Universality of Superconducting Transition Temperatures

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Abstract

It is hypothesized that superconducting transition temperatures are universal properties, which are amenable to a simple theoretical ansatz. The conjecture is supported by measured superconducting transition temperatures of many high quality samples. The experimental data contradict the mainstream view that an interaction between electrons and lattice vibrations is responsible for superconductivity.

Keywords: Superconductivity; transition temperature; universality; fundamental constants; number constants.

Based on various arguments, the author has calculated a heat energy to which all quantum particles of the vacuum couple. The temperature corresponding to this energy depends only on natural constants and is defined [1a] by $k_B\tau \equiv 2^{-17/4}\,(hc)^{3/4}$, where h is Planck's constant, c is the velocity of light in vacuum and k_B is Boltzmann's constant, which converts energy (J) into temperature (K). To get a unit consistent result, the kilogram (kg) must be replaced by ms^2. Based on the above definition, a value of ≈1133 K results for τ, which can also be used to calculate the cosmic microwave background temperature [2].

Like the exotic fractional quantum Hall effect, superconductivity is a cooperative phenomenon of a system of electrons. Both phenomena are not understood at the deepest level. It is conjectured that in both cases the origins rely on strong correlations of electrons. The fractionalization of the Hall resistance as a function of a magnetic field is a well-confirmed experimental fact. The physical origin behind this universal effect could also play a role in other areas of physics, such as the transition of a material from the normal state to the superconducting (zero resistive) state. Science has frequently shown that analogies can unify and thus simplify the description of seemingly different phenomena.

The derivation of τ is rooted on the nine-dimensional hypersphere. For this reason, 55 relatively prime fractions $\upsilon \equiv p/q$ were formed with the numbers $p, q \in \{1, 2\ldots.9\}$. The simple ansatz $\mathbf{T_c = \upsilon\,\kappa\,\tau}$ should apply to the critical temperature T_c, where the factor κ is a dimensionless measure of the pairing mechanism numerically specified by the numbers $(2\pi)^{-1}$, $\alpha/2$ or α^2. The parameter α is the Sommerfeld fine-structure constant defined by the number constant $\alpha \equiv 2^{-6}\pi^{-2/3}$ [1b]. Putting everything together results in the set of critical temperatures T_c listed in ascending order in Table 1. The ansatz implies that superconductivity is driven by a universal mechanism that is not connected with electron-phonon interactions, but with the formation of electron pairs due to electromagnetic correlations.

Yang et al. 2000 [3] found that the correlation between T_c and the doping level evolved from a continuous parabola to discontinuous steps after oxidizing the single crystals. Table 1 may offer a rationale for explaining the observed phenomenon. Chu et al. 2015 [4] tabulated 80 transition temperatures T_c^{max} that have been achieved for various compound classes of high temperature ($T_c \geq 20$ K) superconductors. Assuming that the accuracy of the observed critical temperatures is ±1 K, 58% of the values of Chu et al. corresponds to values in Table 1. Data for 43 optimally doped, high temperature superconducting compounds listed by Harshman et al. 2015 [5] might provide another clue of the pattern of occurrence. In this case, 70% corresponds to values in Table 1 and support the notion that superconductivity relies on universal ingredients. It is worth mentioning that optimally doped materials are not necessarily homogeneous materials with sharp transitions.

The determination of T_c is fraught with many hurdles because poly crystals and single crystals inevitably contain some disordered domains, that is, contain inclusions of secondary phases, stacking faults or impurities. All this determines the T_c and the associated width of the superconducting transition. Ideal behavior is rare except for exceptionally pure single crystals. The T_c is not only sensitive to inhomogeneities of the sample that may span nanometer to mesoscopic scales, but also, to a precise determination and regulation of the temperature in the measurements. It is also important how the transition itself is determined from experimental data, and how well the thermal equilibrium between the thermometer and the sample is settled. An analysis of the existing literature is challenging and each compilation must be examined critically.

In order to support the hypothesis, the author collected data on critical temperatures of samples with different morphologies. The data are summarized without comments for “pure” elements in Table 2, for binaries in Table 3, for complex compounds in Table 4 and for high temperature superconductors ($T_c \geq 20$ K) in Table 5. It is up to the reader to judge to what extent these experiments support the conjecture $T_c = \upsilon\ \kappa\ \tau$ and encompass the critical temperatures with a unified description. Hopefully, additional data obtained on high purity, strain-free “perfect” specimens with sharp superconducting transitions ($\Delta T_c/T_c < 1/64$) will unequivocally determine what is the state of affairs. However, the width of a transition is not sufficient to assess the quality of a sample. Therefore, Table 1 could be a means of clarifying the influence of preparative conditions, microstructures, crystalline defects and stoichiometry on the superconducting transition temperature T_c. Even in the highest quality single crystal disordered domains are present that cannot be distinguished by X-ray spectroscopy or other measurement procedures.

