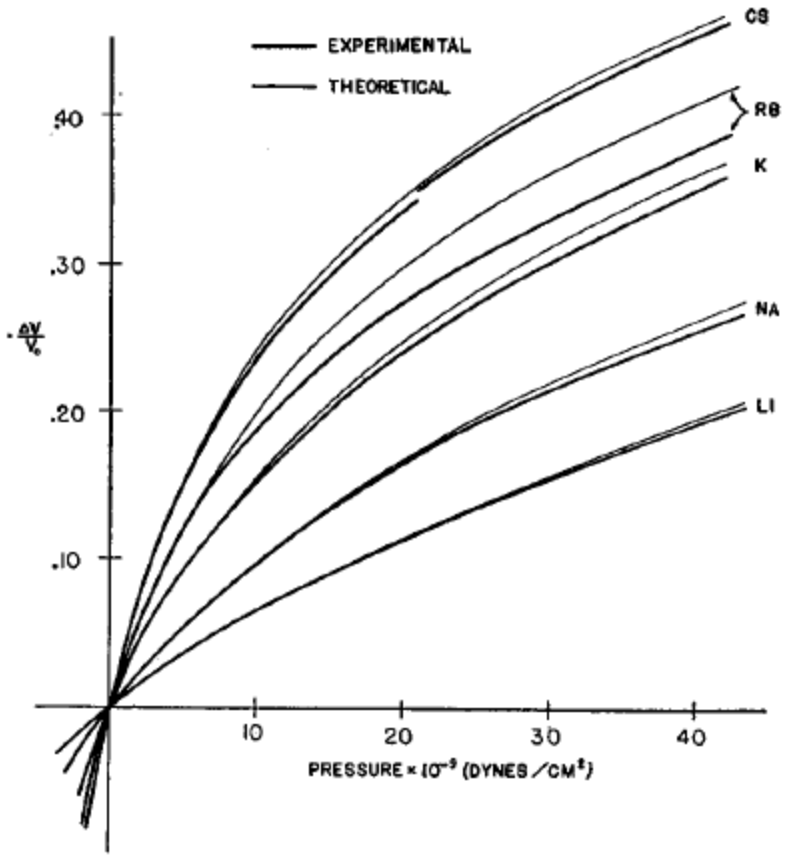


FIG. 1. Relative change in volume of alkali metals with pressure. Light lines are theoretical values obtained from the semi-empirical equation (13). Bridgman's experimental data, extrapolated to $T=0°K$, are represented by the heavy lines. The initial compressibilities have been used to fix the values of the parameters in the semiempirical equation, so that the slopes of the experimental and theoretical curves are in agreement at the origin. The break in the curve for Cs is due to a polymorphic transition.

Grover (1969)

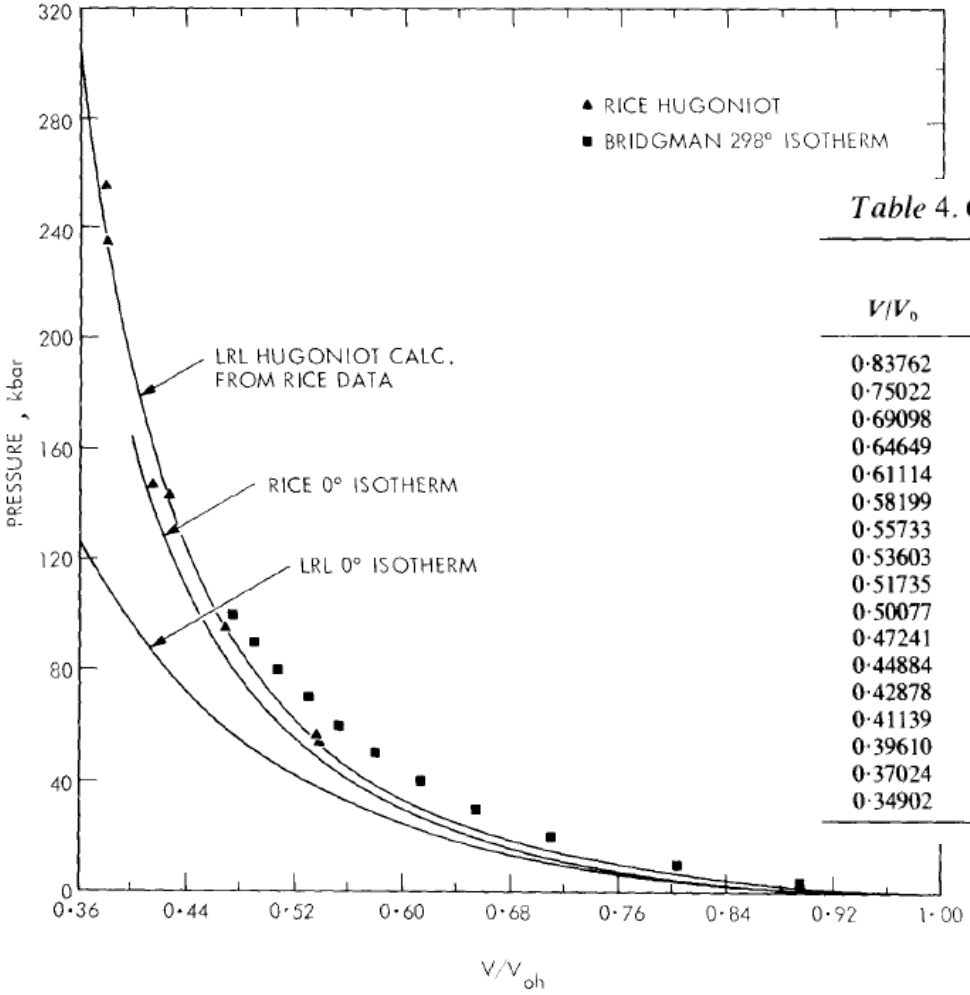


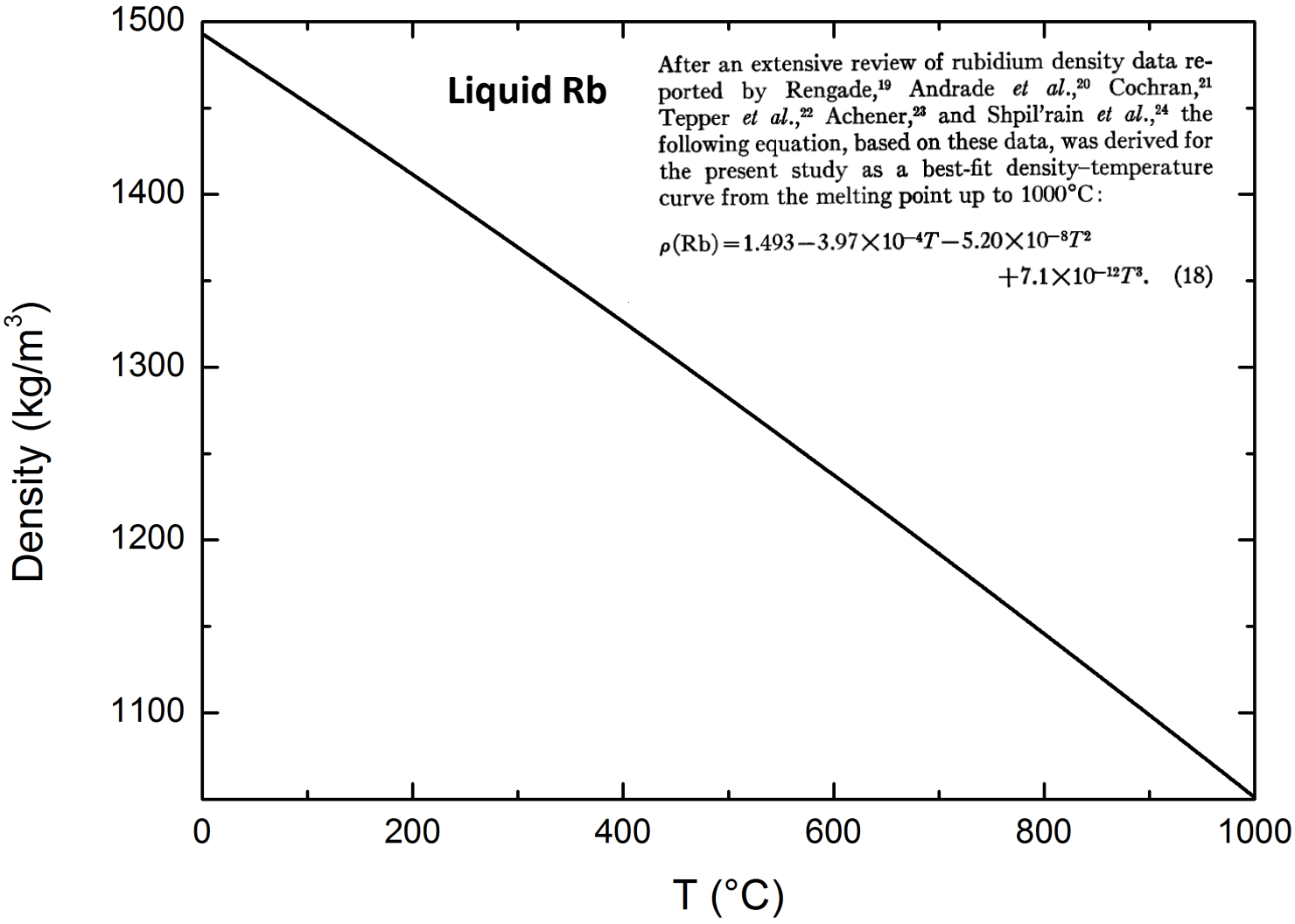
Fig. 4. Comparison of Bridgman isothermal compression data with shock data and calculated isotherms for rubidium.

Table 4. Calculated properties according to DM theory for rubidium

V/V_0	Temperature (°K)	Gamma	$P(0)$ ($bm = 10^3$ kbar)	$P(298)$ (mb)	$P(\mathrm{HUG})$ (mb)
0·83762	$3{\cdot}9226 \times 10^2$	1·2190	0·00340	0·00500	0·00544
0·75022	5·0554	1·1421	0·00835	0·01000	0·01118
0·69098	6·5794	1·1060	0·01328	0·01500	0·01728
0·64649	8·5349	1·0791	0·01822	0·02000	0·02380
0·61114	$1{\cdot}0935 \times 10^3$	1·0548	0·02318	0·02500	0·03074
0·58199	1·3778	1·0321	0·02814	0·03000	0·03811
0·55733	1·7075	1·0110	0·03311	0·03500	0·04594
0·53603	2·0831	0·9916	0·03808	0·04000	0·05423
0·51735	2·5055	0·9736	0·04306	0·04500	0·06299
0·50077	2·9760	0·9571	0·04804	0·05000	0·07226
0·47241	4·0658	0·9276	0·05800	0·06000	0·09238
0·44884	5·3660	0·9019	0·06797	0·07000	0·11476
0·42878	6·8915	0·8792	0·07794	0·08000	0·13960
0·41139	8·6634	0·8589	0·08792	0·09000	0·16716
0·39610	$1{\cdot}0702 \times 10^4$	0·8404	0·09790	0·10000	0·19769
0·37024	1·5682	0·8077	0·11786	0·12000	0·26890
0·34902	2·2084	0·7793	0·13784	0·14000	0·35616

Grover, R., Keeler, R. N., Rogers, F. J., & Kennedy, G.C., On the compressibility of the alkali metals. *Journal of Physics and Chemistry of Solids*, **30(8),** 2091-2103 (1969)

Kim (1971)



M. G. Kim, K. A. Kemp, and S. V. Letcher
Ultrasonic Measurement in Liquid Alkali Metals
J. Acoust. Soc. Am. **49**, 706 (1971)
doi: 10.1121/1.1912406

Liquid Rb
ρ(25°C[298.15 K])=1483.04 kg/m^3
ρ(39.4°C[312.55 K,M.P.])=1477.28 kg/m^3
ρ(300°C[573 K])=1369.41 kg/m^3

Vaidya (1971)

« Final values of V/V_0 calculated from the Murnaghan parameters »

Table 8. (V/V_0) of rubidium obtained from various determinations

Pressure (kb)	Bridgman (1938)	Bridgman (1948)	Shock	This work
0	1·000	1·000	1·000	1·000
5	0·832	0·875	0·838	0·862
10	0·765	0·800	0·750	0·781
15	0·718	0·747	0·691	0·725
20	0·682	0·705	0·646	0·682
25	0·652	0·671	0·611	0·649
30	0·626	0·644	0·582	0·622
35	0·603	0·621	0·557	0·598
40	0·583	0·602	0·536	0·578
45	0·566		0·517	0·560

(@ room T)

P(GPa)	V/V_0
0.0	1.000
0.5	0.862
1.0	0.781
1.5	0.725
2.0	0.682
2.5	0.649
3.0	0.622
3.5	0.598
4.0	0.578
4.5	0.560

S.N. Vaidya, I.C. Getting, G.C. Kennedy,
The compression of the alkali metals to 45 kbar,
Journal of Physics and Chemistry of Solids, **32(11)** 2545-2556 (1971)

Vaidya (1971)

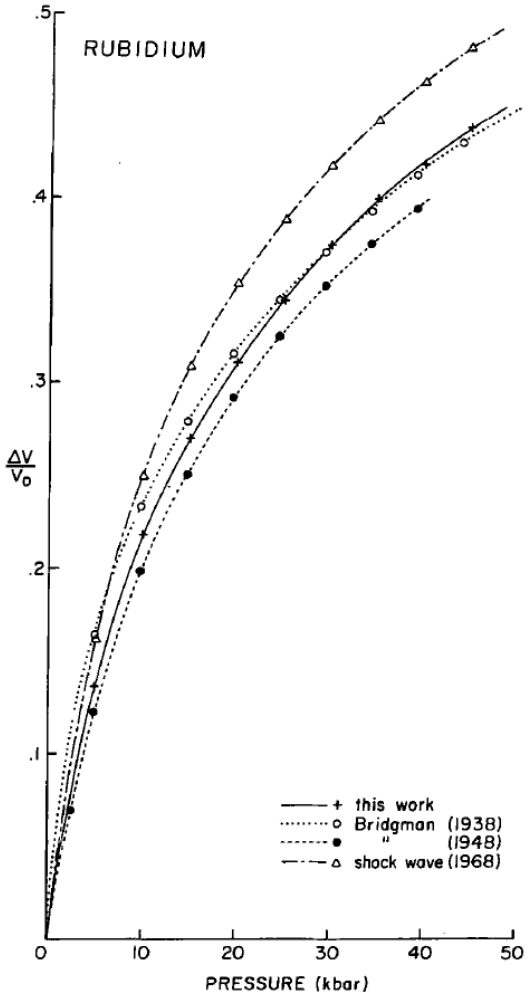


Fig. 5. Comparison of static isothermal compression data and the isotherm caiculated from shock data for rubidium.

Copley (1974)

TABLE I. Measured values of the lattice parameter a for various temperatures T and pressures P. The estimated errors for a and P are better than ±0.005 Å and ±0.01 kbar, respectively. The values of a for $P=0$ were obtained by interpolation of the numbers given in Ref. 10.

$T=80$ K		$T=150$ K		$T=230$ K		$T=295$ K	
P (kbar)	a (Å)	P (kbar)	a (Å)	P (kbar)	a (Å)	P (kbar)	a (Å)
0	5.610	0	5.637	0	5.670	0	5.700
1.86	5.502	0.28	5.622	0.71	5.620	0.34	5.675
2.36	5.475	2.26	5.502	2.71	5.502	1.02	5.620
4.23	5.394	4.43	5.402	4.61	5.408	2.07	5.555
						3.02	5.502
						3.75	5.470
						4.75	5.420

J.R.D. Copley, C.A. Rotter, H.G. Smith, W.A. Kamitakahara, *Measurement of selected phonons in rubidium as a function of temperature and volume*, Physical Review Letters, **33(6)** 365 (1974)

Jarzynski (1975)

51.5°C < T < 178°C

Amb < P < 0.138 GPa

Table 1. Coefficients in the polynomial expansion (eqn. (4)) for the volume of the rubidium sample as a function of temperature and pressure. The units of volume are ccs, temperature is in °C and pressure in bars.

