REVIEWS OF MODERN PHYSICS, VOLUME 78, JULY–SEPTEMBER 2006

Addendum: Non-Fermi-liquid behavior in *d*- and *f*-electron metals

G. R. Stewart

Department of Physics, University of Florida, Gainesville, Florida 32611-8440, USA

(Published 28 July 2006)

In the approximately four years since the first review on this subject appeared, a large amount of additional work—both experimental and theoretical—has been accomplished in the field. In an effort to keep the original review experimentally current, the compilation of resistivity, susceptibility, and specific-heat data that was presented in the original ten-page Table II is herein updated with approximately 60 new systems and 70 new references, adding eight new pages to the compilation. It is worth noting that approximately 15% of these new entries in fact predate the original review's publication; certainly the literature searches employed for this update will also have missed work worthy of inclusion.

DOI: 10.1103/RevModPhys.78.743 PACS number(s): 71.10.Hf, 71.27.+a, 75.20.Hr

The materials properties in this update in tabular form—with, unlike the original review, no accompanying discussion of the various systems—are only a starting point for any serious investigation. An in-depth reading of the original reference(s) and a consideration of the limits of the cited results listed in this short update is perforce left to the reader. As stressed in the 2001 review (Stewart, 2001), one important limit is that exponents determined over less than a decade of temperature (the case for more than half the systems in this update) must be viewed as indicative only. Also, materials issues (including disorder, reproducibility, and possible extraneous second phases) are very often important in these systems. Thus results for systems investigated only once (as is the case for the majority of materials reported here as well as in the original review) may also prove changeable with further work.

The systems reported represent a breadth of the field of non-Fermi-liquid (NFL) behavior. Some which already appeared in the original review—including $Ce(Ru_{1-x}Rh_x)_2Si_2$, $Sr_3Ru_2O_7$, and $YbRh_2Si_2$—have continued to reveal interesting physics; these new data are included here. The original review included three systems based on Yb and none on either Pr or Np; the present update includes five new Yb-based systems as well as extensive continuing work on the already reported $YbRh_2Si_2$, two Pr-based systems—including the first work on the important frontier of sub-mK temperatures, and a preliminary report of NFL behavior in the Np analog of the $UCu_{5-x}Pd_x$ system. In the original review, only one system was reported where the NFL behavior was coexistent with magnetic order; this update includes data on six new examples. As before, the NFL behavior is *lower* in temperature than the magnetic order rather than above as would be straightforward in the theory; see, e.g., Fig. 2 in the original review. The other subfield of NFL behavior that has also enjoyed an acceleration of growth is where magnetic field, rather than doping or pressure, is used as the tuning parameter: the original review reported six such systems while the present update contains nine new systems as well as further work on $Sr_3Ru_2O_7$. The data are organized as before, with the headings in the table the same and the systems under each heading organized approximately according to chronological order.

Great efforts have been expended in extending our theoretical understanding as well. This theoretical work has often been a synergism with experimentalists to understand their measurements. Examples of such work include that by Millis, Schofield, *et al.* (2002), Kim and Millis (2003), and others in explaining the physics of $Sr_3Ru_2O_7$, by Kuechler *et al.* (2003) and Zhu *et al.* (2003) in explaining the behavior of the Grueneisen ratio at quantum critical points and by Pepin (2005) on understanding the rapid divergence of C/T at low temperature in $YbRh_2Si_2$.

However, there have also been numerous theoretical efforts in the field in the last four years that have *provided* the driving motivation for new experiments. Examples of such work include predicting the behavior of the Hall coefficient as a function of tuning through a quantum critical point [Coleman *et al.* (2001), Norman *et al.* (2003), Paschen *et al.* (2004), Fenton and Schofield (2005), and others], predicting a wide range of behavior for the subset of systems that may experience "local" criticality [Si *et al.* (2001, 2003), Sun and Kotliar (2005), and others], behavior of systems involving Griffiths phase [Millis, Morr, and Schmalian (2002), Castro Neto and Jones (2005), and others], predicting the behavior of systems with disorder near a quantum critical point [Sessions and Belitz (2003), Vojta (2003), Belitz, Kirkpatrick, and Rollbuehler (2004), Miranda and Dobrosavljevic (2005), Vojta and Schmalian (2005), and others], as well as a host of other works. An unpublished but readily accessible overview of both the theoretical and experimental status of the physics of quantum phase transitions from the KITP program on this subject in 2005 can be found at http://online.kitp.ucsb.edu/online/qpt05/. Perhaps one or more of the theorists would help further work in this field with a theoretically oriented review of the current status.