Table 1: Universal set of critical temperatures T_c

υ	κ	T_c [K]	$\Delta T_c / T_c$ min
1/9	α^2	0.007	0.125
1/8	α^2	0.008	0.111
1/7	α^2	0.009	0.125
1/6	α^2	0.010	0.143
1/5	α^2	0.012	0.111
2/9	α^2	0.013	0.100
1/4	α^2	0.0150	0.111
2/7	α^2	0.017	0.125
1/3	α^2	0.0200	0.125
3/8	α^2	0.023	0.067
2/5	α^2	0.0240	0.063
3/7	α^2	0.0258	0.037
4/9	α^2	0.027	0.036
1/2	α^2	0.030	0.111
5/9	α^2	0.033	0.029
4/7	α^2	0.034	0.028
3/5	α^2	0.036	0.042
5/8	α^2	0.038	0.040
2/3	α^2	0.040	0.062
5/7	α^2	0.043	0.050
3/4	α^2	0.045	0.037
7/9	α^2	0.047	0.029
4/5	α^2	0.048	0.028
5/6	α^2	0.0501	0.029
6/7	α^2	0.0515	0.021
7/8	α^2	0.0526	0.0159
8/9	α^2	0.0534	***0.0156***
1	α^2	0.060	0.111
9/8	α^2	0.0676	0.0159
8/7	α^2	0.0687	***0.0156***
7/6	α^2	0.0701	0.020
6/5	α^2	0.072	0.028
5/4	α^2	0.075	0.029
9/7	α^2	0.077	0.028
4/3	α^2	0.080	0.036
7/5	α^2	0.084	0.048
3/2	α^2	0.090	0.067
8/5	α^2	0.096	0.042
5/3	α^2	0.1002	0.040
7/4	α^2	0.105	0.029
9/5	α^2	0.108	0.028
2	α^2	0.120	0.100
9/4	α^2	0.135	0.037
9	α^2	0.541	0.047
1/7	$\alpha/2$	0.589	0.082
1/6	$\alpha/2$	0.688	0.143
1/5	$\alpha/2$	0.825	0.111
2/9	$\alpha/2$	0.917	0.100
1/4	$\alpha/2$	1.031	0.111
2/7	$\alpha/2$	1.179	0.125
1/3	$\alpha/2$	1.38	0.125
3/8	$\alpha/2$	1.55	0.067
2/5	$\alpha/2$	1.65	0.063
3/7	$\alpha/2$	1.768	0.037
4/9	$\alpha/2$	1.83	0.036
1/2	$\alpha/2$	2.06	0.111
5/9	$\alpha/2$	2.29	0.029
4/7	$\alpha/2$	2.357	0.028
3/5	$\alpha/2$	2.48	0.042
5/8	$\alpha/2$	2.58	0.040
2/3	$\alpha/2$	2.75	0.063
5/7	$\alpha/2$	2.95	0.050
3/4	$\alpha/2$	3.09	0.037
7/9	$\alpha/2$	3.21	0.029
4/5	$\alpha/2$	3.300	0.028
5/6	$\alpha/2$	3.438	0.029
6/7	$\alpha/2$	3.54	0.021
7/8	$\alpha/2$	3.61	0.0159
8/9	$\alpha/2$	3.667	***0.0156***
1	$\alpha/2$	4.125	0.111
9/8	$\alpha/2$	4.64	0.0159
8/7	$\alpha/2$	4.71	***0.0156***
7/6	$\alpha/2$	4.81	0.020
6/5	$\alpha/2$	4.95	0.028
5/4	$\alpha/2$	5.16	0.029
9/7	$\alpha/2$	5.30	0.028
4/3	$\alpha/2$	5.50	0.036
7/5	$\alpha/2$	5.78	0.048
3/2	$\alpha/2$	6.19	0.067
8/5	$\alpha/2$	6.60	0.042
5/3	$\alpha/2$	6.88	0.040
7/4	$\alpha/2$	7.22	0.029
9/5	$\alpha/2$	7.43	0.028
2	$\alpha/2$	8.25	0.100
9/4	$\alpha/2$	9.282	0.037
7/3	$\alpha/2$	9.63	0.036
1/6	$(2\pi)^{-1}$	30.0	0.039
8	$\alpha/2$	33.0	0.090
1/5	$(2\pi)^{-1}$	36.1	0.030
9	$\alpha/2$	37.1	0.029
2/9	$(2\pi)^{-1}$	40.1	0.073
1/4	$(2\pi)^{-1}$	45	0.111
2/7	$(2\pi)^{-1}$	52	0.125
1/3	$(2\pi)^{-1}$	60.1	0.125
3/8	$(2\pi)^{-1}$	68	0.067
2/5	$(2\pi)^{-1}$	72	0.063
3/7	$(2\pi)^{-1}$	77.3	0.037
4/9	$(2\pi)^{-1}$	80.1	0.036
1/2	$(2\pi)^{-1}$	90.1	0.111
5/9	$(2\pi)^{-1}$	100	0.029
4/7	$(2\pi)^{-1}$	103	0.028
3/5	$(2\pi)^{-1}$	108	0.042
5/8	$(2\pi)^{-1}$	113	0.040
2/3	$(2\pi)^{-1}$	120	0.062
5/7	$(2\pi)^{-1}$	129	0.050
3/4	$(2\pi)^{-1}$	135	0.037
7/9	$(2\pi)^{-1}$	140	0.029
4/5	$(2\pi)^{-1}$	144	0.028
5/6	$(2\pi)^{-1}$	150	0.029
6/7	$(2\pi)^{-1}$	155	0.021
7/8	$(2\pi)^{-1}$	158	0.0159
8/9	$(2\pi)^{-1}$	160	***0.0156***
1	$(2\pi)^{-1}$	180	0.111
9/8	$(2\pi)^{-1}$	203	0.0159
8/7	$(2\pi)^{-1}$	206	***0.0156***
7/6	$(2\pi)^{-1}$	210	0.020
6/5	$(2\pi)^{-1}$	216	0.028
5/4	$(2\pi)^{-1}$	225	0.029
9/7	$(2\pi)^{-1}$	232	0.028
4/3	$(2\pi)^{-1}$	240	0.036
7/5	$(2\pi)^{-1}$	252	0.048
3/2	$(2\pi)^{-1}$	270	0.067
8/5	$(2\pi)^{-1}$	288	0.042
5/3	$(2\pi)^{-1}$	300	0.040
7/4	$(2\pi)^{-1}$	315	0.029
9/5	$(2\pi)^{-1}$	324	0.028
2	$(2\pi)^{-1}$	361	0.100
9/4	$(2\pi)^{-1}$	406	0.037
7/3	$(2\pi)^{-1}$	421	0.036