Liquid Rb

i	B_{i1}	B_{i2}	B_{i3}
1	12·594	$4{\cdot}347 \times 10^{-3}$	$-8{\cdot}714 \times 10^{-7}$
2	$-5{\cdot}981 \times 10^{-4}$	$-1{\cdot}052 \times 10^{-6}$	
3	$6{\cdot}542 \times 10^{-8}$	$2{\cdot}454 \times 10^{-10}$	
4	$-7{\cdot}436 \times 10^{-12}$	$-2{\cdot}707 \times 10^{-14}$	

$$V = B_1(T) + B_2(T)p + B_3(T)p^2 + B_4(T)p^3,$$

$$B_i(T) = B_{i1} + B_{i2}T + B_{i3}T^2.$$

```
V=(12.594+4.347e-3*T-8.714e-7*T^2)+(-5.981e-4-1.052e-6*T)*P+(6.542e-8+2.454e-10*T)*P^2+(-7.436e-12-2.707e-14*T)*P^3
```

J. Jarzynski,
Equation of state of liquid rubidium,
Philosophical Magazine, **31(6)** 1253-1261 (1975)

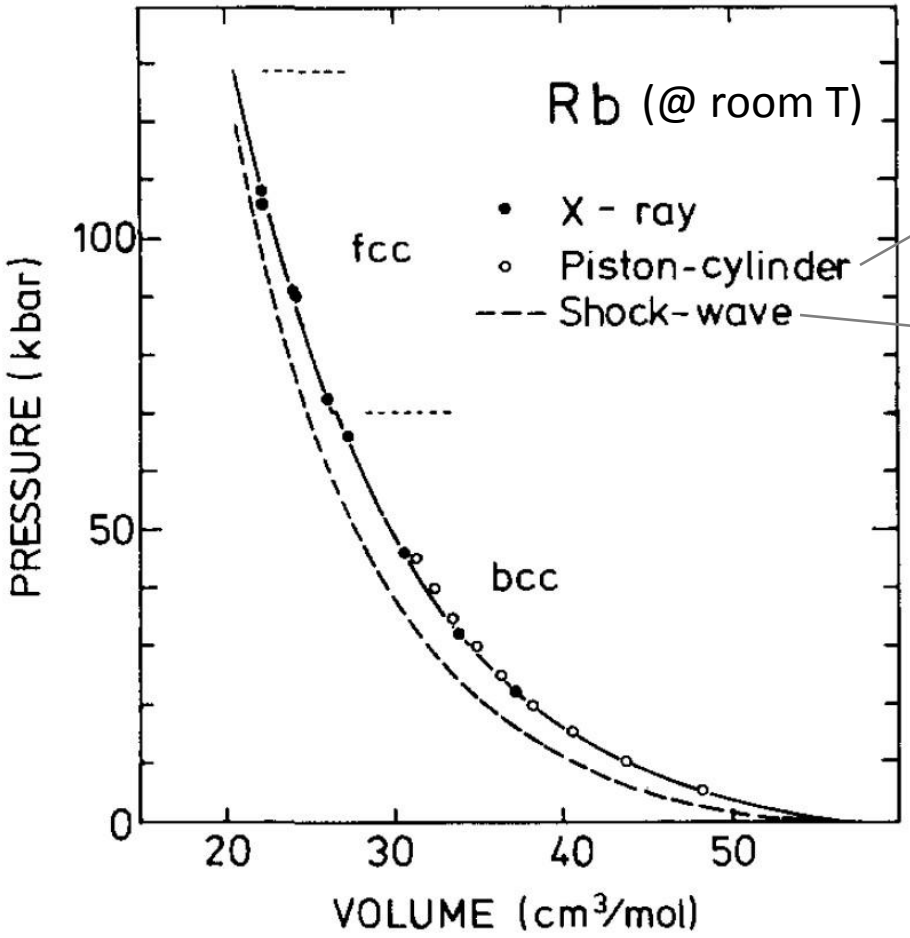
Vargaftik (1978)

TABLE 5. Density of Liquid Rubidium $\rho \cdot 10^{-3}$, kg/m^3, at T, °K

$P \cdot 10^{-5}$, Pa	500	600	700	800	900	1000
P_s	1,387	1,342	1,298	1,253	1,207	1,162
100	1,395	1,351	1,308	1,264	1,219	1,176
200	1,404	1,360	1,318	1,274	1,231	1,189
300	1,412	1,369	1,327	1,284	1,242	1,204
400	1,420	1,378	1,336	1,294	1,253	1,212
500	1,428	1,386	1,345	1,303	1,263	1,224
600	1,435	1,394	1,354	1,313	1,274	1,235
700	1,423	1,402	1,362	1,322	1,284	1,246
800	1,450	1,410	1,371	1,332	1,294	1,257
900	1,458	1,418	1,379	1,341	1,304	1,267
1000	1,465	1,426	1,387	1,350	1,313	1,277

N.B. Vargaftik, V.P. Kozhevnikov, V.A. Alekseev, *An experimental study of the equations of state of liquid alkali metals. II*, Journal of Engineering Physics and Thermophysics, **35(6)** 1415-1419 (1978)

Takemura (1982)



Piston-cylinder : S. N. Vaidya, I. C. Getting and G. C. Kennedy, J. Phys. Chem. Solids 3_22, 2545 (1971)

Shock-wave : R. Grover, R. N. Keeler, F. J. Rogers, and G. C. Kennedy, J. Phys. Chem. Sol. 30, 2091 (1969)

K. Takemura & K. Syassen, *Solid State Communications*, **44** 1161 (1982)

P(GPa)	V/V_0
0	1
2.2	0.669
3.2	0.605
4.6	0.546
6.6	0.486
7	0.47
7.3	0.464
9	0.432
9.1	0.428
10.7	0.398
10.8	0.396

Anderson (1983)

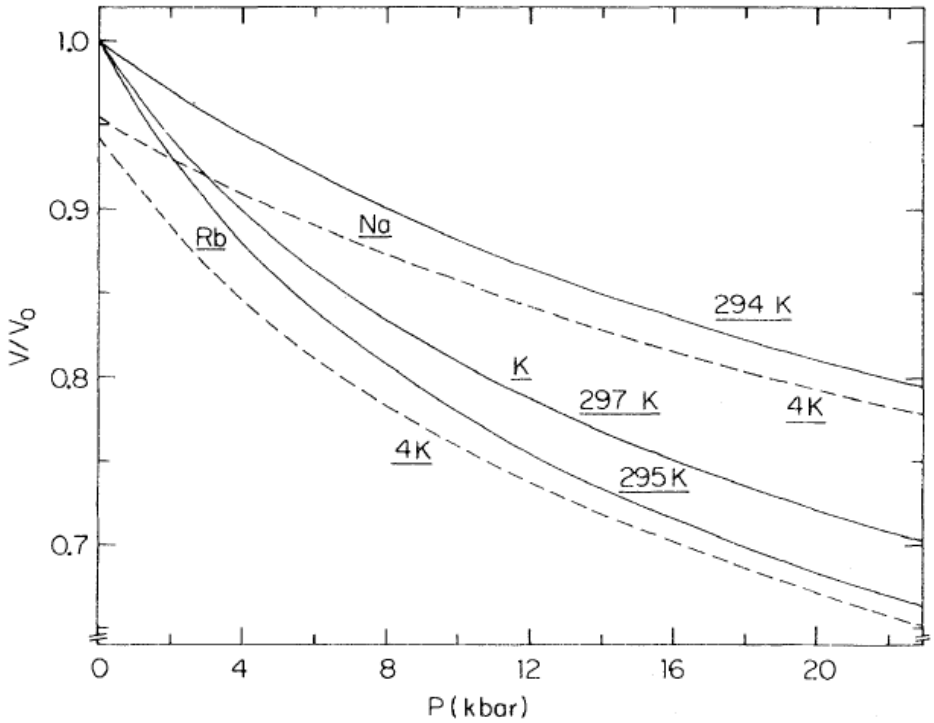


FIG. 1. Relative room-temperature compressions for sodium, potassium, and rubidium. Low-temperature (4-K) compressions are given for sodium and rubidium to illustrate the magnitude of thermal effects.

M. S. Anderson and C. A. Swenson,
Experimental compressions for sodium, potassium, and rubidium metals to 20 kbar from 4.2 to 300 K,
Phys. Rev. B **28** 5395 (1983)

Anderson (1983)

Solid Rb

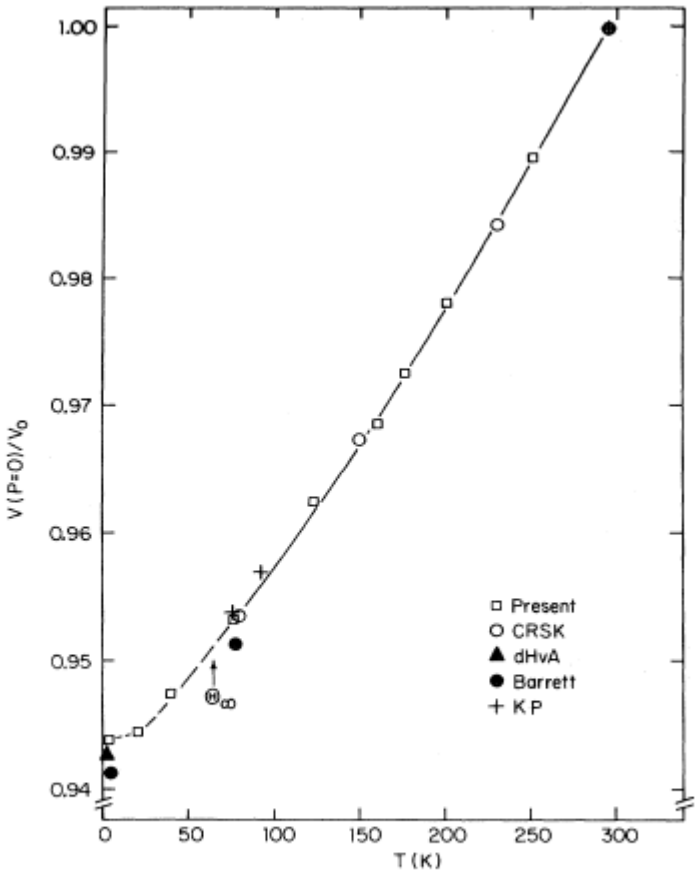


FIG. 15. $P=0$ thermal expansion for rubidium. The symbols refer to published results as follows: CRSK, Ref. 80; dHvA, Ref. 29; Barrett, Ref. 57; KP, Ref. 79.

T (K)	V/V_0	density (kg/m^3)
4	0.9436	1621.44977
21	0.9444	1620.07624
40	0.9475	1614.77573
77	0.9528	1605.79345
123	0.9623	1589.94077
160	0.9685	1579.76252
175	0.9726	1573.10302
200	0.9778	1564.73717
250	0.9894	1546.39175
295	1	1530

$(d\rho/dT)_{Pamb,T=300K} = -0.365$ kg/m^3.K

M. S. Anderson and C. A. Swenson,
Experimental compressions for sodium, potassium, and rubidium metals to 20 kbar from 4.2 to 300 K,
Phys. Rev. B **28** 5395 (1983)

Anderson (1983)

TABLE IV. Summary of the isotherm results for rubidium. The data points for the isotherms are indicated in Figs. 12 and 13.

T (K)	P^* (kbar)	$(V/V_0)_{P=0}$	B_0 (kbar) a	B_0 (kbar) b	B_0'[b]	B_0'' (kbar^{-1})[b]	RMSD (10^{-4} in V/V_0)[b]
295	(0)	(1.0000)[c]	(23.0)	23.01±0.03	4.15∓0.1	−0.057±0.003	2.01
250	−0.25	0.9894	24.0	24.0 ±0.06	4.16∓0.03	−0.061±0.006	1.80
200[d]	−0.54	0.9778	25.2	25.1 ±0.1	4.25∓0.09	−0.087±0.015	1.23
175	−0.68	0.9726	25.8	25.95±0.06	4.03∓0.02	−0.052±0.003	2.46
160[d]	−0.79	0.9685	26.3	26.0 ±0.12	4.28∓0.12	−0.090±0.024	1.71
123	−0.96	0.9623	26.9	26.8 ±0.15	4.15∓0.06	−0.068±0.012	2.05
77	−1.23	0.9528	28.1	28.0 ±0.12	4.12∓0.06	−0.066±0.012	3.30
40	−1.39	0.9475	28.7	28.4 ±0.3	4.24∓0.15	−0.080±0.024	3.84
21	−1.49	0.9444	29.1	28.9 ±0.2	4.20∓0.12	−0.077±0.015	2.46
4	−1.51	0.9436	29.2	29.2 ±0.2	4.10∓0.12	−0.064±0.018	2.46

[a] $P=0$ bulk moduli derived from the 295-K isotherm and P^*.

[b] Parameters derived from nonlinear least-squares fits of Eq. (15) for each isotherm. The 3σ uncertainties are those associated with the fitting procedure and do not include an allowance for systematic effects. A more qualitative assessment gives minimum uncertainties of ±0.25 kbar for B_0, ∓0.1 in B_0', and ±0.01 kbar^{-1} in B_0''.

[c] V_0(295 K, $P=0$) = 55.74 cm^3/mole (Refs. 79 and 80).

[d] 0.354-in. sample holder data only.

M. S. Anderson and C. A. Swenson,
Experimental compressions for sodium, potassium, and rubidium metals to 20 kbar from 4.2 to 300 K,
Phys. Rev. B **28** 5395 (1983)

Anderson (1983)

TABLE VI. Thermodynamic properties of the liquid alkali metals needed for data reduction. All data after Kim *et al.* (Ref. 2) unless otherwise indicated.

Liquid alkali metal	Temperature (°C)	Density (g/cm^3)	α (10^{-6}/deg)	C_p (j/g deg)	$\frac{1}{\alpha^2}\left(\frac{\partial\alpha}{\partial T}\right)_{P=0}$	$\frac{1}{\alpha K_T}\left(\frac{\partial K_T}{\partial T}\right)_{P=0}$
Sodium						
	109.4	0.9243	238	1.377	2.26	−3.81
	129.7	0.9198	241	1.367	2.24	−3.85
	148.9	0.9156	243	1.358	2.22	−3.87
Potassium						
	84.8	0.8228	269	0.815	1.87	−4.09
	100.0	0.8194	271	0.812	1.85	−4.14
	114.2	0.8163	273	0.808	1.83	−4.16
	150.1	0.8082	278	0.799	1.80	−4.27
Rubidium						
	60.1	1.4690	274	0.398	1.92	−3.99
	78.8	1.4614	277	0.394	1.90	−4.04
	108.3	1.4494	282	0.388	1.87	−4.12
	130.9	1.4402	285	0.384	1.84	−4.18
	150.1	1.4323	288	0.381	1.82	−4.22
Cesium						
	49.7	1.8283	284	0.267	1.53	−4.17
	71.8	1.8168	287	0.263	1.46	−4.23
	89.4	1.8076	289	0.261	1.41	−4.29
	108.3	1.7977	291	0.258	1.36	−4.36

Shaw (1985)