It is the hope that this updated compilation of system

TABLE II. Compilation of resistivity, susceptibility, and specific-heat data for non-Fermi-liquid systems. † = unannealed unless otherwise noted; A is in the appropriate units, i.e., $\mu\Omega\,\mathrm{cm}/\mathrm{K}^{\alpha}$. $^{*}\Leftrightarrow$ not lowest temperature of measurement; results in **bold** print are reanalyzed published data that have been scanned and fit to a different temperature dependence for this review than was used in the original publication; values for the residual resistivity ratio $[\equiv R(300\ \mathrm{K})/R(T\rightarrow 0)]$, or RRR, are given where known.

System†	$\rho=\rho_0+AT^{\alpha}$ $(A\equiv\rho_0/T_0^{\alpha})$						$\chi=f(T)$ (e. g. $\chi_0(1-aT^{1/2})$ / $T^{-1+\lambda}$ / $-\log T$)			
	ρ_0 ($\mu\Omega$-cm)	A#	T_0 (K)	α	T range (K)			χ_0(memu/molU,Ce)	$a(K^{-1/2})$ or λ	T range(K)
I. Doped Systems										
1. Antiferromagnetism 'Distant' in the Phase Diagram:										
$Ce_{1-x}Y_xRhIn_5$[96]						RRR				
x=0.4	1.5	+0.28	5.2	1	0.15-10	12	$\Delta\chi\sim T^{-1+\lambda}$	χ(1.8 K) ~ 8	λ=0.55	1.8-30
x=0.6	5.7					3	$\Delta\chi\sim T^{-1+\lambda}$	χ(1.8 K) ~ 11	λ=0.53	1.8-30
x=0.8	11					3.6	$\Delta\chi\sim T^{-1+\lambda}$	χ(1.8 K) ~ 15	λ=0.52	1.8-30
x=0.9	9.8					5	$\Delta\chi\sim T^{-1+\lambda}$	χ(1.8 K) ~ 23	λ=0.57	1.8-30
						RRR				
$Yb_2Pd_2In_{0.9}Sn_{0.1}$	95[97-99]	3.2	15	1.25	0.5-3	1.2				
$Ce_{0.5}La_{0.5}RhIn_5$[100]										
						RRR				
$Ce_{0.5}La_{0.5}Ni_9Ge_4$	42	3.4	23	~0.8	0.03-2[101]	1.6	$\chi\sim-\log T$	χ(2 K)=94		2*-10
$CeCoIn_{5-x}Sn_x$[102]						RRR				
x=0.03,H=5.3 T	2	4	0.6	1.5	0.05-0.4	15				
x=0.15,H=0										
$NpCu_{3.5}Pd_{1.5}$[102]										
$Pr_xLa_{1-x}Pb_3$[104]										
x=0.01										
x=0.03										
$Pr_{0.1}La_{0.9}InAg_2$[105]							$\chi\sim-\log T$	χ(1.8 K)=75		1.8-6
						RRR				
$CeRhSb_{0.86}Sn_{0.14}$[106]						1	$\Delta\chi\sim T^{-1+\lambda}$	χ(2 K) ~ 5.2	λ=0.83	2-10
$Yb_{1-x}La_xRh_2Si_2$[107]										
x=0.1										
x=0.5										
2. T_N just suppressed to 0 or just about to be induced via doping:										
$Ce(Rh_{0.6}Ru_{0.4})_3B_2$[108]				1.5				χ(2 K) ~ 1.7		
						RRR				
$Ce(Pd_{0.05}Cu_{0.95})_2Si_2$[109]						~1.2				
$Ce(Pd_{0.6}Rh_{0.4})_2Si_2$[110]							$\chi\sim-\log T$	χ(2 K)=8.7		2-80

TABLE II. (*Continued.*)

$C/T = -R[(0.25/T_0)\ln(T/0.41T_0)]$			$C/T \sim T^{-1+\lambda}$		S_{elec}(10 K)/mol U/Ce
T_0 (K)	C/T at 1 K/ (mJ/molU/Ce/Yb/Pr K^2)	T range/ scaling β (K)	λ	T range (K)	(fraction of Rln2) ($S_{elec}=S_{measured}-S_{lattice}$)
12	640	0.6-10			
12	620	0.6-9	0.82	0.9*-9	
	730		0.66	0.7*-17	
	900		0.30	0.6-17	
240	235	0.2-4.7			
5.7	600	0.4-4.5			0.82
0.8	2000	0.07*-10			
C/T obeys Moriya theory 0.12-2 K, y_0=0.001 / C/T(1 K)=530					
15	500	0.6*-4[103]	**0.35**	**0.35-4**	
3.1	1050 (2.8 K)	2.8-11.6			
2.5	80	0.12-0.3	**1.00**	**0.12-0.4**	
3.4	110	0.12-0.3	**0.82**	**0.12-0.5**	
3.1	1350	1-6			
			0.6	0.05-0.2	
			0.49	0.05-0.2	
300	66 (1.5 K)	0.5-1.5			
15	450	0.5-10			0.47
17	450	0.5-6[111]			0.5
19	580	0.4-1.4[112]			