υ	κ	T_c [K]	$\Delta T_c / T_c$ min
7/3	α^2	0.1402	0.036
5/2	α^2	0.150	0.067
8/3	α^2	0.1603	0.062
3	α^2	0.180	0.111
7/2	α^2	0.210	0.143
4	α^2	0.240	0.125
9/2	α^2	0.270	0.111
5	α^2	0.300	0.100
6	α^2	0.361	0.167
7	α^2	0.421	0.090
1/9	α/2	0.458	0.049
8	α^2	0.481	0.047
1/8	α/2	0.516	0,049
5/2	α/2	10.31	0.067
8/3	α/2	11.0	0.063
3	α/2	12.4	0.111
7/2	α/2	14.4	0.143
4	α/2	16.5	0.125
9/2	α/2	18.6	0.079
1/9	$(2\pi)^{-1}$	20.0	0.030
5	α/2	20.6	0.029
1/8	$(2\pi)^{-1}$	22.5	0.085
6	α/2	24.8	0.040
1/7	$(2\pi)^{-1}$	25.8	0.039
7	α/2	28.9	0.040
5/2	$(2\pi)^{-1}$	451	0.067
8/3	$(2\pi)^{-1}$	481	0.062
3	$(2\pi)^{-1}$	541	0.111
7/2	$(2\pi)^{-1}$	631	0.143
4	$(2\pi)^{-1}$	721	0.125
9/2	$(2\pi)^{-1}$	811	0.111
5	$(2\pi)^{-1}$	901	0.100
6	$(2\pi)^{-1}$	1082	0.167
7	$(2\pi)^{-1}$	1262	0.143
8	$(2\pi)^{-1}$	1442	0.125
9	$(2\pi)^{-1}$	1622	0.111

Note: The dimensionless transition width $\Delta T_c/T_c$ indicates the smallest temperature difference to the neighboring critical temperatures. The inequality $1/64 \leq \Delta T_c/T_c \leq 1/6$ applies.

Table 2: Elements

Element [a]		experiment [K]	Conj [b] [K]	T_c^{χ} [c] [K]	T_c^{C} [d] [K]	T_c^{ρ} [e] [K]	ΔT_c^{ρ} [f] [K]	varia	ref
W morphol. unknown		0.0152(1) [g]	0.0150						[6]
Be morphol. unknown		0.0201(1) [g]	0.0200						[6]
Be		0.0244	0.0240	x					[7]
Be morphol. unknown		0.026	0.0258	x					[8]
Ir morphol. unknown		0.0990(5) [g]	0.1002						[6]
Ir polycr. melt		0.140	0.1402	x					[9]
Pa^{231}		0.430	0.421	x					[10]
Ti		0.480	0.481	x					[11]
Cd		0.518	0.516		x				[12]
Ti morphol. unknown		0.511(5)	0.516	x					[13]
Ru polycr. melt		0.509(2)	0.516		x				[14]
Os polycr. melt		0.71(2)	0.69	x					[15]
Zn		0.825	0.825		x				[16]
Mo		0.917 0.830	0.917 0.825		x				[17]
α-Ga polycr.		1.078	1.031		x				[12]
Al morphol. unknown		1.178(2) [g]	1.179						[6]
Th polycr. melt		1.374(1)	1.375		x				[18]
SIC-Pb / Si(111) epitaxial		1.83	1.83					STM	[19]
Tl^{205}		2.386(1)	2.357	x					[20]
Cr / MgO(001) epitaxial		3.20	3.21			x		50nm	[21]
Pd irradiated		3.20	3.21			x		T_c max	[22]
In^{113} polycr. melt		3.433	3.438	x					[23]
In		3.431(1)	3.438	x				Tl	
Sn^{123}		3.6669	3.6669	x					[24]
Sn^{124}		3.666(3)	3.667	x				Tl	
α-$Hg^{203.4}$ morphol. unknown		4.126	4.125	x					[25]
dhcp-La polycr.		5.04	4.95		x				[26]
V		5.13	5.16	x					[27]
V zone melting		5.31(4)	5.30	x					[28]
Pb / Si(111) epitaxial	5L	5.75	5.78			5.9	0.3	double coil	[29]
β-Ga nanowire array		6.2	6.19	x					[30]
Pb		7.191(2)	7.219					μSR	[31]
Pb porous glass nanocomposite		7.22	7.219	x					[32]
bcc-Te phase boundary		7.4	7.43			x		@ 35 GPa	[33]
Nb		9.288(2)	9.282	x					[34]
β-Zr polycr. foil @ 30 GPa		11.0	11.0			x		T_c max	[35]

Table 3: Binaries

Compound [a]		experiment [K]	Conj [b] [K]	T_c^{χ} [c] [K]	T_c^{C} [d] [K]	T_c^{ρ} [e] [K]	ΔT_c^{ρ} [f] [K]	varia	ref
$AuAl_2$ morphol. unknown		0.1607(5) [g]	0.1603						[6]
$AuIn_2$ morphol. unknown		0.208(1) [g]	0.210						[6]
$TaSi_2$		0.345(10)	0.361	0.345(10)	0.353(3)				[36]
TiO/MgO(001) epitaxial		0.45	0.458			x			[37]
UPt_3		0.514	0.516		x			doublet	[38]
		0.460	0.458					figure 4.2	
UPt_3		0.543(2)	0.541		x			doublet	[39]
		0.489(2)	0.481						
WP		0.84	0.825	0.84		0.85	0.02		[40]
$NbSe_2$/6H-SiC epitaxial	1L	0.920	0.917					STS	[41]
$CoSi_2$		1.03	1.031			x			[42]
$CaSn_3$		1.178	1.179		x				[43]
NbO polycr. melt		1.38	1.38	x					[44]
$Ba_{24}Si_{100}$ polycr.		1.55	1.55	x					[45]
$PdTe_2$		1.64	1.65	x					[46]
SrC_6		1.65	1.65	1.65	1.65				[47]
UTe_2	S2	1.68(3)	1.65		x				[48]
	S3	1.77(3)	1.77						
	S4	1.85(3)	1.83						
	S6	2.00(4)	2.06						
UTe_2		2.05	2.06		2.05	x			[49]
OsB_2		2.06	2.06	2.06	2.1				[50]
$NbGe_2$		2.06	2.06		x	2.05	0.07		[51]
$WB_{4.2}$ polycr.		2.05	2.06	2.0	2.05	2.25	0.2		[52]
$AuSn_4$		2.35	2.36			x			[53]
LiBi		2.48	2.48	2.38	2.48				[54]
Bi-metal graphite		2.48(2)	2.48	x					[55]
$Fe^{10}B_4$ polycr.		2.95	2.95	x					[56]
2H-TaS_2 exfoliation	2L	3.0	2.95	x					[57]
	3L	2.5	2.48						
	5L	2.05	2.06						
Pb_2Pd		2.95	2.95	2.85(10)	2.95	3.0	0.1		[58]
$LaAl_2$		3.301(2)	3.300	x					[59]
BeAu polycr.		3.3	3.30	3.3	3.3	3.3	0.05		[60]
KBi_2		3.57	3.54	3.52	3.57	3.55	0.1		[61]
$PdBi_{1-x}$		3.5	3.54	3.5		3.5	0.15	x=0.07	[62]
$CaSn_3$		4.15	4.13	4.15		4.2	0.2		[63]
IrGe polycr.		4.74(3)	4.71	4.74	4.6	4.7(1)	0.1		[64]
β-Bi_2Pd		4.95(5)	4.95		4.95(5)	5.0	0.1		[65]
β-Bi_2Pd		4.9	4.95		4.8	5.0	0.02		[66]
IrGe polycr.		5.17	5.16		5.17	5.5	0.5		[67]
2H-$NbSe_2$		6.90	6.88			x			[68]
2H-$NbSe_2$		7.20	7.22			7.20			[69]
TaC		10.3	10.31	10.3	9.7	10.7	0.4		[70]
NbN/SiC epitaxial		16.5	16.50			x		50nm	[71]