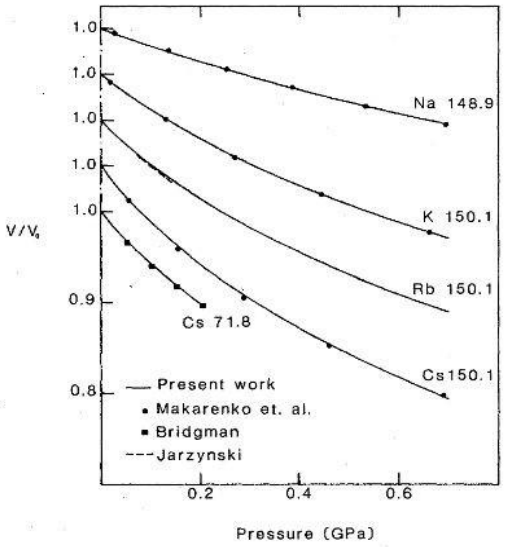


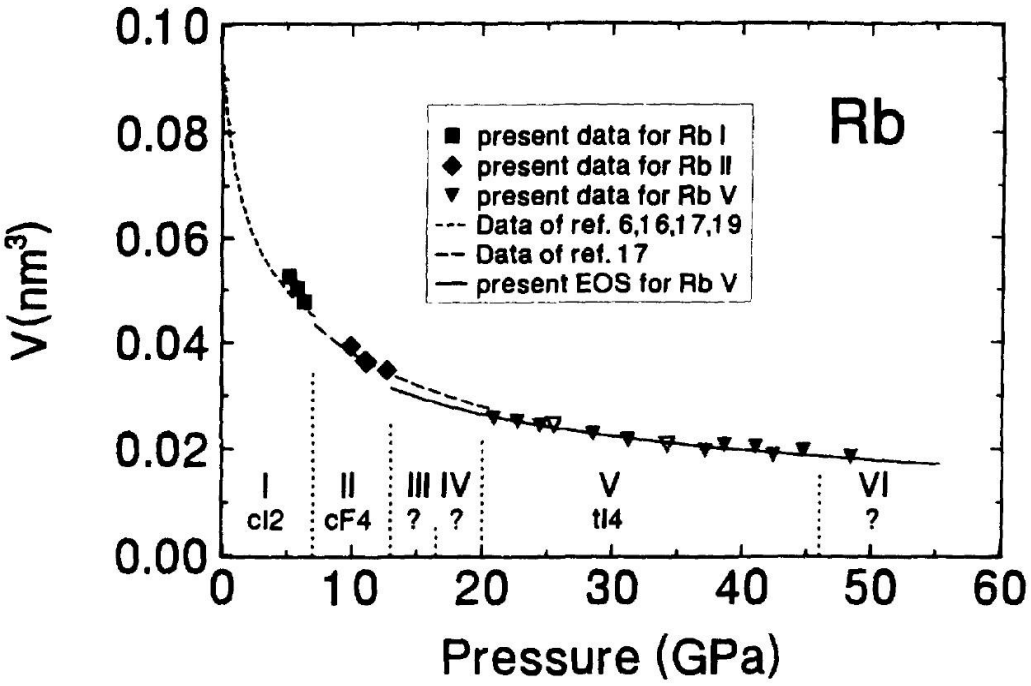
FIG. 11. Compression curves for the liquid-alkali metals. Compressions calculated from the present data using the second-order Murnaghan equation. Comparisons are made with piezometer determinations of Makarenko *et al.* (Ref. 18) for sodium, potassium, and cesium for the highest temperature runs, where the pressure range is the greatest. The data of Makarenko *et al.* were interpolated to the comparison temperatures. Their data were also extrapolated to get the data point at the highest pressure in each case. A comparison is also shown with the rubidium data of Jarzynski (Ref. 19) as calculated from his equation at 150.1 °C. A separate curve is also given for cesium at 71.8 °C and comparison made with Bridgman's (Ref. 17) data for cesium at 75 °C.

Rb T=150.1°C

P (GPa)	V/V0
0.00137	0.99993
0.01233	0.99334
0.02055	0.98895
0.0274	0.98528
0.0411	0.97869
0.04932	0.97503
0.06027	0.9699
0.06849	0.96623
0.08356	0.95818
0.09863	0.95305
0.11918	0.94499
0.1411	0.9362
0.16438	0.92741
0.18493	0.91935
0.20548	0.91275
0.22603	0.90543
0.25616	0.8959
0.28356	0.88785
0.30685	0.88052
0.33151	0.87393
0.36027	0.86587
0.38493	0.85927
0.40959	0.85268
0.43151	0.84755
0.46438	0.83949
0.48904	0.83363
0.5137	0.82851
0.54795	0.81971
0.58082	0.81239
0.61644	0.80579
0.64795	0.7992
0.6726	0.79481
0.69863	0.79041

Sound-wave velocities in liquid alkali metals studied at temperatures up to 150 °C and pressures up to 0.7 GPa
Phys. Rev. B **32**. 7937 (1985)
George H. Shaw and D. A. Caldwell

Winzenick (1994)



P (GPa)	V (nm³/atome)
0	0.09274
5.1853	0.05285
5.728	0.05065
6.3795	0.04791
9.9503	0.03967
11.141	0.03665
12.76	0.035
20.965	0.02646
22.691	0.0259
24.416	0.02507
25.601	0.02534
28.514	0.02368
31.21	0.02229
34.337	0.02118
37.248	0.02034
38.647	0.02143
41.126	0.02115
42.422	0.01922
44.791	0.02058
48.457	0.01919

TABLE III. EOS parameter values for the phases Rb I, Rb II, and Rb V. The quoted "restricted" uncertainties represent only the statistical uncertainties of uncorrelated parameter variations (Ref. 21).

Phase	V_0 (nm³/atom)	K_0 (GPa)	K_0'
Rb I	0.092 74	2.301(3)	4.1(3)
Rb II	0.081(11)	5.8(3)	2.00(8)
Rb V	0.093(6)	1.92(5)	3.42(7)

M. Winzenick, V. Vijayakumar, W.B. Holzapfel, *High-pressure x-ray diffraction on potassium and rubidium up to 50 Gpa,* Phys. Rev. B, **50(17)** 12381 (1994)

Nelmes (2002)

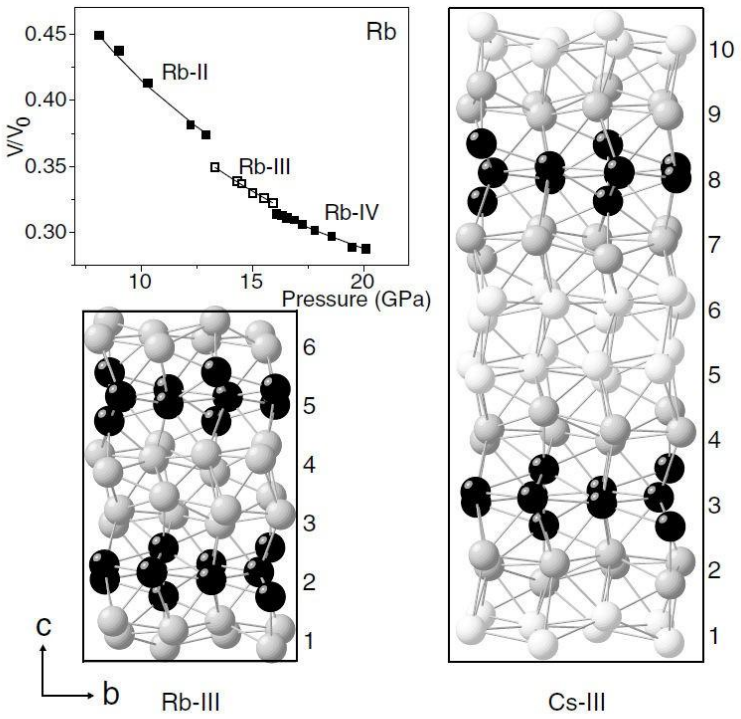
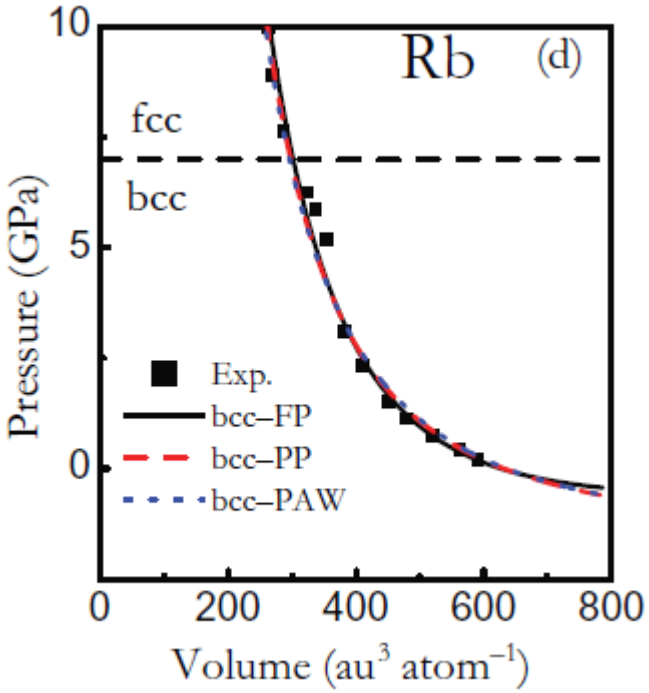


FIG. 2. Crystal structures of Rb-III and Cs-III, on the same scale, viewed along the *a* axis of the $C222_1$ unit cell. Rb-III is drawn with a nonstandard origin on a 2_1 screw axis along *a* to facilitate comparison with Cs-III which is drawn with the standard origin on a twofold axis (see text and note [20]). The 8- and 10-atom *a*-*b* layers in the two structures are numbered. Nonequivalent 8-atom layers in Cs-III are in two different shades of grey. Contact distances of up to 4.1 Å for Rb-III and 4.7 Å for Cs-III are shown as solid lines. Inset: equation of state of Rb-II, III, and IV. The lines are guides to the eye.

P (GPa)	V/V0
8.1015	0.44963
8.9845	0.43766
10.287	0.41372
12.185	0.38192
12.892	0.37406
13.289	0.34938
14.305	0.3389
14.503	0.33703
14.989	0.32993
15.497	0.32618
15.894	0.32282
16.049	0.31459
16.291	0.31309
16.512	0.3116
16.865	0.30973
17.219	0.30599
17.77	0.30187
18.543	0.29701
19.426	0.28915
20.044	0.28766

R. J. Nelmes, M. I. McMahon, J. S. Loveday, and S. Rekhi, Phys. Rev. Lett. **88**, 155503 (2002)

Xie (2008)

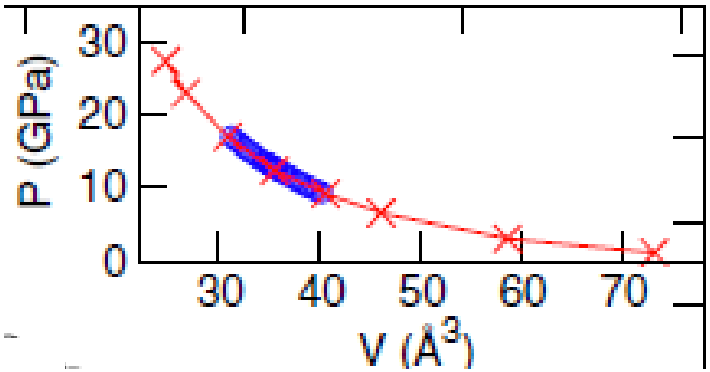


« Analysis of the calculated results suggested that the elastic instabilities associated with the softening phonon modes are the driving force of the phase transition in the bcc alkali metals. »

Y. Xie, Y.M. Ma, T. Cui, Y. Li, J. Qiu, G.T. Zou,
Origin of bcc to fcc phase transition under pressure in alkali metals,
New Journal of Physics, **10(6)** 063022 (2008)

Bryk (2013)

Liquid Rb, simulations



$$V(m^3/atome) = \frac{V_m(m^3/mole)}{N_A(atome/mole)}$$

P (GPa)	V (Å^3)
1.3491	73.029
1.5373	71.583
1.8199	69.518
2.0083	68.141
2.2908	66.007
2.383	64.492
2.6662	62.702
2.7594	61.601
3.3272	58.571
3.5161	57.401
3.9914	55.749
4.4668	54.165
4.8464	52.582
5.7016	49.484
6.6522	46.179
8.083	43.287
9.2268	40.671
10.946	37.986
12.474	35.645
15.342	32.685
16.967	31.033
18.403	30.069
20.412	28.692
21.848	27.728
22.996	26.833
25.198	25.869
27.4	24.836

T.Bryk *et al,* Phys. Rev. Lett. **111** 077801 (2013)

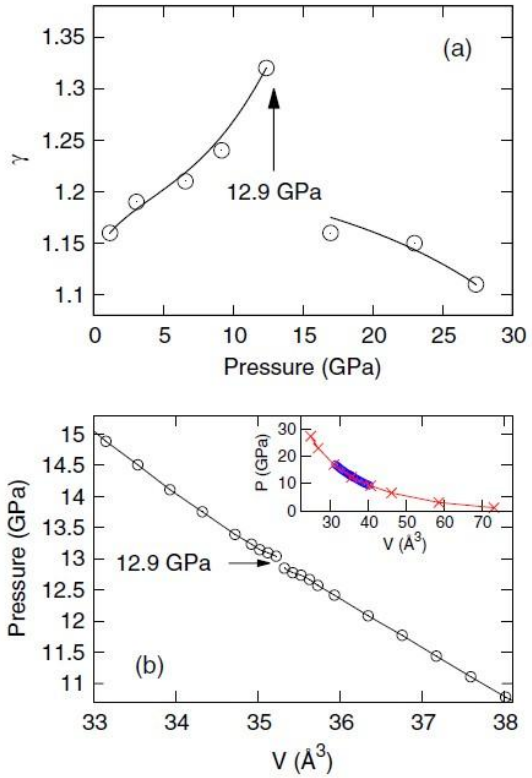
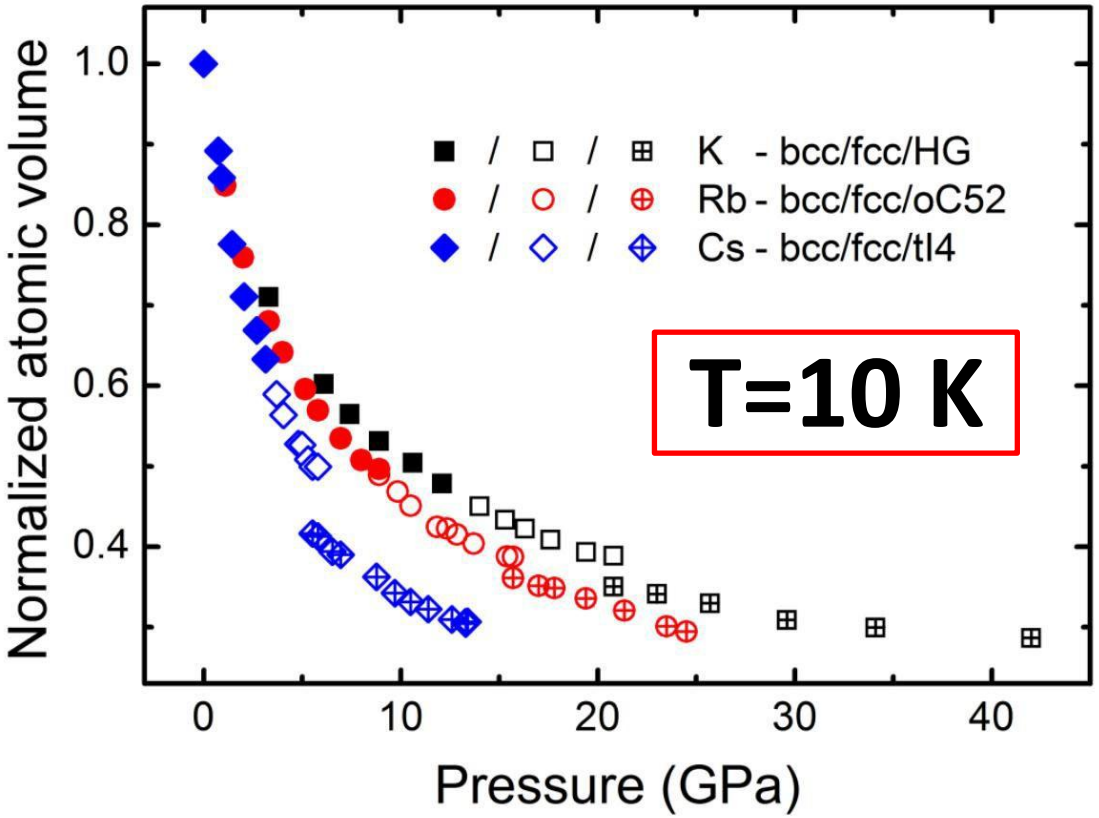


FIG. 3 (color online). Thermodynamic properties of liquid Rb at 573 K, as a function of pressure. (a) The ratio of the specific heats γ versus pressure. Lines are guides for the eye. (b) P-V equation of state of liquid Rb at 573 K. The reduction of the P-V slope in the region about 12.9 GPa (arrow) corresponds to an increasing isothermal compressibility. In the inset, the full P-V curve is shown: results obtained from AIMD simulations with 300 (cross symbols) and 64 (plus symbols) particles.