TABLE II. (*Continued.*)

System[†]	$\rho=\rho_0+AT^\alpha$ ($A\equiv\rho_0/T_0^\alpha$)						$\chi=f(T)$ (e. g. $\chi_0(1-aT^{½})$ / $T^{-1+\lambda}$ / $-\log T$)		
	ρ_0 ($\mu\Omega$-cm)	A[#]	T_0 (K)	α	T range (K)		χ_0(memu/molU,Ce)	a($K^{-½}$) or λ	T range(K)
$\mathrm{CeNi_{0.95}Cu_{0.05}Sn}$[113]									
$\mathrm{Ce(Ru_{1-x}Rh_x)_2Si_2}$						RRR			
x=0.35				*(for ρ and χ data, see p. 814, Oct. 2001 version)*					
x=0.4[115]	165	48	6	0.70	0.3-6	3.4	*(for χ data, see p. 814, Oct. 2001 version)*		
x=0.5[115]	115	26	7	0.75	0.3-8	3.4	*(for χ data, see p. 814, Oct. 2001 version)*		
$\mathrm{CeIn_{2.4}Sn_{0.6}}$[118]				~ 1.2	0.5-?	1			
$\mathrm{CeNi(Ge_{0.5}Si_{0.5})_2}$									
I |/⊥ b	530/325	7.88/7.37	67/44	1	0.5-2[119]				
$\mathrm{CeNi_{0.7}Co_{0.3}Ge_2}$	145			1	0.5-1.7[121]	RRR 0.8			
$\mathrm{Ce_{0.7}La_{0.3}Pd_2Al_3}$[122]									
$\mathrm{CePd_{2-x}Ni_xAl_3}$[123]				x=0.5: 1	1.4-5		x=0.45: $\boldsymbol{\chi^{-1}-\chi_0^{-1}=aT}$	**χ(2 K)=28, a=1.82**	**2-50**
$\mathrm{Ce_{0.5}La_{0.5}RhSn}$[124]							$\Delta\chi\sim T^{-1+\lambda}$ χ(1.8 K) ~ 3	λ=0.67	1.8-10
$\mathrm{YbRh_2(Si_{0.95}Ge_{0.05})_2}$[125]							$\Delta\chi\sim T^{-1+\lambda}$ χ(2 K) ~ 120	λ=0.4	0.3*-10
$\mathrm{Yb_{0.95}La_{0.05}Rh_2Si_2}$[126]						RRR 8			
$\mathrm{Ce_xLa_{1-x}B_6}$[127]		x=0.5/0.4		1.5/1.2	0.05-0.3				
$\mathrm{CeRu_{0.48}Fe_{1.52}Ge_2}$[128-129]									
3. nFl behavior coexistent with long range magnetic order:									
$\mathrm{U_{1-x}Th_xCu_5Sn}$[130-131] x=0/0.7	180/195					RRR 0.9/1	T_{ferri} ~ 53 K / ~ 20 K		
$\mathrm{Ni_3Al}$[132]	0.84	0.018	10	1.65	0.4*-3.5		T_{Curie} ~ 41 K		
$\mathrm{YNi_3}$[132]	0.92	0.033	7	1.65	0.05-3		T_{Curie} ~ 30 K		
$\mathrm{U_3Ni_5Al_{19}}$[133]	2	1.31	1.5	1	1-5	RRR 30	T_{Neel} = 23 K		
$\mathrm{URu_{1.4}Re_{0.6}Si_2}$[134]				1.4	0.1-15	RRR 1.7	T_{Curie}= 18 K		
$\mathrm{Ce(Ru_{0.4}Rh_{0.6})_2Si_2}$	73	17.5	8	0.67	0.3-4[115]	RRR 2.7	T_{Neel} = 12 K		
4. doping just suppresses or just induces ferromagnetism:									
$\mathrm{URu_{1.8}Re_{0.2}Si_2}$[134]				1.2	0.2* -8	RRR 4.2	$\Delta\chi\sim T^{-1+\lambda}$	λ=0.8	2-5
$\mathrm{Y_{0.95}Gd_{0.05}Co_2}$[135]	110	~ -0.01				RRR 1.4	$T_{spin\ glass}$ ~ 3 K		