Table 4: Complex compounds

Compound [a]	experiment [K]	Conj [b] [K]	T_c^{χ} [c] [K]	T_c^{C} [d] [K]	T_c^{ρ} [e] [K]	ΔT_c^{ρ} [f] [K]	varia	ref
$Ag_5Pb_2O_6$	0.0524	0.0526	x					[72]
$CePt_3Si$	0.46	0.458		0.46	0.8	0.05		[73]
Sr_2RuO_4	1.03	1.031					mag. rel.	[74]
	0.050	0.0501						
$LaTr_2Al_{20}$ Tr = Ta	1.03(2)	1.031		x				[75]
Tr = Nb	1.05(2)	1.031		x				
Tr = Ti	0.46(1)	0.458		x				
Tr = V	0.15(2)	0.150		x				
$YNiSi_3$	1.36(3)	1.38	1.36(3)	1.35(5)	1.42(2)			[76]
$A_xV_2Al_{20}$ polycr. A_x=$Ge_{0.2}$	1.66	1.65		x				[77]
A_x=Y	0.69	0.688		x				
$(Au_{1-x}Pd_x)Ga_2$ polycr. melt	1.773(20)	1.768	x				x=0.07	[78]
$CeCoIn_5$	2.3	2.29		x				[79]
$PuCoIn_5$	2.5	2.48		x				[80]
$SnTaS_2$	2.97	2.95	2.97	2.88	3.00	0.05		[81]
$LiGa_2Ir$ polycr.	2.95	2.95	2.95	2.94	3.0	0.05		[82]
$La_3T_4Sn_{13}$ T = Rh	3.1	3.09	3.1	3.1				[89]
T = Ir	2.5	2.48	2.5	2.5				
$Ba(Ni_{1-x}Cu_x)_2As_2$	3.20	3.21	3.2	3.2			$x_{opt}\approx0.292$	[83]
$LaTr_2Al_{20}$ Tr = Mo	3.22	3.21		x				[84]
Tr = W	1.81	1.83		x				
$CaIrSi_3$	3.3	3.30		x				[85]
$BaNi_2(As_{1-x}P_x)_2$ phase boundary	3.3	3.30		3.3	3.35	0.05	$x_{opt}\approx0.077$	[86]
	0.7	0.69		x			x≈0.07	
$TlNi_2Se_2$	3.7	3.67	3.7	3.7	3.7	0.05		[87]
Bi_2PdPt	4.0(1)	4.13	3.99(2)		4.0(1)	0.1		[88]
$Sr_3T_4Sn_{13}$ T = Rh	4.15	4.13	4.2	4.15				[89]
T = Ir	4.95	4.95	5.0	4.95				
$Sc_5Rh_6Sn_{18}$	4.8	4.81	5.0	4.8				[90]
	5.15	5.16		4.97			μSR	[91]
$Y_7Ru_4InGe_{12}$	5.8	5.78	5.8		5.8	0.2		[92]
$DyNi_2B_2C$	6.2(1)	6.19	6.1		6.4	0.4		[93]
$MgCNi_3$	6.85	6.88		x				[94]
β-$ThRh_{1-x}Ir_xGe$ polycr.	6.88	6.88	x				x_{opt}=0.5	[95]
$W_7Re_{13}B$ polycr.	7.22(2)	7.22	7.22(2)		7.3	0.1		[96]
$LaRu_4P_{12}$ powdered	7.20	7.22	x					[97]
Mo_5Ge_2P polycr.	8.24	8.25		x				[98]
$LaRu_4As_{12}$ polycr.	10.3	10.31		10.3	10.6	0.6		[99]
$TmNi_2B_2C$ isotopically enriched B	11 [g]	11.0						[100]
$LiTi_2O_4$ / $MgAl_2O_4$ epitaxial	11.00(25)	11.00					tunnelling	[101]
$Fe_{1+y}Te_{0.6}Se_{0.4}$	14.5	14.4		x			T_c opt	[102]
$PuCoGa_5$	18.5	18.6	18.5	18.5	18.6	0.4		[103]