T.Bryk *et al,* Phys. Rev. Lett. **111** 077801 (2013)

Fabbris (2015)



Rubidium. The bcc to fcc transition occurs at 8.9 ± 1 GPa, at 15.7 ± 1 GPa the Rb-III (*oC*52) phase is stable, with fcc/Rb-III coexistence seen at 15.7 GPa. Rb-III is stable to at least 24.5 GPa; at room temperature transitions to Rb-IV and Rb-V are observed in this pressure range (see Fig. 7).

« The DAC was kept at 10 K throughout the experiment using a He flow cryostat and pressure was applied *in situ* using a gearbox.”

V_0 =
K: 71.507 Å^3,
Rb: 87.338 Å^3,
Cs:110.617 Å^3.

G. Fabbris. J. Lim. L. S. I. Veiga. D. Haskel. and J. S. Schilling,
Electronic and structural ground state of heavy alkali metals at high pressure
Phys. Rev. B **91** 085111 (2015)

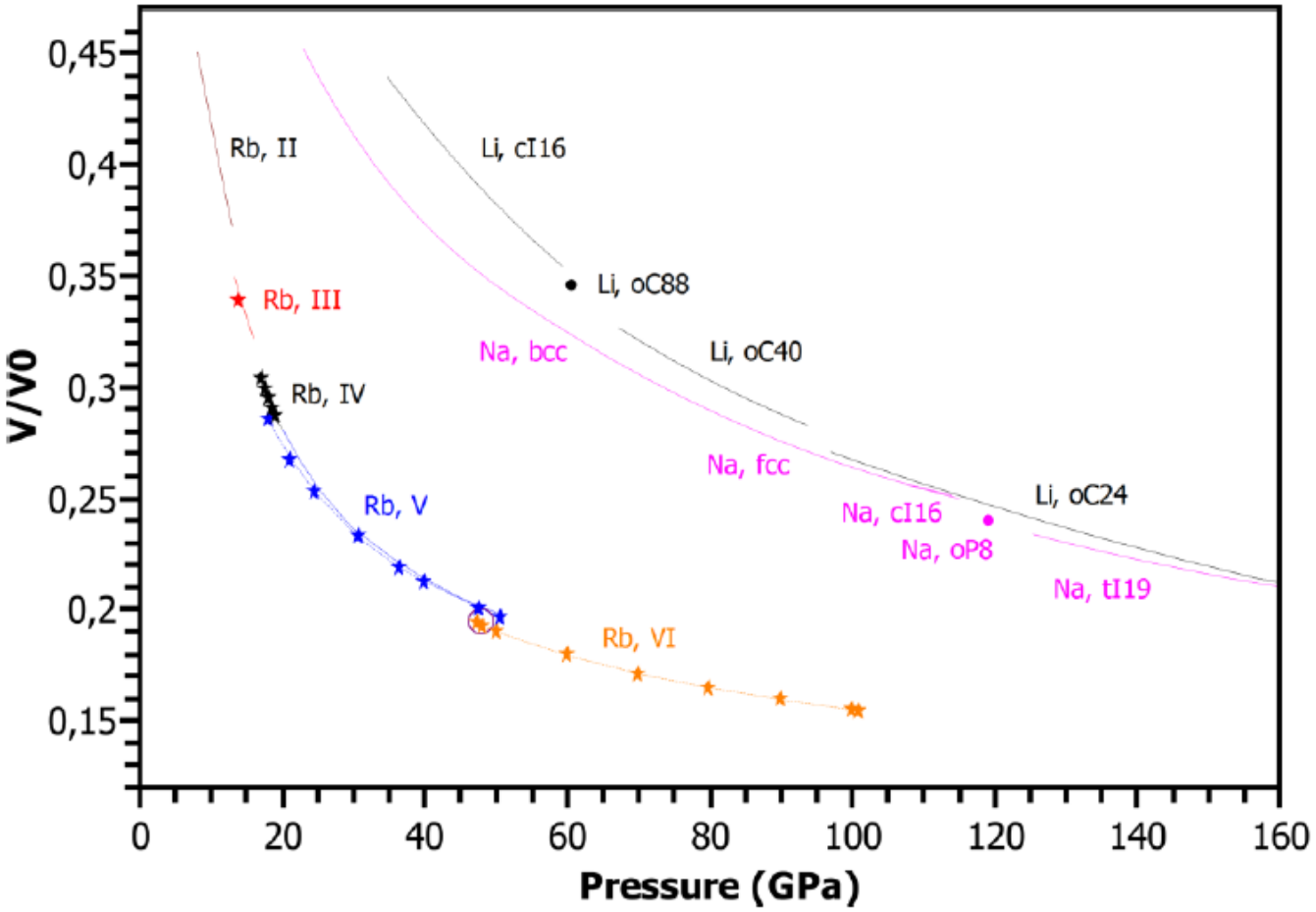
$$\rho = (85.4678\times10^{-3}\ \text{kg/mole})/(6.022\times10^{23}\ \text{mol}^{-1}\times 87.338\times10^{-30}\ \text{m}^{-3}\times\ V/V_0)$$

T=10 K P (GPa)	V/V0	density (kg/m^3)
0	1	1625.01933
1.0851	0.84668	1919.28394
1.9729	0.75976	2138.85876
3.2552	0.68008	2389.4532
3.9457	0.64145	2533.35307
5.1295	0.59557	2728.51106
5.7707	0.56901	2855.8713
6.9051	0.534	3043.10736
7.9901	0.50744	3202.38714
8.8779	0.49779	3264.46761
8.8779	0.48934	3320.83895
9.815	0.46881	3466.26422
10.506	0.4507	3605.54544
11.837	0.42414	3831.3277
12.33	0.42294	3842.19825
12.873	0.41569	3909.20958
13.662	0.40362	4026.11201
15.339	0.38793	4188.94989
15.684	0.38793	4188.94989
15.684	0.36137	4496.82965
16.967	0.3505	4636.2891
17.756	0.34809	4668.38843
19.433	0.33602	4836.07919
21.356	0.32032	5073.11229
23.477	0.30101	5398.55596
24.513	0.29376	5531.79238

TABLE I. Atomic volume at ambient pressure (V_0), bulk modulus (B_0), and pressure derivative of the bulk modulus (B_0') as obtained here and from the literature. DFT-FP stands for density functional theory using the full-potential linear augmented plane-wave method.

Alkali	Method	T (K)	V_0 (Å^3)	B_0 (GPa)	B_0'
K	this work	10	75(2)	4.2(9)	3.5(1)
	piston-diplacement [86]	4	75.7	3.7	4.1
	x-ray diffraction [87]	300	75.65	2.96	4.06
	DFT-FP [52]	0	74.09	3.68	3.66
Rb	this work	10	95(3)	3.1(6)	3.5(1)
	piston-diplacement [86]	4	92.6	2.9	4.1
	x-ray diffraction [87]	300	92.74	2.3	4.1
	DFT-FP [52]	0	93.07	2.84	3.52
Cs	this work	10	118(1)	2.8(5)	3.1(1)
	piston-diplacement [88]	4	110.4	2.1	4.0
	DFT-FP [52]	0	112.68	2.29	3.17

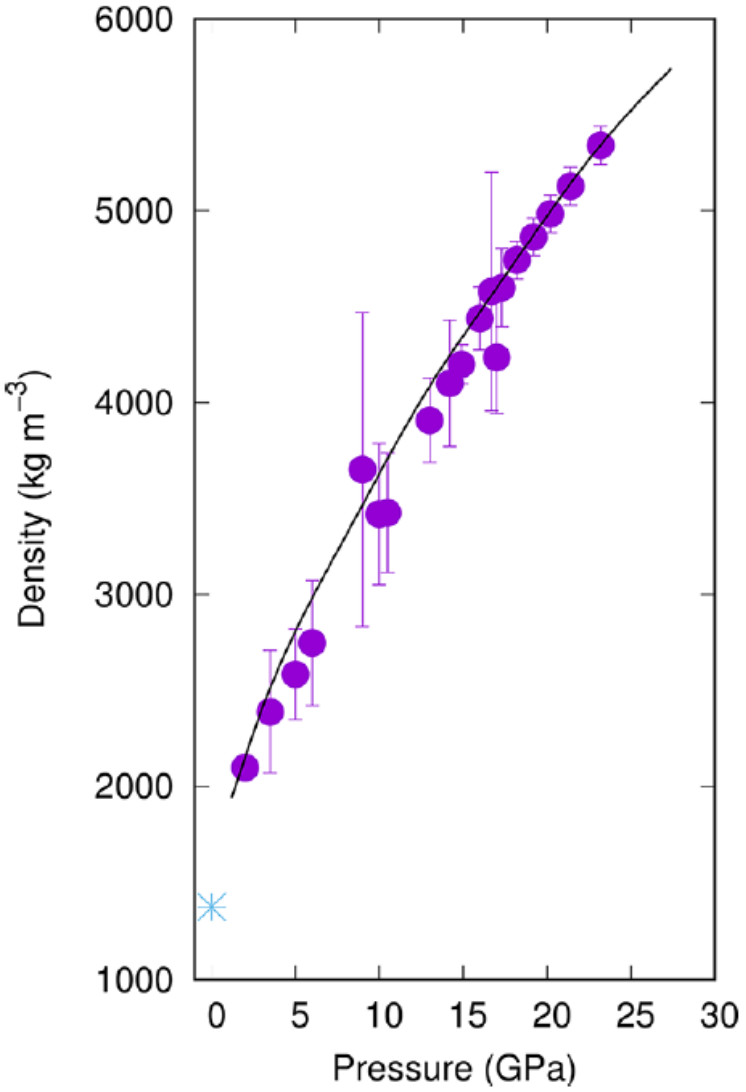
Santoro (2018)



M. Santoro, D. Colognesi, B. Monserrat, E. Gregoryanz, L. Ulivi, and F. A. Gorelli, *High-pressure vibrational properties of dense rubidium*, Phys. Rev. B **98**, 104107 (2018)

Gorelli (2018)

Liquid (T=573 K)

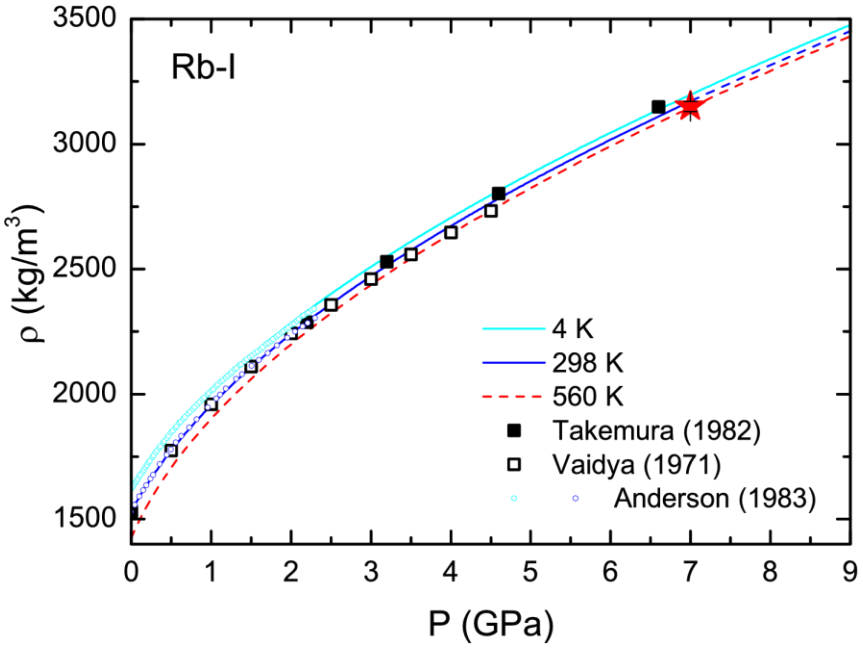


Continuous line: AIMD density. Blue cross: density at ambient pressure and 573 K.

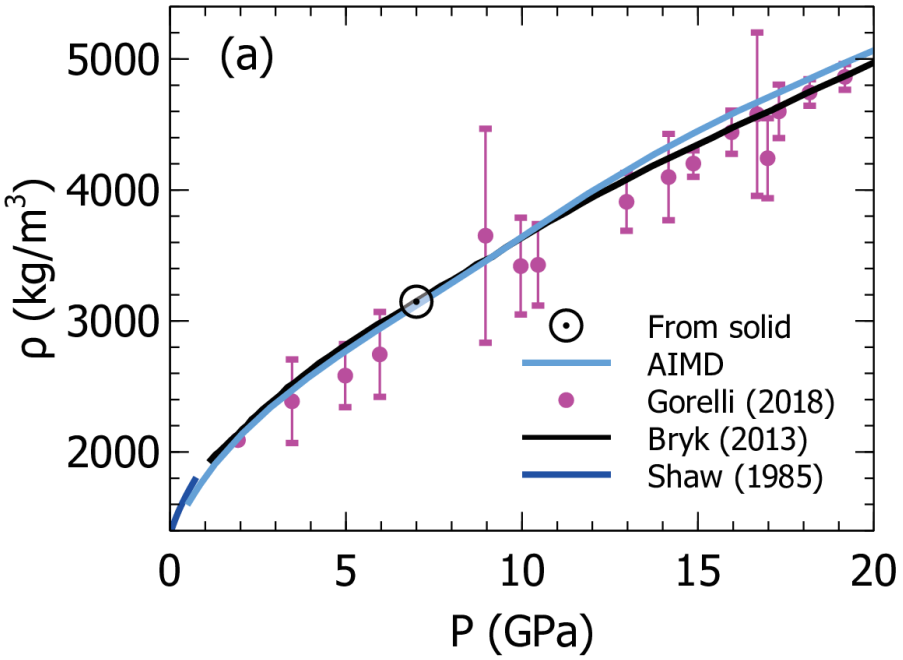
F.A. Gorelli *et al*, *Simple-to-Complex Transformation in Liquid Rubidium,* J. Phys. Chem. Lett., **9** 2909 (2018)

Ayrinhac (2020)

Solid (T=5-560 K)

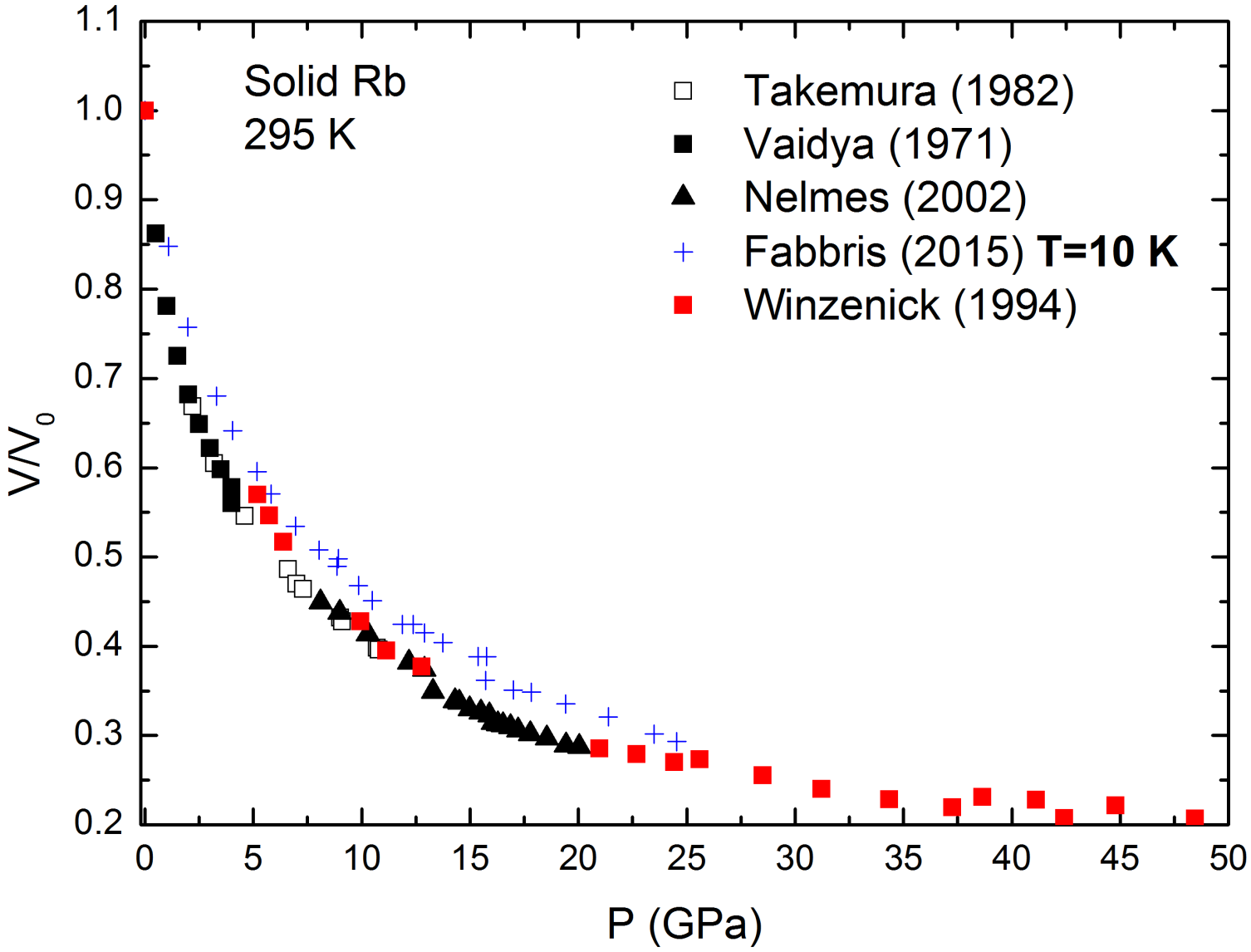


Liquid (T=573 K)