TABLE II. (*Continued.*)

$C/T = -R[(0.25/T_0)\ln(T/0.41T_0)]$			$C/T \sim T^{-1+\lambda}$		S_{elec}(10 K)/mol U/Ce
T_0 (K)	C/T at 1 K/ (mJ/molU/Ce K^2)	T range/ scaling β (K)	λ	T range (K)	(fraction of Rln2) ($S_{elec}=S_{measured}-S_{lattice}$)
	250		0.71	0.1-1.4	
C/T obeys[114] Moriya theory 0.4-6 K, $C/T=710(1-(T/T_0)^{0.5})$, T_0=14 K / C/T(1 K)=520					
C/T obeys[115] Moriya theory, 0.08-3K, y_0=0.004 / C/T (1 K)=570 (these data for x=0.4 contradict the C/T~logT					
C/T obeys[116] Moriya theory, 0.75-3K, y_0=0.003 / C/T (1 K)=550 *dependence reported in the Oct. 2001 version)*					
*C/T obeys[115] Moriya theory, 0.09-10 K, y_0=0.001(**0.004**[117]) / C/T (1 K)=560*					
10	600	0.4-5			
10	500	0.5-2[120]			0.53
5.6	900	0.5-3			
6.9	800	0.4-3.8 (C/T data for $Ce_{0.5}La_{0.5}Pd_2Al_3$ and $Ce_{0.3}La_{0.7}Pd_2Al_3$, i. e. not near T_N=0, are similar to those for $Ce_{0.7}La_{0.3}Pd_2Al_3$)			
x=0.5: *C/T obeys $C/T=570\ (1-(T/T_0)^{0.5})$, T_0=18 K, 0.5* -6 K / C/T(1 K)=440*					
16	470	0.35-10			
14	530	0.8*-10			
x=0/0.7 21/31	340/390	1*-6.5[131]/1-6.5[130]			
C/T obeys Moriya theory 0.4-4 K, y_0=0.001/ C/T(1 K)=160					
130	160	0.6-6			
23	470	0.04-10			
100	130	0.9-3			
60	70 (2 K)	2-5			

TABLE II. (*Continued.*)

System[†]	$\rho=\rho_0+AT^\alpha$ ($A\equiv\rho_0/T_0^\alpha$)						$\chi=f(T)$ (e. g. $\chi_0(1-aT^{1/2})$ / $T^{-1+\lambda}$ / -logT)			
	ρ_0 ($\mu\Omega$-cm)	A[#]	T_0 (K)	α	T range (K)			χ_0(memu/molU,Ce)	a($K^{-1/2}$) or λ	T range(K)
$Ca_{0.8}Sr_{0.2}RuO_3$[136]				1.6	2-10	RRR=2.9				
II. Undoped Systems:										
Yb_2Ni_2Al[137]	120									
$PrInAg_2$[138]				0.5	0.00018-0.08					
$Ce_{0.98}Ni_{2.005}Ge_{1.995}$[139]										
$Ce_2Co_6Al_{19}$[140]	36	4.7	7.7	1	2.5*-30	RRR 8.7	$\chi=\chi_0(1-aT^{1/2})$	5.3	a=0.061	2.8*-14
$CeRh_2Ga$[141]	370	8.3	45	1	1.6-4	RRR 0.48	$\Delta\chi_\perp \sim T^{-1+\lambda}$	$\chi_\perp$ (1.8 K) ~ 70	λ=0.21	1.8-50
							$\Delta\chi_{\vert\vert} \sim T^{-1+\lambda}$	$\chi_{\vert\vert}$ (1.8 K) ~ 18	λ=0.52	1.8-20
$CeNi_9Ge_4$[142]								χ(2 K) ~ 50		
$CeRhBi$[143]	20	58	0.34	1	0.4-2	RRR 18	$\Delta\chi \sim T^{-1+\lambda}$	χ(1.8 K) ~ 13	λ=0.75	2-6
							$\chi^{-1}-\chi_0^{-1}=aT^{1/2}$, a=22.7			**1.8-48**
$CeRhSn$[144]						RRR				
a-axis:	133	3.6	11	1.5	0.4-2.3	2	$\Delta\chi_a \sim T^{-1+\lambda}$	χ_a (1.8 K) ~ 4	λ=0.65	0.4-15
c-axis:	45	0.82	54	1	0.4-1.2	2.3	$\Delta\chi_c \sim T^{-1+\lambda}$	χ_c (1.8 K) ~ 30	λ=-0.1	0.6*-3
III. Pressure Induced nFl Behavior										
Superconductivity induced by pressure:										
Fe P_c ($T_C \to 0$) ~ 130 kbar[145]										
at 158 kbar:	1.25			1.67	1.9 (=T_c)-35[146]					
at 248 kbar:	0.63 (B=0)			1.67	1.9 (=T_c)-35					
	0.63 (B=1 T)			1.67	0.05-4					
Non-superconducting systems under pressure:										
$BaVS_3$[147] (metal-insulator transition at 20 kbar)						RRR				
at 22.5 kbar:	6			1.25	1.4-40	90				
$CePd_2Ge_2$[148] at $P_c(T_N\to0)$=138 kbar										
	5.7	0.30	6.3	1.6	0.04-2					
$CePd_{2.02}Ge_{1.98}$ at $P_c(T_N\to0)$=110 kbar										
	3.1	0.37	3.8	1.6	0.04-2					
$Ce_2Rh_3Ge_5$ $P_c(T_N\to0)$=4.5 kbar[149]										
at 5.8 kbar	21			1.45	0.25-5					
at 12.7 kbar	21			1.45	0.25-10		12 kbar: $\chi_c=\chi_0-DT^{+0.28}$	χ_c (1.8 K)=13.5		0.7-4
$CePt$[150]						RRR				
at $P_c(T_C\to0)$ ~ 120 kbar				1	0.04-30	2.1				