Table 5: Superconductors with $T_c \geq 20$ K

Compound [a]	experiment [K]	Conj [b] [K]	T_c^{χ} [c] [K]	T_c^{C} [d] [K]	T_c^{ρ} [e] [K]	ΔT_c^{ρ} [f] [K]	varia	ref
K_3C_{60}	19.8	20.0			19.8	0.2		[104]
$BaFe_{2-x}Ni_xAs_2$	20.5	20.0 20.6			20.5	1	$x_{opt}\approx 0.096$	[105]
$YPd_5B_3C_{0.3}$ polycr.	22.6	22.5	22.6		23	1		[106]
$Ba_{1-x}Rb_xFe_2As_2$	22.6(2)	22.5	x				$x_{opt}\approx 0.1$	[107]
$Ba(Fe_{1-x}Co_x)_2As_2$	25.5	25.8			25.5	0.7	$x_{opt}\approx 0.063$	[108]
$BaFe_2(As_{1-x}P_x)_2$	29.2	28.9		x			$x_{opt}\approx 0.3$	[109]
	30.0	30.0	30.0		30.0	0.4	$x_{opt}\approx 0.33$	[110]
$CsCa_2Fe_4As_4F_2$	30.0	30.0	29.4		30.0	0.6		[111]
$CaKFe_4As_4$ polycr.	33.2	33.0	x					[112]
$EuRbFe_4As_4$	36.5	36.1	36.5		36.7	0.4		[113]
MgB_2 polycr. grains	37.25 mean	37.13	x					[114]
	37.1		x					[115]
MgB_2/Al_2O_3 epitaxial	40.2	40.1			40.2	0.15	1.3µm	[116]
$SmFeAsO_{0.8}F_{0.2}$	45(1)	45.1	x					[117]
$PrFeAsO_{1-y}$	45	45.1	x					[118]
Li^+ - FeSe nanoflake	45.0	45.1			x		T_c opt	[119]
PdH_x morphol. unknown	52	52			x		figure 4-7	[120]
$NdFeAsO_{1-y}$ polycr.	53	52	x				T_c saturation	[121]
	33	33.0	x				T_c boundary	
$YBa_2Cu_3O_{6+x}$	61(2) [g]	60.1					x≈0.60	[122]
	90(1) [g]	90.1					x=1	
PdD_x morphol. unknown	60	60.1			x		figure 4-8	[120]
$PrBa_2Cu_3O_x$	80	80.1	x					[123]
$YBa_2Cu_3O_{7-\delta}$ single phase	90 [g]	90.1					T_c max	[124]
$Bi_2Sr_2CaCu_2O_{8+\delta}$	90	90.1	x				T_c max	[125]
	77	77.3					T_c min	
FeSe/$SrTiO_3$(001) epitaxial 1L	100	100			100	1	figure S4	[126]
	109	108			x		figure 3b	
$(Cu,C)Ba_2Ca_3Cu_4O_{11+\delta}$	112	113	112		111	1.4		[127]
Hg-1223 polycr.	135 [g]	135						[128]
Hg-1234 polycr.	120 [g]	120					annealed	
Hg-1212 polycr	104 [g]	103					as prepared	
Hg-1256 polycr.	100 [g]	100					annealed	
Hg-1245 polycr.	101 [g]						as prepared	
SH_x morphol. unknown @ 155 GPa	203(1)	203	203(1)				figure 4a	[129]
$LuH_{3-\delta}N_{\varepsilon}$ morphol. unknown @ 16kbar	269	270	269		269	2	figure 12	[130]
thin film resistor amorphous	408 [h]	406			408	<5	figure 16.23	[1c]

Notes to the tables 2 – 5

a) Samples are single crystals unless otherwise noted.
b) The corresponding υ, κ and ΔT_c / T_c can be found in Table 1.
c) Defined as the onset of the diamagnetism.
d) Determined by specific heat using an equal-area entropy construction.
e) Defined as the temperature T_c^ρ (onset) at which ρ begins to deviate from the normal-state behavior.
f) The width ΔT_c of the superconducting transition given by the difference T_c^ρ (onset) and T_c^ρ (ρ=0).
g) Measurement method unknown.
h) Transient, exceptionally low resistivity in a four-point measurement.

References

[1] On the Origin of Natural Constants
Hans Peter Good, De Gruyter Berlin (2018)
a) p. 111, b) p. 42, c) p. 236

[2] Hans Peter Good viXra 2201.0187 (2022)

[3] Discrete superconducting transition temperatures and pronounced Tc depression related of the 1/8 problem in $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$ single crystals.
WL Yang et al Phys Rev B **62** 1361 (2000)

[4] Hole-Doped Cuprate High Temperature Superconductors.
CW Chu et al Phys C Supercond Appl **514** 290 (2015)

[5] Superconducting interaction charge in thallium-based high-TC cuprates: Roles of cation oxidation state and electronegativity.
DR Harshman et al J Phys Chem Solids **85** 106 (2015)

[6] Evaluation of SRD1000 Superconductive Reference Devices.
S Schöttl et al J Low Temp Phys **138** 941 (2005)

[7] The superconductive critical magnetic field of beryllium.
RJ Soulen et al J Low Temp Phys **124** 515 (2001)

[8] Superconductivity of hexagonal beryllium.
RL Falge Phys Lett A **24** 579 (1967)

[9] Superconductivity of Iridium.
RA Hein et al Phys Rev Lett **8** 408 (1962)

[10] Superconducting Properties of Protactinium.
JL Smith et al Science **205** 188 (1979)

[11] Fully Automated AC Susceptometer for milli-Kelvin Temperatures in a DynaCool PPMS.
A Amann et al IEEE Trans Appl Supercond **27** 1 (2017)

[12] Low-Temperature Heat Capacities of Gallium, Cadmium, and Copper.
NE Phillips Phys Rev **134** A385 (1964)

[13] Investigation of the titanium superconducting transition as a temperature reference point
A Peruzzi et al Metrologia **37** 229 (2000)

[14] Critical Magnetic Fields of Superconducting Ruthenium Isotopes and Search for an Isotope Effect
JW Gibson et al Phys Rev **141** 407 (1966)

[15] Superconducting Properties of Rhenium, Ruthenium, and Osmium
JK Hulm et al Phys Rev **106** 659 (1957)

[16] Heat Capacity of Superconducting Zinc
NE Phillips Phys Rev Lett **1** 363 (1958)