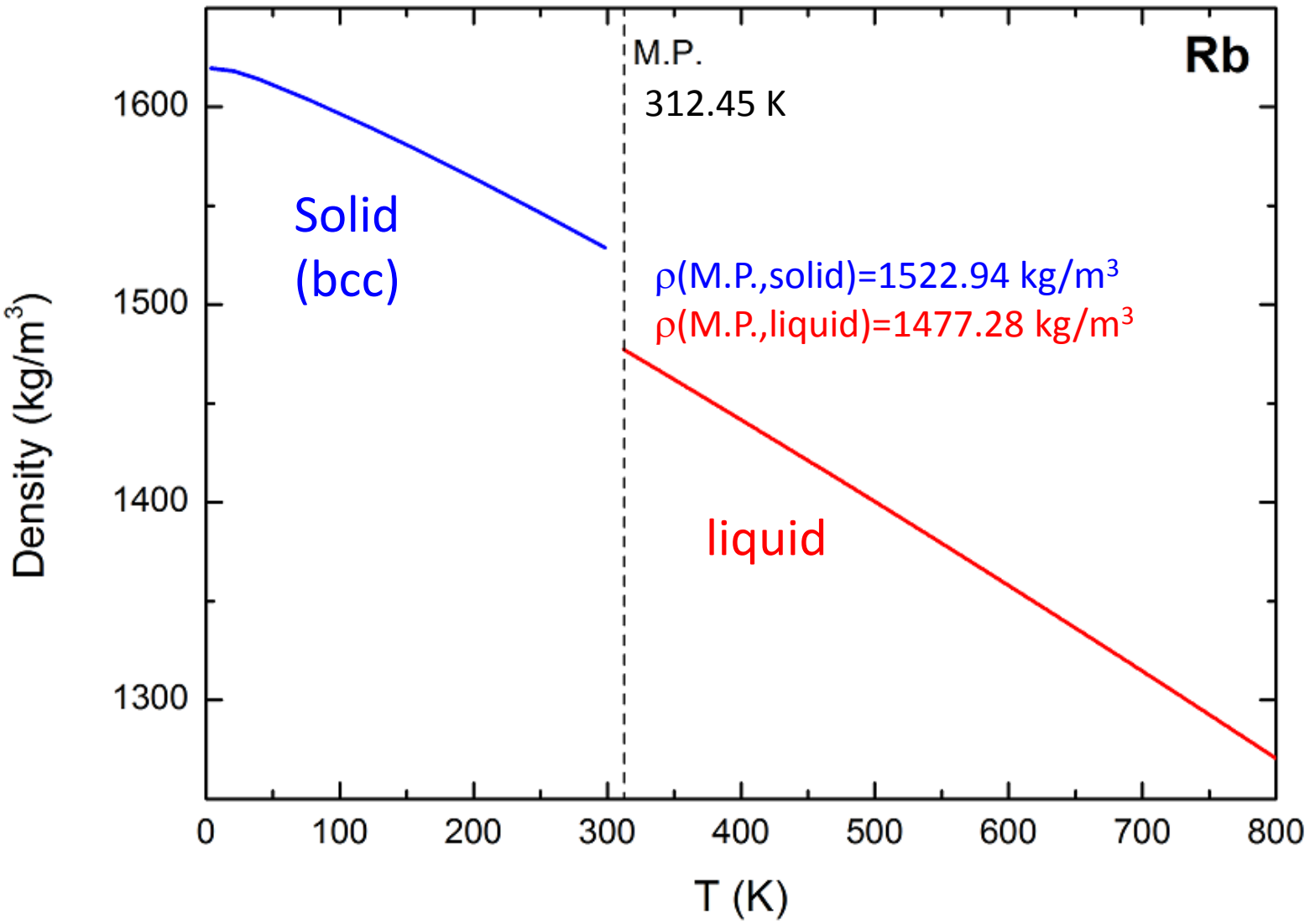


S. Ayrinhac, V.N. Robinson, F. Decremps, M. Gauthier, D. Antonangeli, S. Scandolo, and M.Morand, *Phys. Rev. Materials* **4**, 113611 (2020)

Overview, part I



Overview, part II



Bulk modulus

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Suzuki (1968)

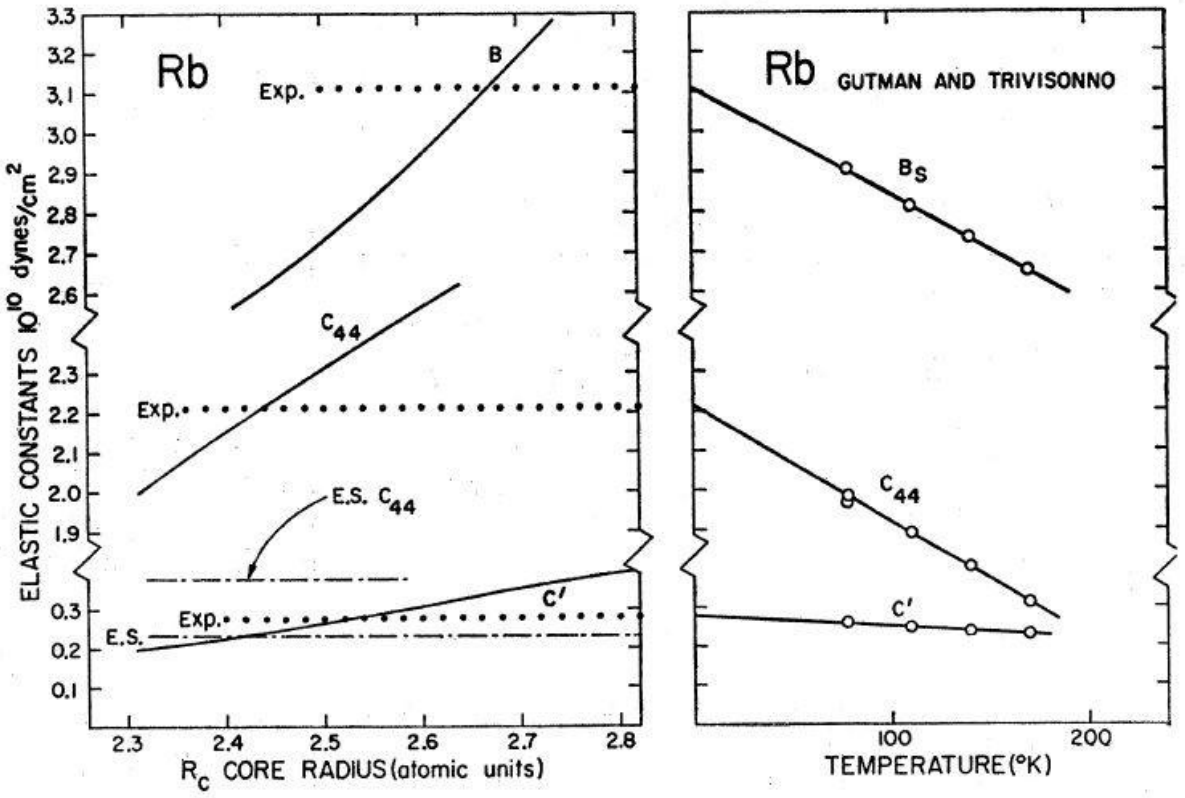


FIG. 4. Second-order elastic constants of rubidium. Notations are the same as Fig. 1.

Suzuki, T., Granato, A. V., & Thomas Jr, J. F., *Second-and third-order elastic constants of alkali metals,* Physical Review, **175**, 766 (1968)

Pasternak (1968)

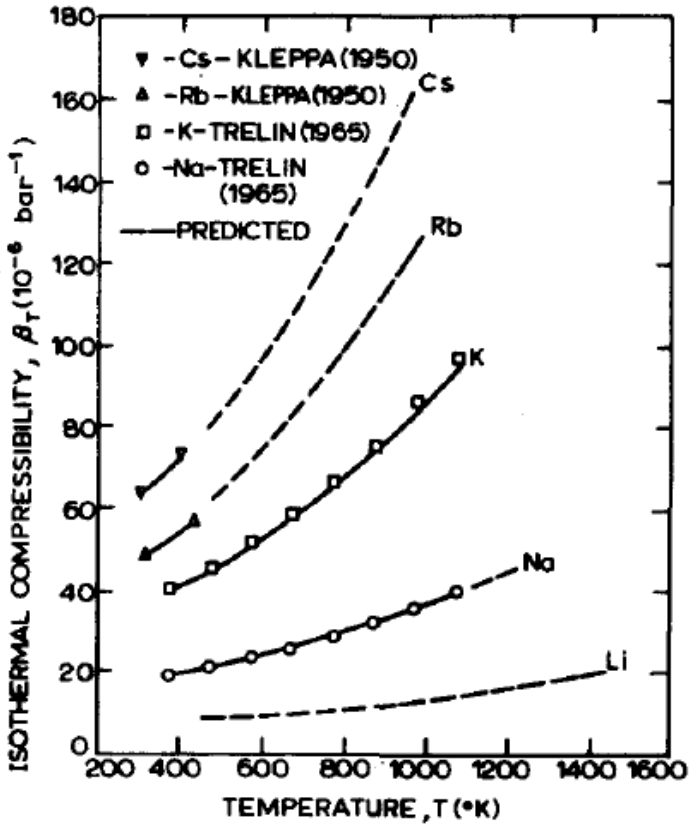


Fig. 2. Compressibilities of the liquid alkali metals.

Liquid Rb

T (K)	Isothermal Bulk modulus (GPa)
319.74	2.0633
436.77	1.75988
485.4	1.59469
514.64	1.53459
534.08	1.47892
563.32	1.42708
582.77	1.37883
611.98	1.32503
631.45	1.29144
660.64	1.2366
675.24	1.21448
699.53	1.16588
723.87	1.13344
748.16	1.091
762.74	1.06814
830.74	0.96684
850.21	0.94886
874.5	0.91895
893.92	0.89477
913.29	0.86445
937.66	0.84998
991.05	0.79378

A.D. Pasternak, *Isothermal compressibility of the liquid alkali metals*, Materials Science and Engineering, **3(2)**, 65-70 (1968)

Vaidya (1971)

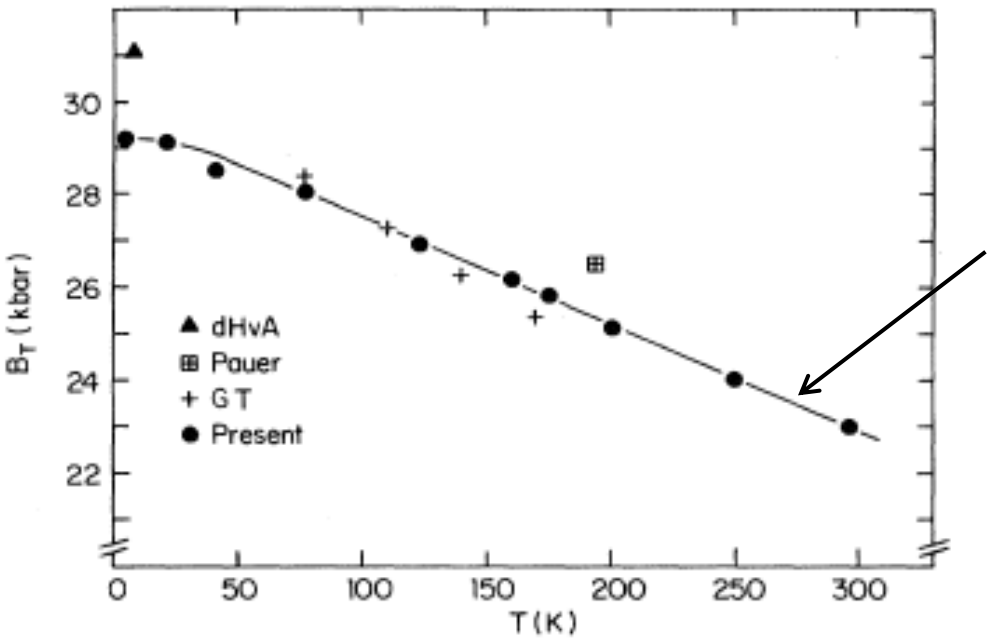
Gruneisen constants

Element	Temp. (°K)	B_T (kbar)	B_T'	B_T'' (kbar^{-1})	γ_{calc}[c]	γ_{th}	Reference
Rubidium	*RT*	26·6 ± 0·2	3·23 ± 0·02		1·45	1·80[d]	ME This work
	RT	26·0 ± 0·1	3·37 ± 0·06	−0·009 ± 0·005	1·52	1·06[13]	MME This work
	RT	30·4	3·29		1·48	1·17[e]	ME Bridgman[4]
	RT	31·1	3·12	0·011	1·39		MME Bridgman[4]
	RT	22·7	2·90		1·27		ME Keeler[14]
	RT	21·0	3·34	−0·026	1·50		MME Keeler[14]
	195	26·3	3·79		1·72		Pauer[12]
	170	26·5					Gutman & Trivisonno[27]

S.N. Vaidya, I.C. Getting, G.C. Kennedy,
The compression of the alkali metals to 45 kbar,
Journal of Physics and Chemistry of Solids, **32(11)** 2545 (1971)

Anderson (1983)

Solid Rb



$(\partial B_T/\partial T)_{P=0} = -2.41\times10^{-3}$ GPa/K

FIG. 16. Temperature dependence of the $P=0$ isothermal bulk modulus for rubidium. The symbols refer to published results as follows: GT, Ref. 83; Pauer, Ref. 84; dHvA, Ref. 29.

M. S. Anderson and C. A. Swenson
Experimental compressions for sodium. potassium. and rubidium metals to 20 kbar from 4.2 to 300 K
Phys. Rev. B **28**. 5395 (1983)

Anderson (1983)

Solid Rb

TABLE IV. Summary of the isotherm results for rubidium. The data points for the isotherms are indicated in Figs. 12 and 13.

T (K)	P^* (kbar)	$(V/V_0)_{P=0}$	B_0 (kbar) a	B_0 (kbar) b	B_0'[b]	B_0'' (kbar^{-1})[b]	RMSD (10^{-4} in V/V_0)[b]
295	(0)	(1.0000)[c]	(23.0)	23.01±0.03	4.15∓0.1	−0.057±0.003	2.01
250	−0.25	0.9894	24.0	24.0 ±0.06	4.16∓0.03	−0.061±0.006	1.80
200[d]	−0.54	0.9778	25.2	25.1 ±0.1	4.25∓0.09	−0.087±0.015	1.23
175	−0.68	0.9726	25.8	25.95±0.06	4.03∓0.02	−0.052±0.003	2.46
160[d]	−0.79	0.9685	26.3	26.0 ±0.12	4.28∓0.12	−0.090±0.024	1.71
123	−0.96	0.9623	26.9	26.8 ±0.15	4.15∓0.06	−0.068±0.012	2.05
77	−1.23	0.9528	28.1	28.0 ±0.12	4.12∓0.06	−0.066±0.012	3.30
40	−1.39	0.9475	28.7	28.4 ±0.3	4.24∓0.15	−0.080±0.024	3.84
21	−1.49	0.9444	29.1	28.9 ±0.2	4.20∓0.12	−0.077±0.015	2.46
4	−1.51	0.9436	29.2	29.2 ±0.2	4.10∓0.12	−0.064±0.018	2.46

[a] $P=0$ bulk moduli derived from the 295-K isotherm and P^*.
[b] Parameters derived from nonlinear least-squares fits of Eq. (15) for each isotherm. The 3σ uncertainties are those associated with the fitting procedure and do not include an allowance for systematic effects. A more qualitative assessment gives minimum uncertainties of ±0.25 kbar for B_0, ∓0.1 in B_0', and ±0.01 kbar^{-1} in B_0''.
[c] V_0(295 K, $P=0$) = 55.74 cm^3/mole (Refs. 79 and 80).
[d] 0.354-in. sample holder data only.

M. S. Anderson and C. A. Swenson
Experimental compressions for sodium. potassium. and rubidium metals to 20 kbar from 4.2 to 300 K
Phys. Rev. B **28**. 5395 (1983)

Boehler (1984)

TABLE II. Melting temperatures, adiabats $(\partial T/\partial P)_s$, compression, isothermal bulk modulus, and Grüneisen parameter of rubidium at high pressures.

P (kbar)	T_m (°C)	$(\partial T/\partial P)_s$ (°C/kbar)	V/V_0 [a]	B_T [a] (kbar)	γ
0	39.4	14.5	1	25.0	1.35
5	115.0	4.75	0.861	43.3	0.71
10	161.5	2.87	0.781	60.1	0.59
15	193.0	2.17	0.725	75.8	0.56
20	216.5	1.75	0.683	90.7	0.54
25	234.0	1.45	0.649	104.7	0.52
30	248.0	1.27	0.620	118.1	0.51
35		1.13	0.596	131.1	0.50

[a]Calculated average from compression measurements by Anderson and Swenson (Ref. 8) and by Takemura and Syassen (Ref. 6).

R. Boehler, M. Ross, *Grüneisen parameter of cesium and rubidium at high pressure and the nature of the isostructural electronic transition*, Physical Review B, **29(6),** 3673 (1984)

Schlosser (1989)

TABLE I. Isothermal bulk modulus and pressure derivative.

	Input		Output		
	B_0 (GPa)	B_0'	B_0 (GPa)	B_0'	r
Na[a]	5.14	3.8	5.1406	3.793	0.999 998
K[b]	2.38	4.1	2.3811	4.094	0.999 995
Rb[b]	1.86	4.1	1.8618	4.082	0.999 987
Cs[b]	1.39	4.2	1.3925	4.172	0.999 973

[a] $T = 148.9\,^{\circ}\mathrm{C}$.
[b] $T = 150.1\,^{\circ}\mathrm{C}$.

Liquid Rb

TABLE II. Adiabatic bulk modulus.

	B_0^s (GPa)[a]	B_0^s (GPa)[b]
Na	5.7537	5.74
K	2.7370	2.71
Rb	2.1425	2.11
Cs	1.6289	1.57

[a] This work.
[b] Reference 3.

H. Schlosser, P. Vinet, J. Ferrante,
Pressure dependence of the melting temperature of metals,
Physical Review B, **40(9)**, 5929 (1989)

Belashchenko (2016)

Liquid Rb
(molecular dynamics (MD) using the interparticle potential EAM)

Table 5. Bulk modulus K_T of rubidium models, GPa; $V_0 =$ 55.861 cm^3/mol

T, K	$Y = V/V_0$								
	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
300	1.78	2.25	3.55	4.64	6.47	9.77	16.4	32.0	77.7
500	1.68	2.15	3.38	4.62	6.64	10.2	17.2	32.8	76.7
700	1.78	2.15	3.36	4.67	6.80	10.5	17.7	33.6	77.3
1000	1.68	2.15	3.39	4.76	6.99	10.9	18.3	34.6	78.9
1500	1.78	2.20	3.51	4.97	7.31	11.4	19.0	35.8	81.1
2000	2.00	2.35	3.67	5.18	7.60	11.8	19.7	36.8	82.9
2500	2.10	2.55	3.88	5.42	7.89	12.1	20.2	37.7	84.7
3000	2.20	2.65	4.06	5.64	8.16	12.5	20.7	38.5	86.2
3500	2.42	2.90	4.27	5.88	8.44	12.8	21.1	39.2	87.5

D. K. Belashchenko,
Russian Journal of Physical Chemistry A
90(9), 1707 (2016)

Ramasamy (2019)

Table 3. Isothermal compressibility of liquid rubidium.

T_K	$\beta_T(10^{-10}\ ms^2/kg^{-1})$
313	1.1452
400	1.5762
500	2.1759
600	2.8975
700	3.8133
800	4.9325
900	6.3061
960	7.3787
1000	8.1639
1100	10.6044
1200	13.9865
1300	18.2983
1400	26.3632
1500	39.2961
1600	65.9748
1700	150.0592
1897	800.2653
1907	1052.052
1917	1721.123
1927	2681.215
1937*	8421.277

*-Vapor-Liquid critical point.

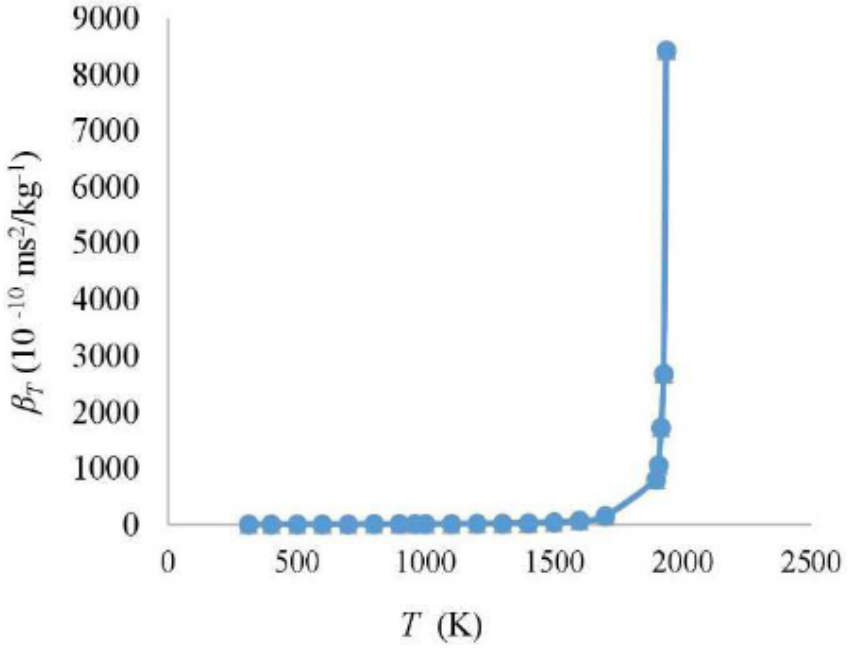


Figure 2. Isothermal compressibility of liquid rubidium.

Ramasamy, B., & Murukaiyan, *Isothermal Compressibility of Liquid Alkali Metals*, American Journal of Chemistry and Materials Science, **6(2),** 36 (2019)

Heat capacity

back to the table of contents

Data from NIST

Liquid Rb

Liquid Phase Heat Capacity (Shomate Equation)

$C_p^\circ = A + B*t + C*t^2 + D*t^3 + E/t^2$

$H^\circ - H^\circ_{298.15} = A*t + B*t^2/2 + C*t^3/3 + D*t^4/4 - E/t + F - H$

$S^\circ = A*\ln(t) + B*t + C*t^2/2 + D*t^3/3 - E/(2*t^2) + G$

C_p = heat capacity (cal/mol*K)

H° = standard enthalpy (kcal/mol)

S° = standard entropy (cal/mol*K)

t = temperature (K) / 1000.

View plot Requires a JavaScript / HTML 5 canvas capable browser.

View table.

39.5 - 697.235 °C

Temperature (K)	312.65 - 970.385
A	8.484052
B	-3.076819
C	2.043511
D	-0.000676
E	-0.000028
F	-1.888860
G	31.11370
H	0.521989
Reference	Chase, 1998
Comment	Data last reviewed in December, 1983

http://webbook.nist.gov/cgi/inchi?ID=C7440177&Units=CAL&Mask=2#Thermo-Condensed

Data from NIST

Solid Rb

Solid Phase Heat Capacity (Shomate Equation)

$C_p° = A + B*t + C*t^2 + D*t^3 + E/t^2$

$H° - H°_{298.15} = A*t + B*t^2/2 + C*t^3/3 + D*t^4/4 - E/t + F - H$

$S° = A*\ln(t) + B*t + C*t^2/2 + D*t^3/3 - E/(2*t^2) + G$

C_p = heat capacity (cal/mol*K)
H° = standard enthalpy (kcal/mol)
S° = standard entropy (cal/mol*K)
t = temperature (K) / 1000.

View plot Requires a JavaScript / HTML 5 canvas capable browser.

View table.

Temperature (K)	298. - 312.65
A	2.257711
B	15.60990
C	10.87770
D	-6.402871
E	-0.025748
F	-1.536691
G	15.85700
H	0.000000
Reference	Chase, 1998
Comment	Data last reviewed in December, 1983

Very small range

http://webbook.nist.gov/cgi/inchi?ID=C7440177&Units=CAL&Mask=2#Thermo-Condensed

Lien (1964)

TABLE IV. The heat capacity of rubidium: measurements in the liquid-helium temperature cryostat. The units of heat capacity are mJ mole^{-1} deg^{-1}. Temperatures are based on the 1958 He^4 scale.[a]

T	C	T	C	T	C
1.1991	24.07	4.0713	1009.	3.6579	757.7
1.3249	32.22	1.1952	23.83	4.0081	969.1
1.4630	43.46	1.3076	30.99	1.5881	55.89
1.6163	59.22	1.4365	41.12	1.7361	73.97
1.7867	81.31	1.5882	56.00	1.9055	99.58
1.9718	111.4	1.7523	76.35	2.0910	134.4
2.1610	149.7	1.9314	104.3	2.2887	179.3
2.3660	200.3	2.1287	142.6	2.5015	238.5
2.5961	269.1	2.3342	191.4	2.7254	313.0
2.8521	361.7	2.5471	251.8	2.9798	412.5
3.1428	486.5	2.7886	336.9	3.2642	543.7
3.4535	644.5	3.0530	445.1	3.5784	711.6
3.7762	827.6	3.3361	581.4	3.9231	914.7

[a] See Ref. 10.

W.H. Lien, N.E. Phillips,
Low-Temperature Heat Capacities of Potassium, Rubidium, and Cesium,
Physical Review, **133(5A)**, A1370 (1964).

William (1964)

TABLE III. The heat capacity of rubidium: measurements in the adiabatic demagnetization cryostat. The units of heat capacity are mJ mole^{-1} deg^{-1}. Temperatures are based on the 1958 He^4 scale.[a]

T	C	T	C	T	C
0.2002	0.5701	0.2548	0.8022	0.5867	3.810
0.2191	0.6439	0.2798	0.9257	0.6418	4.724
0.2391	0.7282	0.3048	1.063	0.7053	5.924
0.2616	0.8336	0.3285	1.201	0.7736	7.457
0.2936	0.9953	0.3511	1.350	0.8497	9.489
0.1954	0.5537	0.3830	1.582	0.9289	11.87
0.2143	0.6223	0.4177	1.863	1.011	14.93
0.2321	0.6968	0.4527	2.172	1.098	18.85
0.2548	0.8001	0.4882	2.538	0.6381	4.617
0.2819	0.9344	0.5252	2.979	0.7084	5.947
0.3140	1.113	0.5686	3.555	0.7862	7.735
0.3456	1.309	0.6151	4.229	0.8634	9.845
0.3816	1.569	0.6573	4.931	0.9455	12.49
0.4185	1.868	0.7245	6.264	1.041	16.26
0.4615	2.260	0.7969	7.952	1.135	20.71
0.5015	2.693	0.8708	10.02	1.237	26.43
0.5549	3.358	0.4168	1.860	1.214	25.13
0.1859	0.5189	0.4596	2.255	1.167	22.46
0.2087	0.6064	0.5002	2.681	1.245	26.88
0.2326	0.7025	0.5395	3.121		

[a] See Ref. 10.

TABLE IV. The heat capacity of rubidium: measurements in the liquid-helium temperature cryostat. The units of heat capacity are mJ mole^{-1} deg^{-1}. Temperatures are based on the 1958 He^4 scale.[a]

T	C	T	C	T	C
1.1991	24.07	4.0713	1009.	3.6579	757.7
1.3249	32.22	1.1952	23.83	4.0081	969.1
1.4630	43.46	1.3076	30.99	1.5881	55.89
1.6163	59.22	1.4365	41.12	1.7361	73.97
1.7867	81.31	1.5882	56.00	1.9055	99.58
1.9718	111.4	1.7523	76.35	2.0910	134.4
2.1610	149.7	1.9314	104.3	2.2887	179.3
2.3660	200.3	2.1287	142.6	2.5015	238.5
2.5961	269.1	2.3342	191.4	2.7254	313.0
2.8521	361.7	2.5471	251.8	2.9798	412.5
3.1428	486.5	2.7886	336.9	3.2642	543.7
3.4535	644.5	3.0530	445.1	3.5784	711.6
3.7762	827.6	3.3361	581.4	3.9231	914.7

[a] See Ref. 10.

W.H. Lien, N.E. Phillips,
Low-Temperature Heat Capacities of Potassium, Rubidium, and Cesium,
Physical Review, **133(5A)**, A1370 (1964).