[17] Thermodynamic Properties of Molybdenum in Its Superconducting and Normal State
DC Rorer et al Phys Rev **138** A1661 (1965)

[18] Superconductivity of Thorium and Uranium
JE Gordon et al Phys Rev **152** 432 (1966)

[19] Superconductivity in one-atomic-layer metal films grown on Si(111)
T Zhang et al Nature Physics **6** 104 (2010)

[20] Threshold field properties of some superconductors
E Maxwell Phys Rev **95** 333 (1954)

[21] The electrical resistivity of epitaxially deposited chromium films
M Sawabu et al J Phys Conf Ser **871** 012002 (2017)

[22] Superconductivity in irradiated palladium
B Stritzker Phys Rev Lett **42** 1769 (1979)

[23] I. Similarity principle and isotope effect in superconducting indium. II. Low-temperature heat capacity of niobium.
SN Mehmet LBNL, University of California, Berkeley (1965)

[24] Superconductivity of the isotopes of tin
E Maxwell Phys Rev **86** 235 (1952)

[25] Superconductivity of Isotopes of Mercury
CA Reynolds et al Phys Rev **78** 487 (1950)

[26] Heat capacity of high-purity lanthanum
PH Pan et al Phys Rev B **21** 2809 (1980)

[27] Superconductivity of Vanadium
A Wexler et al Phys Rev **85** 85 (1952)

[28] Superconductivity of vanadium
RB Martin et al Physics Letters **19** 467 (1965)

[29] Ultrathin two-dimensional superconductivity with strong spin–orbit coupling
H Nam et al PNAS **113** 10513 (2016)

[30] Superconducting Properties in Arrays of Nanostructured β-Gallium
KO Moura et al Scientific Reports **7** 15306 (2017)

[31] Isotropic single-gap superconductivity of elemental Pb
R Khasanov et al Phys Rev B **104** L100508 (2021)

[32] Double peaks on ac magnetization in a superconducting Pb-porous glass nanocomposite
YS Ciou et al Physics Letters A **374** 4942 (2010)

[33] Pressure-induced superconductivity and phase transition in selenium and tellurium
Y Akahama et al Solid State Commun **84** 803 (1992)

[34] Investigation of the superconducting transition of ultra-high-purity niobium
B Fellmuth et al Physica Status Solidi A **100** 597 (1987)

[35] Superconductivity and phase transition of zirconium under high pressure up to 50 GPa
Y Akahama et al J Phys Soc Jpn **59** 3843 (1990)

[36] Superconductivity in $TaSi_2$ single crystals
U Gottlieb et al Phys Rev B **45** 4803 (1992)

[37] Single-crystalline epitaxial TiO film: A metal and superconductor, similar to Ti metal
F Li et al Sci Adv **7** eabd4248 (2021)

[38] Visualization of Chiral Superconductivity in UPt_3
P Garcia-Campos, Université Grenoble-Alpes, page 77 (2021)

[39] On the interplay of small-moment magnetism and superconductivity in UPt_3
A de Visser et al J Magn Magn Mater **177** 287 (1998)

[40] Superconductivity in WP single crystal
Z Liu et al Phys Rev B **99** 184509 (2019)

[41] Disorder-induced multifractal superconductivity in monolayer niobium dichalcogenides
K Zhao et al Nature Physics **15** 904 (2019)

[42] The high residual resistivity of $CoSi_2$: Evidence for a homogeneity range
A Briggs et al Appl Surf Sci **38** 88 (1989)

[43] Emergence of intrinsic superconductivity below 1.178 K in the topologically non-trivial semimetal state of $CaSn_3$
YL Zhu et al J Phys Condens Matter **31** 245703 (2019)

[44] Superconductivity in the TiO and NbO systems
JK Hulm J Low Temp Phys **7** 291 (1972)

[45] Superconductivity in the $Ba_{24}Si_{100}$ cubic clathrate with sp^2 and sp^3 silicon bondings
R Viennois et al J Phys Condens Matter **17** L311 (2005)

[46] Type I superconductivity in the Dirac semimetal $PdTe_2$
H Leng et al Phys Rev B **96** 220506 (2017)

[47] Superconductivity in Heavy Alkaline-Earth Intercalated Graphites
JS Kim et al Phys Rev Lett **99** 027001 (2007)

[48] Single thermodynamic transition at 2 K in superconducting UTe_2 single crystals
PFS Rosa et al Commun Mater **3** 33 (2022)

[49] First Observation of de Haas-van Alphen Effect and Fermi Surfaces in Unconventional Superconductor UTe_2
D Aoki et al J Phys Soc Jpn **91** 083704 (2022)

[50] Multigap superconductivity and Shubnikov-de Haas oscillations in single crystals of the layered boride OsB_2
Y Singh et al Phys Rev B **82** 144532 (2010)

[51] Fermiology and type-I superconductivity in the chiral superconductor $NbGe_2$ with Kramers-Weyl fermions
E Emmanouilidou et al Phys Rev B **102** 235144 (2020)

[52] Superconductivity in the superhard boride $WB_{4.2}$
EM Carnicom et al Supercond Sci Technol **31** 115005 (2018)

[53] Superconductivity and band structure of layered $AuSn_4$
E Herrera et al arXiv 2205.09975

[54] Superconductivity on a Bi Square Net in LiBi
K Górnicka et al Chem Mater **32** 3150 (2020)

[55] Magnetic-field-induced superconductor–metal insulator transitions in bismuth metal graphite
M Suzuki et al Phys Rev B **66** 014533 (2002)

[56] Discovery of a superhard iron tetraboride superconductor
H Gou et al Phys Rev Lett **111** 157002 (2013)

[57] Enhanced superconductivity upon weakening of charge density wave transport in 2H-TaS_2 in the two dimensional limit
Y Yang et al Phys Rev B **98** 035203 (2018)

[58] Type-I superconductivity in single crystal Pb_2Pd
K Arushi et al Phys Rev B **103** 184506 (2021)

[59] Magnetization of superconducting $LaAl_2$ single crystal
B Vlcek et al Jpn J Appl Phys **26** 967 (1987)

[60] Noncentrosymmetric superconductor BeAu
A Amon et al Phys Rev B **97** 014501 (2018)

[61] Type-I superconductivity in KBi_2 single crystals
S Sun et al J Phys Condens Matter **28** 085701 (2016)

[62] Crystal growth and physical properties of the noncentrosymmetric superconductor PdBi
K Okawa et al Physics Procedia **45** 101 (2013)

[63] Nematic superconductivity in the topological semimetal $CaSn_3$
H Siddiquee et al Phys Rev B **105** 094508 (2022)

[64] Microscopic investigation of the superconducting properties of the strongly coupled superconductor IrGe via μSR
Arushi et al Phys Rev B **105** 054517 (2022)

[65] Single gap superconductivity in β-Bi_2Pd
J Kačmarčík et al Phys Rev B **93** 144502 (2016)

[66] Superconducting gap of the single crystal β-$PdBi_2$
H Matsuzaki et al J Phys Conf **871** 012004 (2017)

[67] Strong Electron-Phonon Coupling Superconductivity Induced by a Low-lying Phonon in IrGe
D Hirai et al J Phys Soc Jpn **82** 124701 (2013)

[68] Ising pairing in superconducting $NbSe_2$ atomic layers
X Xi et al Nature Physics **12** 139 (2016)

[69] Charge density wave and superconductivity in 2H- and 4H-$NbSe_2$: A revisit
I Naik et al Pramana **76** 957 (2011)

[70] Superconductivity in centrosymmetric topological superconductor candidate TaC
DY Yan et al Supercond Sci Technol **34** 035025 (2021)

[71] An all-epitaxial nitride heterostructure with concurrent quantum Hall effect and superconductivity
P Dang et al Sci Adv **7** eabf1388 (2021)

[72] Type-I superconductivity of the layered silver oxide $Ag_5Pb_2O_6$
S Yonezawa et al Phys Rev B **72** 180504(R) (2005)

[73] Multiband Superconductivity in Heavy Fermion Compound $CePt_3Si$ without Inversion Symmetry: An NMR Study on a High-Quality Single Crystal
H Mukuda et al J Phys Soc Jpn **78** 014705 (2009)

[74] Transition into a low temperature superconducting phase of unconventional pinning in Sr_2RuO_4
AC Mota et al Phys B Condens Matter **259** 934 (1999)

[75] Superconductivity in Cage Compounds $LaTr_2Al_{20}$ with Tr = Ti, V, Nb, and Ta
A Yamada et al J Phys Soc Jpn **87** 033707 (2018)

[76] Superconductivity in monocrystalline $YNiSi_3$ and $LuNiSi_3$
FR Arantes et al Phys Rev B **99** 224505 (2019)

[77] Superconductivity in an Einstein Solid $A_xV_2Al_{20}$ (A = Al and Ga)
A Onosaka et al J Phys Soc Jpn **81** 023703 (2012)

[78] Superconducting properties of AuGa and $AuGa_2$ compounds
RH Hein et al J Less Common Met **62** 197 (1978)

[79] Heavy-fermion superconductivity in $CeCoIn_5$ at 2.3 K
C Petrovic et al J Phys Condens Matter **13** L337 (2001)

[80] Localized 5f electrons in superconducting $PuCoIn_5$: consequences for superconductivity in $PuCoGa_5$
ED Bauer et al J Phys Condens Matter **24** 052206 (2012)

[81] Superconducting properties in a candidate topological nodal line semimetal $SnTaS_2$ with a centrosymmetric crystal structure
DY Chen et al Phys Rev B **100** 064516 (2019)

[82] Superconductivity in $LiGa_2Ir$ Heusler type compound with VEC = 16
K Górnicka et al Scientific Reports **11** 16517 (2021)

[83] Copper Doping of $BaNi_2As_2$: Giant Phonon Softening and Superconductivity Enhancement
K Kudo et al arxiv 1704.04854v1

[84] Superconductivity enhanced by d-band filling in $LaTr_2Al_{20}$ with Tr = Mo and W
R Miyawaki et al arXiv 2009.13952v1

[85] Large spin-orbit splitting and weakly anisotropic superconductivity revealed with single-crystalline noncentrosymmetric $CaIrSi_3$
G Eguchi et al Phys Rev B **86** 184510 (2012)

[86] Giant Phonon Softening and Enhancement of Superconductivity by Phosphorus Doping of $BaNi_2As_2$
K Kudo et al Phys Rev Lett **109** 097002 (2012)

[87] Multiband Superconductivity of Heavy Electrons in $TlNi_2Se_2$ single crystal
H Wang et al Phys Rev. Lett **111** 207001 (2013)

[88] Superconductivity in Bi based Bi_2PdPt
A Kataria et al Mater Adv **3** 5375 (2022)

[89] Superconducting state in the ternary stannide superconductors $R_3T_4Sn_{13}$ (R = La, Sr; T = Rh, Ir) with a quasiskutterudite structure
N Kase et al Phys Rev B **83** 184509 (2011)

[90] Superconducting gap structure of the cage compound $Sc_5Rh_6Sn_{18}$
N Kase et al J Phys Soc Jpn **81** SB016 (2012)

[91] Conventional isotropic s-wave superconductivity with strong electron-phonon coupling in $Sc_5Rh_6Sn_{18}$
M Feig et al Phys Rev B **102** 024508 (2020)

[92] Superconductivity in $Y_7Ru_4InGe_{12}$
JK Bao et al Phys Rev Materials **3** 024802 (2019)

[93] Onset of superconductivity in the antiferromagnetically ordered state of single-crystal $DyNi_2B_2C$
BK Cho et al Phys Rev B **52** R3844 (1995)

[94] Specific heat of superconducting MgCNi3 single crystals
J Kacmarcík et al J Phys Conf Ser **150** 052087 (2009)