Filby (1965)

Solid Rb

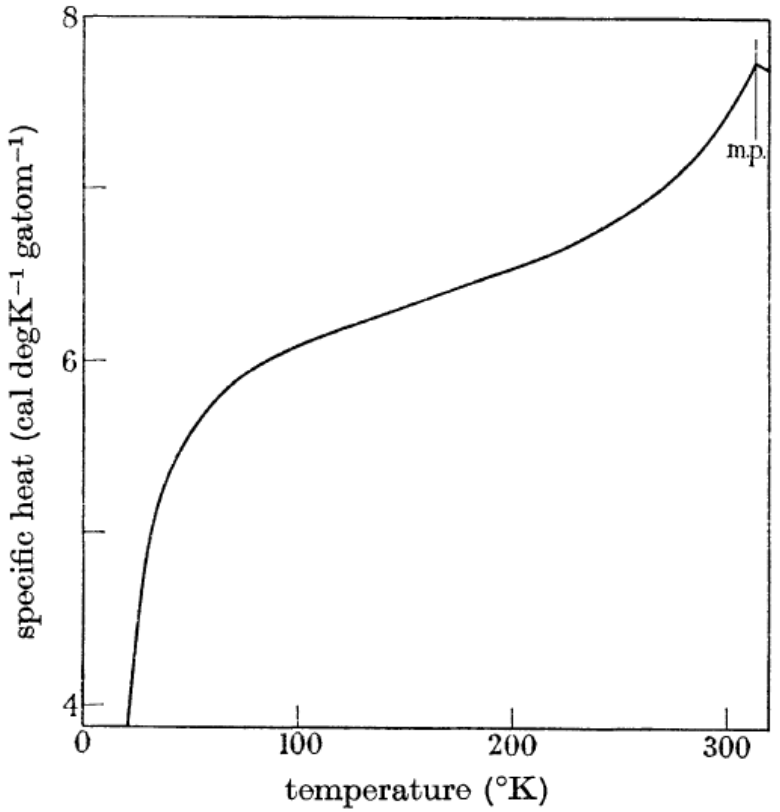
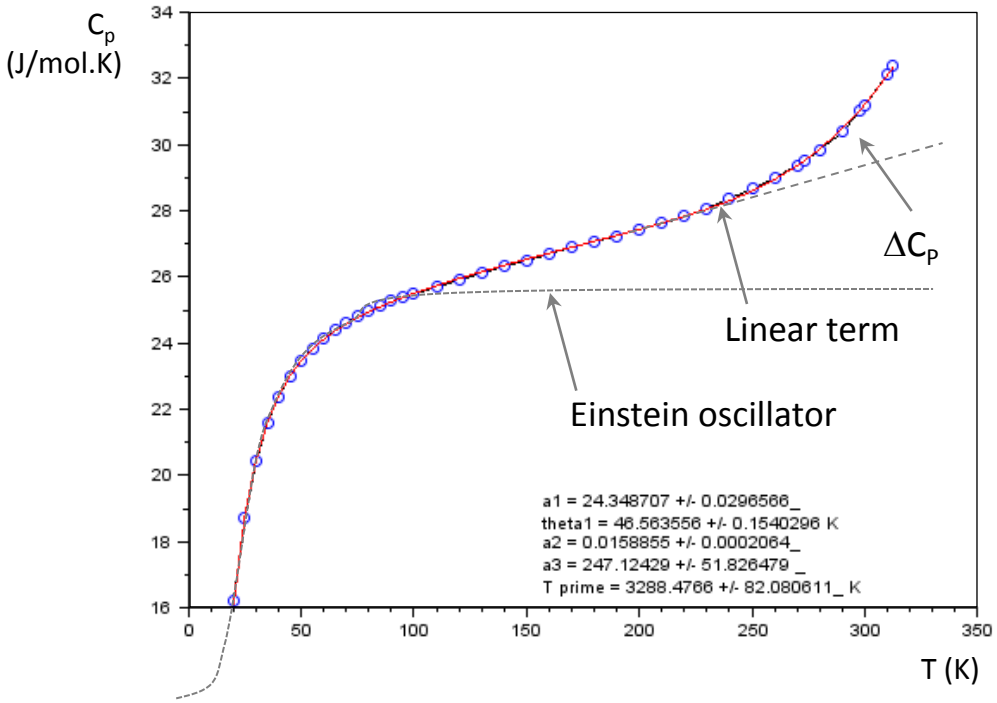


FIGURE 8. Specific heat of rubidium above 20 °K.

J.D. Filby, D.L. Martin, *The Specific Heats Below 320 °K of Potassium, Rubidium and Caesium,* In Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, **284** 83-107 (1965)

T (K)	CP (J/mole.K)	CV (J/mole.K)
20	16.19208	16.15024
25	18.70248	18.6188
30	20.41792	20.25056
35	21.58944	21.38024
40	22.3844	22.13336
45	23.012	22.71912
50	23.47224	23.13752
55	23.8488	23.47224
60	24.14168	23.72328
65	24.39272	23.93248
70	24.60192	24.09984
75	24.81112	24.2672
80	24.97848	24.39272
85	25.14584	24.4764
90	25.27136	24.43456
95	25.39688	24.64376
100	25.48056	24.72744
110	25.68976	24.85296
120	25.89896	24.93664
130	26.10816	25.06216
140	26.31736	25.18768
150	26.48472	25.27136
160	26.69392	25.39688
170	26.90312	25.48056
180	27.07048	25.56424
190	27.23784	25.64792
200	27.44704	25.68976
210	27.6144	25.81528
220	27.8236	25.89896
230	28.07464	26.02448
240	28.36752	26.19184
250	28.6604	26.3592
260	28.99512	26.5684
270	29.37168	26.7776
273.15	29.4972	26.86128
280	29.83192	27.07048
290	30.37584	27.44704
298.15	31.04528	27.90728
300	31.1708	27.99096
310	32.13312	28.6604
312.64	32.38416	28.82776

Solid Rb : C_P Fit



Model

- One Einstein oscillator and a linear term :

$$C_P = a_1 \frac{x^2 e^x}{(e^x - 1)^2} + a_2 T + \Delta C_P \qquad x = \frac{\Theta_1}{T}$$

- Extra specific heat due to defects (formation of vacant lattice sites) :

$$\Delta C_P = \frac{R_0 a_3}{2} \left(\frac{T'}{T}\right)^2 exp\left(-\frac{T'}{T}\right)$$

Comparison with Na, K

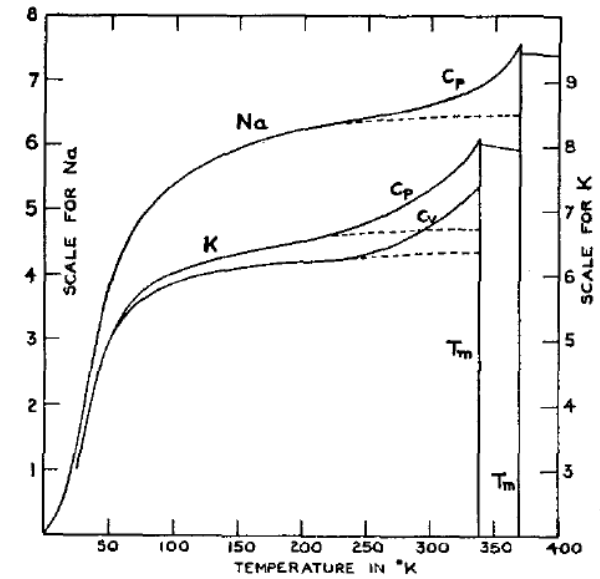


FIG. 1. The atomic heats of K and Na in cal deg^{-1} mole^{-1}.

Carpenter, L. G., *Some Properties of Sodium and Potassium Near Their Melting Points,* The Journal of Chemical Physics, **21(12),** 2244 (1953).

Eq.(4) from : L.E. Fried, W.M. Howard, Phys. Rev. B **61(13)** 8734 (2000)

Eq.(3) from : R.W. Christy, A.W. Lawson, The Journal of Chemical Physics, **19(4),** 517-517 (1951)

Kim (1971)

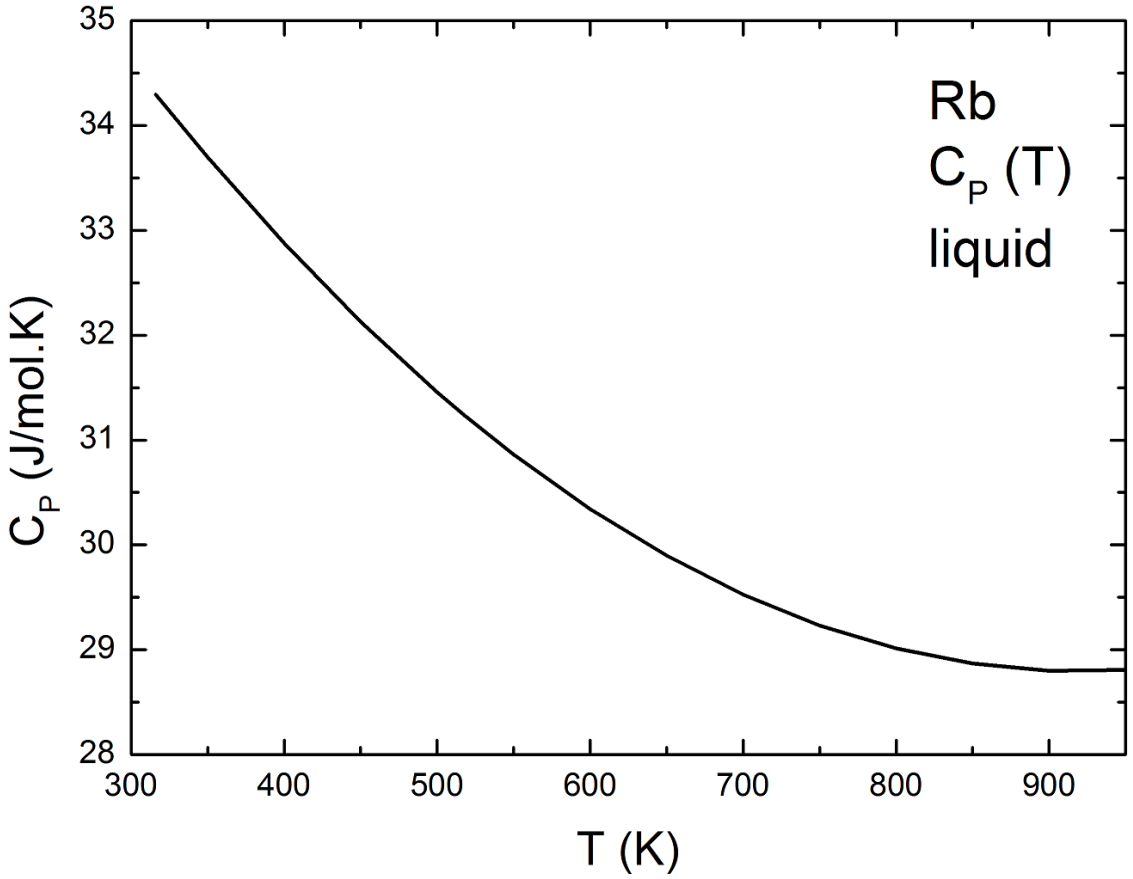
Liquid Rb

Numerous investigators have made calorimetric measurements on liquid rubidium in order to ascertain the enthalpy and, indirectly, the specific heat as functions of temperature. The enthalpy equation as a cubic function of temperature given by Achener[23] adequately represents the data of Rengade,[19] Tepper *et al.*,[22] Kelley,[33] and Stull *et al.*[34] and leads to the following equation for the specific heat of liquid rubidium:

$$C_p(\mathrm{Rb}) = 0.09817 - 5.4512 \times 10^{-5} T + 4.209 \times 10^{-8} T^2. \quad (22)$$

M. G. Kim, K. A. Kemp, and S. V. Letcher, *Ultrasonic Measurement in Liquid Alkali Metals,* J. Acoust. Soc. Am. **49**, 706 (1971)

Kim (1971)


Rb
C_P (T)
liquid
C_P (J/mol.K)
T (K)
35
34
33
32
31
30
29
28
300
400
500
600
700
800
900

Sharma (1972)

Rubidium	1.3–12	k
	0.4–320	i
	0.2–4.2	j
	1.2–4.2	k
Cesium	1.3–12	l
	0.4–320	i
	0.2–4.2	j

a) Simon, F. and Swain, R. C., Z. physik. Chem. **B28** (1935) 189.
b) Martin, D. L., Proc. Roy. Soc. (London) **A254** (1960) 444.
c) Filby, J. D. and Martin, D. L., Proc. Roy. Soc. (London) **A276** (1963) 187.
d) Roberts, L. M., Proc. Phys. Soc. **B70** (1957) 744.
e) Martin, D. L., Proc. Roy. Soc. (London) **A254** (1960) 433.
f) Simon, F. and Zeidler, W., Z. physik. Chem. **123** (1926) 383.
g) Parkinson, D. H. and Quarrington, J. E., Proc. Phys. Soc. **A68** (1955) 762.
h) Krier, C. A., Craig, R. S. and Wallace, W. E., J. phys. Chem. **61** (1957) 522.
i) Filby, J. D. and Martin, D. L., Proc. Roy. Soc. (London) **A284** (1965) 83.
j) Lien, W. H. and Phillips, N. E., Phys. Rev. **133** (1964) A 1370.
k) Manchester, F. D., Canad. J. Phys. **37** (1959) 525.
l) McCollum, Jr., D. C. and Silsbee, H. B., Phys. Rev. **127** (1962) 119.

P.K. Sharma, N. Singh,
Lattice vibrations and debye temperatures of alkali metals.
Physica, **59(1),** 109-127 (1972)

Vaks (1978)

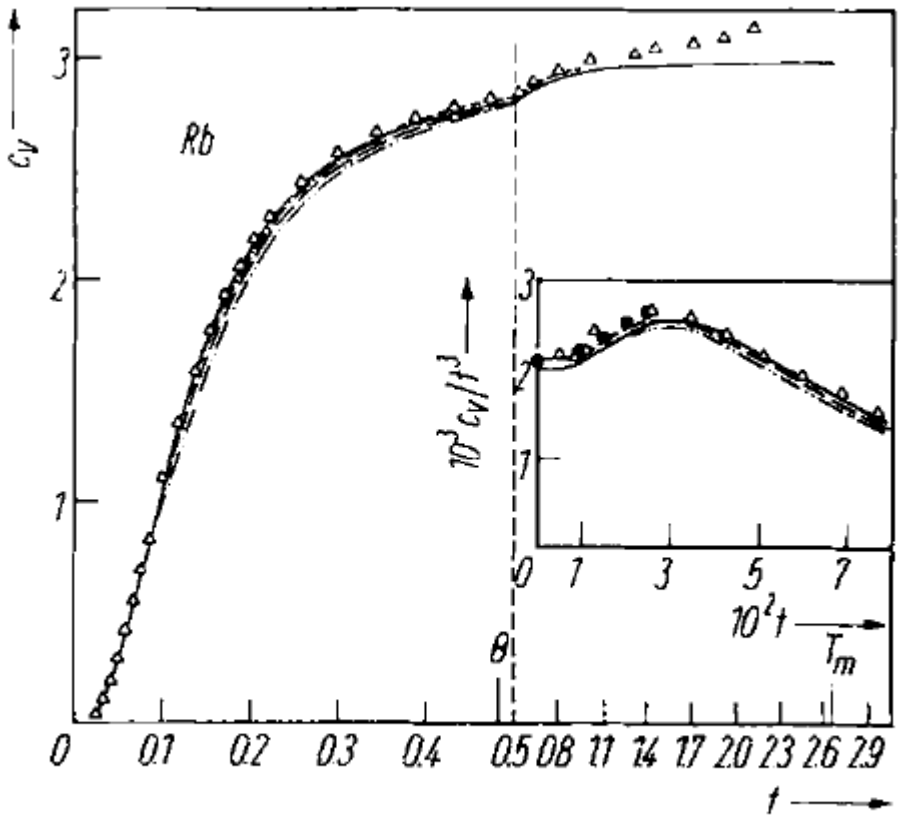
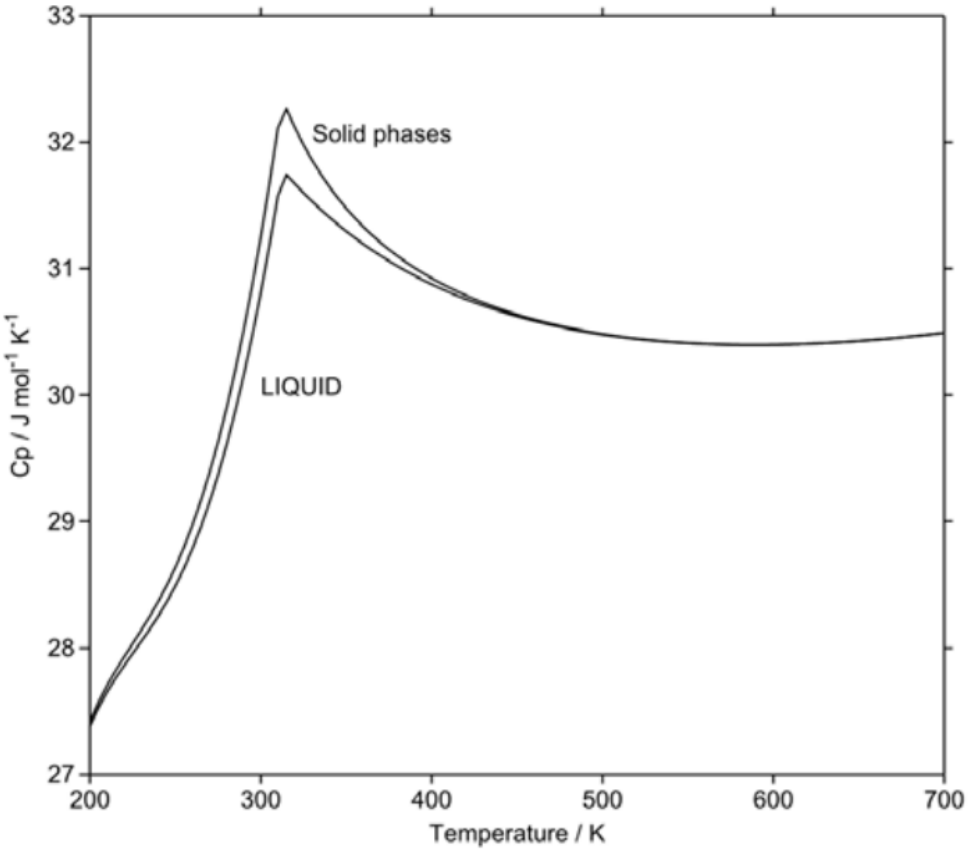


Fig. 5

● D. L. Martin, Canad. J. Phys. **48**, 1327 (1970)
Δ J. D. FILBY and D. L. MARTIN, Proc. Roy. SOC A. **234**, 83 (1965)

Vaks, V. G., Zarochentsev, E. V., Kravchuk, S. P., Safronov, V. P., & Trefilov, A. V., *Lattice heat capacity and thermal vibrations in alkali metals*, *Physica status solidi (b)*, **85(1),** 63-74 (1978).