[95] Enhancement of superconductivity on the verge of a structural instability in isovalently doped β-$ThRh_{1-x}Ir_xGe$
G Xiao et al npj Quantum Materials **7** 57 (2022)

[96] Magnetic, transport and high-pressure properties of a $W_7Re_{13}B$ superconducting compound
B Andrzejewski et al Supercond Sci Technol **20** 728 (2007)

[97] Magnetic Field Effect on s-wave Superconductor $LaRu_4P_{12}$ Studied by ^{31}P-NMR
K Kinjo et al J Phys Soc Jpn **88** 065002 (2019)

[98] Tunable Superconductivity in Phosphorus-Doped Topological Transition-Metal Germanide Mo_5Ge_3
G Xiao et al Adv Quantum Technol **5** 2200097 (2022)

[99] Superconducting Properties of $LaRu_4As_{12}$ synthesized at high pressure
T Namiki et al J Phys Soc Jpn **77** 336 (2008)

[100] Intertwined symmetry of the magnetic modulation and the flux-line lattice in the superconducting state of $TmNi_2B_2C$
MR Eskildsen et al Nature **393** 242 (1998)

[101] Anomalous magnetoresistance in the spinel superconductor $LiTi_2O_4$
K Jin et al Nat Commun **6** 7183 (2015)

[102] Dynamics and mechanism of oxygen annealing in $Fe_{1+y}Te_{0.6}Se_{0.4}$ single crystal
Yue Sun et al Scientific Reports **4** 4585 (2014)

[103] Plutonium-based superconductivity with a transition temperature above 18 K
JL Sarrao et al Nature **420** 297 (2002)

[104] Synthesis and Electronic Transport of single Crystal K_3C_{60}
XD Xiang et al Science **256** 1190 (1992)

[105] Superconductivity induced by Ni doping in $BaFe_2As_2$ single crystals
LJ Li et al New J Phys **11** 025008 (2009)

[106] Superconductivity at 23 K in yttrium palladium boride carbide
RJ Cava et al Nature **367** 146 (1994)

[107] Superconductivity at 23 K and Low Anisotropy in Rb-Substituted $BaFe_2As_2$ Single Crystals
Z Bukowski et al Phys Rev B **79** 104521 (2009)

[108] Improving superconductivity in $BaFe_2As_2$-based crystals by cobalt clustering and electronic uniformity
L Li et al Scientific Reports **7** 949 (2017)

[109] Doping dependence of the specific heat of single crystal $BaFe_2(As_{1-x}P_x)_2$
C Chaparro et al Phys Rev B **85** 184525 (2012)

[110] Evolution from non-Fermi- to Fermi-liquid transport properties via isovalent doping in $BaFe_2(As_{1-x}P_x)_2$ superconductors
S Kasahara et al Phys Rev B **81** 184519 (2010)

[111] Giant anisotropy in superconducting single crystals of $CsCa_2Fe_4As_4F_2$
ZC Wang et al Phys Rev B **99** 144501 (2019)

[112] Optimization of superconducting properties of the stoichiometric $CaKFe_4As_4$
SJ Singh et al Supercond Sci Technol **33** 025003 (2020)

[113] Topological magnetic order and superconductivity in $EuRbFe_4As_4$
M Hemmida et al Phys Rev B **103** 195112 (2021)

[114] Cryogenic milling for the fabrication of high J_c MgB_2 bulk superconductors
DN Kim et al Prog Supercond Cryog **19** 19 (2017)

[115] Superconducting properties of MgB_2 bulks processed in high magnetic fields
A Xu et al Physica C **445** 811 (2006)

[116] MgB_2 thick film with T_C = 40.2 K deposited on sapphire substrate
K Zhang et al Physica Status Solidi A **203** 2463 (2006)

[117] Anisotropy of superconducting single crystal $SmFeAsO_{0.8}F_{0.2}$ studied by torque magnetometry
S Weyeneth et al J Supercond Nov Magn **22** 325 (2008)

[118] Growth of $PrFeAsO_{1-y}$ single crystals and its characterization
M Ishikado et al Physica C **470** S322 (2010)

[119] Two-dimensional multiband superconductivity of the optimally and uniformly Li-intercalated FeSe nanoflakes
YH Kim et al Curr Appl Phys **46** 27 (2023)

[120] Transient High-Temperature Superconductivity in Palladium Hydride
Hasnain, Syed Muhammad, Griffith University, Queensland, Australia (2016)

[121] Synthesis and superconductivity of F-free $NdFeAsO_{1-y}$
A Iyo et al J Phys Conf Ser **150** 052083 (2009)

[122] Doping dependence of the chemical potential and surface electronic structure in $YBa_2Cu_3O_{6+x}$ and $La_{2-x}Sr_xCuO_4$ using hard x-ray photoemission spectroscopy
K Maiti et al Phys Rev B **80** 165132 (2009)

[123] Bulk Superconductivity in Single Crystals of $PrBa_2Cu_3O_x$
Z Zou et al Jpn J Appl Phys **36** L18 (1997)

[124] NIST Materials Properties Databases for Advanced Ceramics
RG Munro J Res Natl Inst Stand Technol **106** 1045 (2001)

[125] Growth and properties of oxygen- and ion-doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals
DB Mitzi et al Phys Rev B **41** 6564 (1990)

[126] Superconductivity above 100 K in single-layer FeSe films on doped $SrTiO_3$
JF Ge et al Nature Materials **14** 285 (2015)

[127] Characterization of the (Cu,C)$Ba_2Ca_3Cu_4O_{11+\delta}$ single crystals grown under high pressure
C He et al Supercond Sci Technol **35** 025004 (2022)

[128] High pressure synthesis and properties of the $HgBa_2Ca_{n-1}Cu_nO_{2n+2+\delta}$ (n=1−6) superconductors
JJ Capponi et al Physica C Supercond **235** 146 (1994)

[129] Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system
AP Drozdov et al Nature **525** 73 (2015)

[130] Evidence of near-ambient superconductivity in a N-doped lutetium hydride
N Dasenbrock-Gammon et al Nature **615** 244 (2023)