Dinsdale (1991)



Heat capacity of Rb

Dinsdale, A., *SGTE data for pure elements*, calphad, **15(4)** 317-425 (1991)

Alcock (1994)

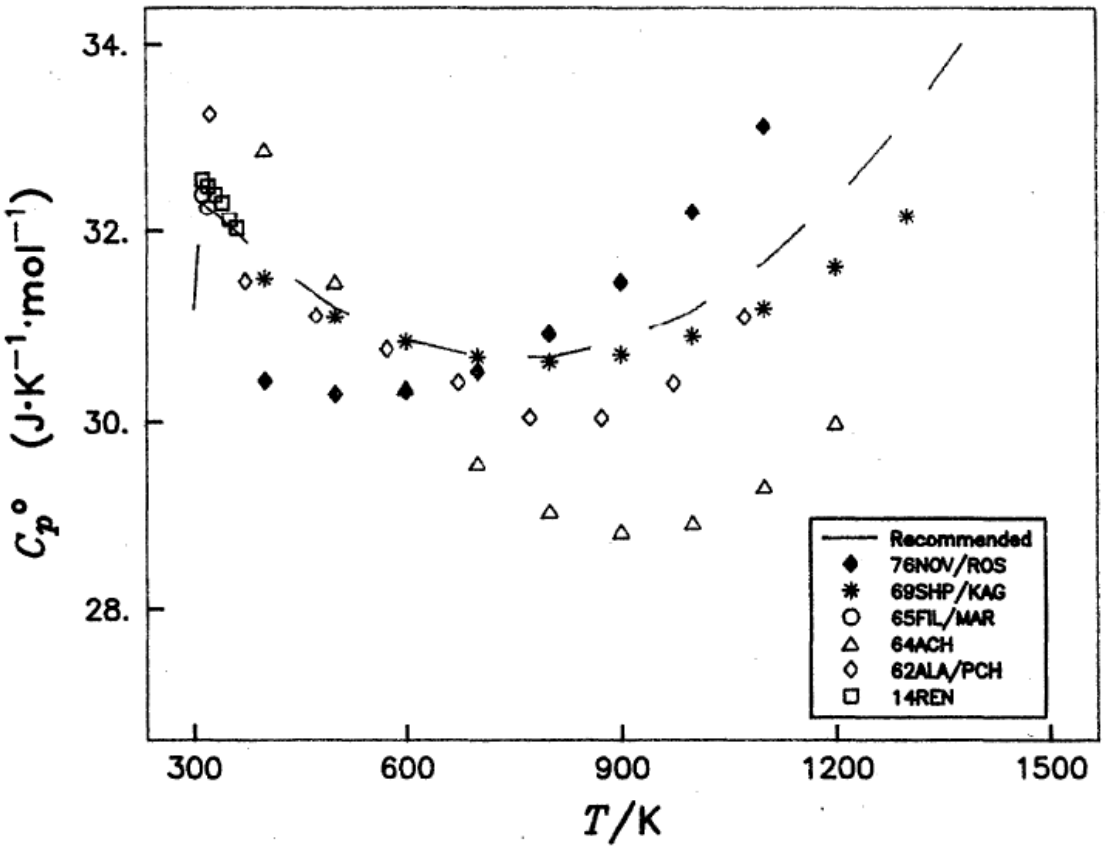


FIGURE 5.4. Heat Capacity of Liquid Rb

Liquid Rb
Temperature range 312.45 − 1600 K.
$C_p^\circ = 35.494 - 12.864\times10^{-3}T + 8.541\times10^{-6}T^2$
J·K^{-1}·mol^{-1}.

(p.464)

C.B. Alcock, M.W. Chase, V.P. Itkin, *Thermodynamic properties of the group IA elements,* Journal of physical and chemical reference data, **23(3)** 385-497 (1994)

Singh (2007)

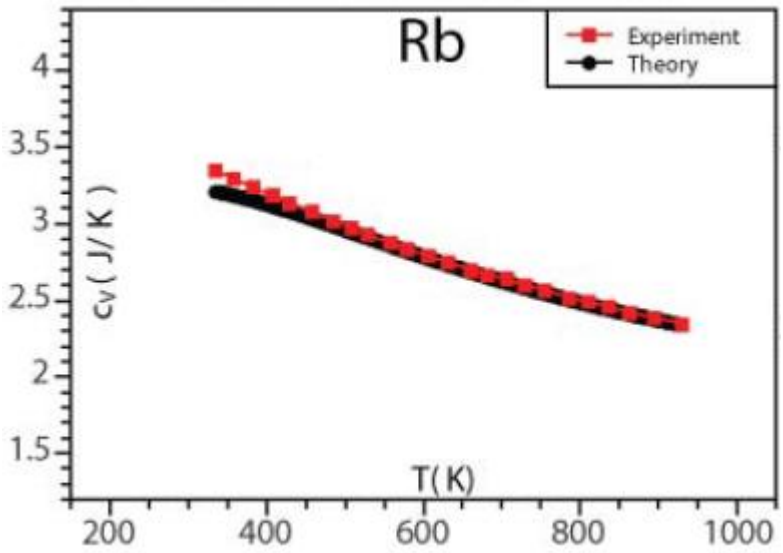
Table 1
Temperature variation of coefficient of volume expansion (β), isentropic compressibility (κ_s), ratio of specific heat (γ), Grüneisen function (ξ), specific heat at constant volume (C_v), isothermal compressibility (κ_T) and acoustic impedance (Z) for s-, d- and p-bonded liquid metals

Metals	T (K)	β (K^{-1}) $\times 10^{-6}$	κ_s (Pa^{-1}) $\times 10^{-12}$	γ	ξ	Cv ($J\,K^{-1}mol^{-1}$)	κ_T (Pa^{-1}) $\times 10^{-12}$	Z Pa s m^{-1} $\times 10^{6}$
Na	**371**	**253.51**	**168.40**	**1.11**	**1.17**	**28.68**	**186.97**	**2.35**
	400	255.38	171.76	1.12	1.18	28.14	192.44	2.31
	500	262.08	184.08	1.16	1.19	26.42	212.90	2.21
	600	269.13	197.61	1.19	1.20	24.95	236.01	2.10
	700	276.57	212.51	1.23	1.20	23.74	262.00	2.00
	800	284.44	228.94	1.27	1.19	22.76	291.15	1.90
	900	292.77	247.11	1.31	1.18	21.98	323.81	1.80
K	**337**	**290.21**	**342.12**	**1.12**	**1.25**	**28.65**	**383.87**	**1.55**
	350	291.30	345.95	1.13	1.25	28.38	390.00	1.54
	400	295.61	361.21	1.15	1.25	27.46	414.61	1.50
	500	304.61	394.53	1.19	1.25	25.80	469.51	1.41
	600	314.19	432.09	1.23	1.23	24.46	532.63	1.33
	700	324.38	474.56	1.27	1.21	23.40	605.05	1.25
	800	335.25	522.80	1.32	1.18	22.61	687.87	1.17
Rb	**312**	**304.05**	**425.60**	**1.11**	**1.20**	**30.89**	**474.01**	**1.86**
	400	310.47	459.92	1.15	1.21	28.57	529.09	1.78
	500	320.42	507.25	1.20	1.22	26.27	606.67	1.66
	600	331.03	561.30	1.24	1.22	24.41	697.55	1.56
	700	342.36	623.31	1.29	1.21	22.89	804.00	1.45
Cs	**302**	**309.78**	**581.20**	**1.08**	**0.90**	**39.43**	**630.17**	**1.78**
	350	314.46	607.95	1.11	0.96	35.54	672.50	1.73
	400	319.48	637.58	1.13	1.04	31.77	722.10	1.67
	500	330.03	702.88	1.20	1.19	25.41	840.76	1.57
	600	341.29	777.42	1.26	1.28	21.54	981.87	1.47
	700	353.35	862.87	1.32	1.30	19.72	1139.42	1.37

Temperature-dependent thermo-elastic properties of s-, p- and d-block liquid metals, R.N. Singh, S. Arafin, A.K. George, Physica B **387** 344–351 (2007)

Bolmatov (2012)

Liquid Rb



D. Bolmatov, V.V. Brazhkin, K. Trachenko, *The phonon theory of liquid thermodynamics,* Scientific reports, **2**, 421 (2012)

Bryk (2013)

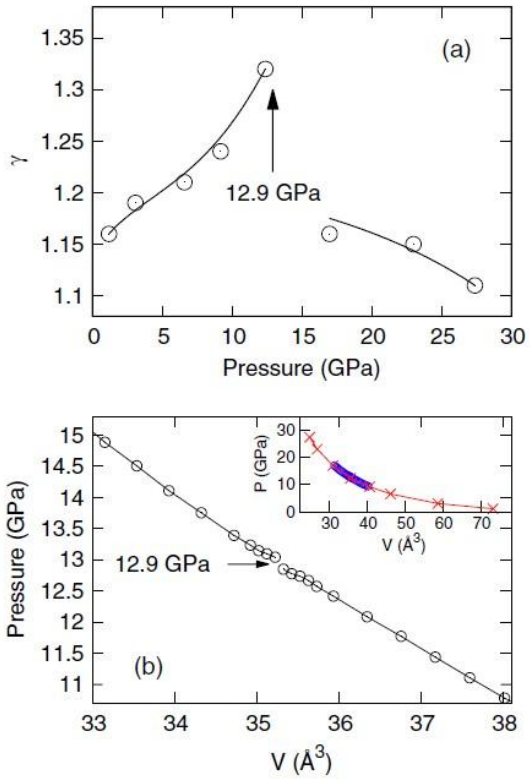


FIG. 3 (color online). Thermodynamic properties of liquid Rb at 573 K, as a function of pressure. (a) The ratio of the specific heats γ versus pressure. Lines are guides for the eye. (b) P-V equation of state of liquid Rb at 573 K. The reduction of the P-V slope in the region about 12.9 GPa (arrow) corresponds to an increasing isothermal compressibility. In the inset, the full P-V curve is shown: results obtained from AIMD simulations with 300 (cross symbols) and 64 (plus symbols) particles.

T.Bryk *et al* PRL **111** 077801 (2013)

Belashchenko (2016)

Liquid Rb
(molecular dynamics (MD) using the interparticle potential EAM)

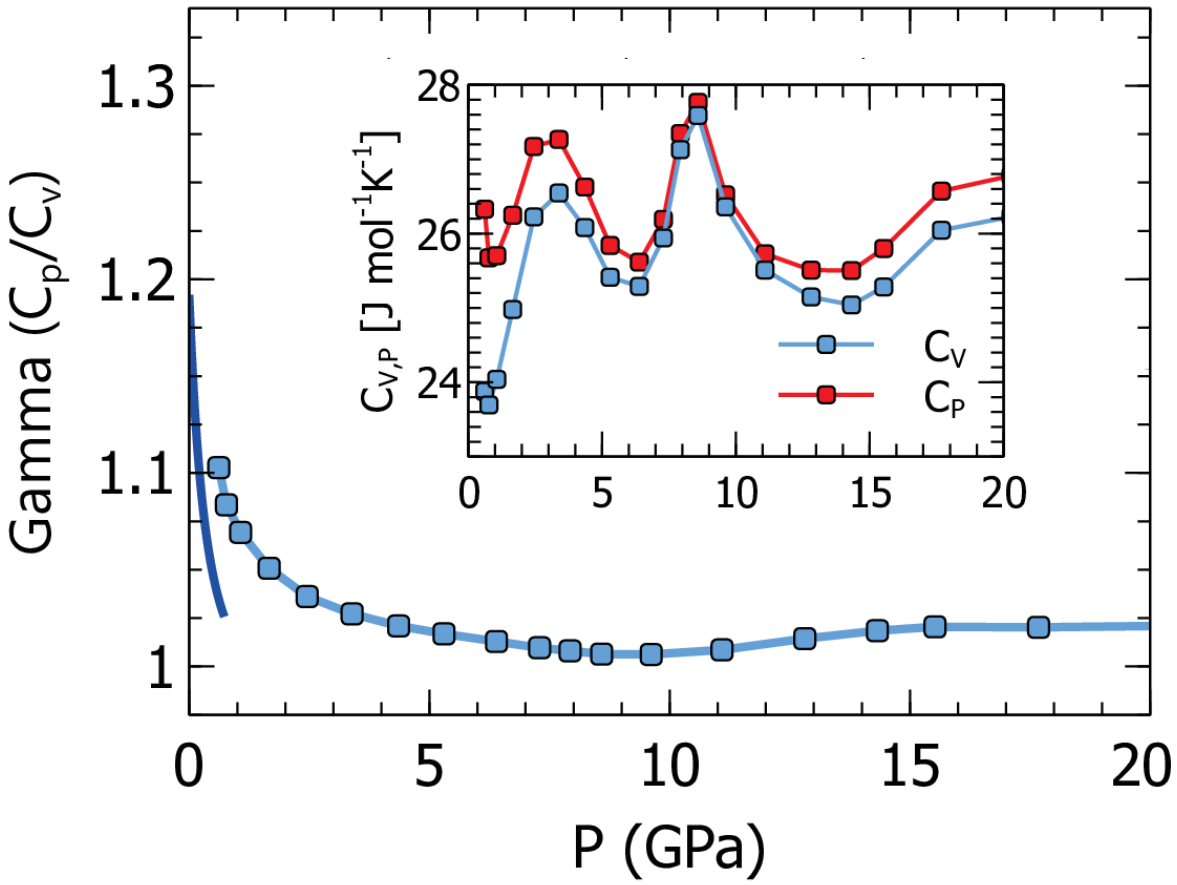
D. K. Belashchenko, *Russian Journal of Physical Chemistry A* **90**(9), 1707 (2016)

Table 4. Heat capacities C_V and C_p of the rubidium models; $V_0 = 55.861$ cm^3/mol

T, K	$Y = V/V_0$							
	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4
	Heat capacity C_V (J/mol. K)							
300	29.1	30.4	30.6	29.7	28.1	26.6	25.1	28.6
500	26.8	27.6	27.7	27.1	26.0	24.8	24.3	27.1
700	25.1	25.5	25.6	25.3	24.5	23.6	23.8	26.0
1000	23.5	23.7	23.8	23.6	23.2	22.7	23.3	24.9
2000	22.2	22.4	22.5	22.4	22.4	22.4	22.6	23.6
3000	22.6	22.5	22.4	22.4	22.4	22.3	22.7	23.5
3500	23.2	23.6	23.5	23.3	23.3	23.8	23.5	23.4
	Heat capacity C_p (J/mol. K)							
300	31.2	31.8	31.2	30.0	28.3	26.7	25.6	29.5
500	29.8	29.6	28.7	27.7	26.3	25.1	25.1	28.3
700	28.4	28.1	27.1	26.2	25.1	24.2	24.7	27.3
1000	27.6	27.0	25.9	25.2	24.4	23.7	24.4	26.1
2000	28.5	27.9	26.3	25.6	25.0	24.5	24.2	25.0
3000	30.7	29.7	27.7	26.8	25.9	25.1	24.8	25.3
3500	28.9	30.3	29.7	29.0	28.2	27.4	25.9	24.9

Ayrinhac (2020)

From AIMD simulations



S. Ayrinhac, V.N. Robinson, F. Decremps, M. Gauthier, D. Antonangeli, S. Scandolo, and M.Morand, *Phys. Rev. Materials* **4**, 113611 (2020)

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