TABLE II. (*Continued.*)

$C/T = -R[(0.25/T_0)\ln(T/0.41T_0)]$			$C/T \sim T^{-1+\lambda}$		S_{elec}(10 K)/mol U/Ce
T_0 (K)	C/T at 1 K/ (mJ/molU/Ce K^2)	T range/ scaling β (K)	λ	T range (K)	(fraction of Rln2) ($S_{elec}=S_{measured}-S_{lattice}$)
400	170 (2.6 K)	2.6*-10			
11	600	0.5-5			
C/T obeys $C/T=450\ (1-(T/T_0)^{0.5})$, T_0=15 K, 0.14* -1 K / C/T(1 K)=340					
37	170 (3 K)	2.6-30			
	620 (1.2 K)		0.15	1.2-7	
C/T obeys Moriya theory, 0.08-10 K, y_0=0.005 / C/T (1 K)=1800					
17	500	0.6-7			
C/T obeys $C/T=235\ (1-(T/T_0)^{0.64})$, ***$T_0$=12 K, 0.5 -4 K / C/T(1 K)=190***					
At 5.7 kbar, C/T obeys Moriya theory, 0.5-1.5 K, y_0=0.4 / C/T (1 K)=500					

TABLE II. (*Continued.*)

System[†]	$\rho=\rho_0+AT^\alpha$ ($A\equiv\rho_0/T_0^\alpha$)					$\chi=f(T)$ (e. g. $\chi_0(1-aT^{1/2})$ / $T^{-1+\lambda}$ / $-\log T$)		
	ρ_0 ($\mu\Omega$-cm)	A[#]	T_0 (K)	α	T range (K)	χ_0(memu/molU,Ce)	a($K^{-1/2}$) or λ	T range(K)
$U_3Ni_5Al_{19}$[133]	at P_c ($T_N\to0$) ~55.2 kbar							
	7.7	2.6	2.1	1.5	1.3-2.5			
CePdAl[151-152]	$P_c(T_N\to0)$ =9.5 kbar							
at 10 kbar	8	15	0.5	1	0.6-2	χ_c (1.8 K)=72	**$\chi^{-1}-\chi_0^{-1}=aT^{1.3}$, a=0.55**	**0.6-8**
IV. Field Induced nFl Behavior:								
Ce_7Ru_3[153]								
$YbRh_2Si_2$[154]	at $B_c(T_N\to0)$ = 0.06 / 0.7 T, B ⊥ / $\parallel$ c							
	1.47/1.68	1.6/1.9	0.9/0.9	1	0.02-0.14			
$Y_{0.85}Gd_{0.15}Co_2$[155]								
at B=15 T				1	0.1-30			
$CeIrIn_5$[156]								
at B $\parallel$ c =17 T	1.9	0.62	2.1	1.5	0.05-0.45			
YbAgGe[157]	$B_c(T_N\to0)$ = 4 / 8 T, B $\parallel$ ab / c							
at B_{ab}=10 T:	25	12	2.1	1	0.4-1.7			
at B_c=13 T:	53	11	4.7	1	0.4-1.2			
$Sr_3Ru_2O_7$	at B(meta)=7.8 T, B $\parallel$ c and I $\parallel$ c							
	1970			$\alpha<2$	0.4*-0.8[158]			
	at B(meta)=7.9 T, B $\parallel$ c and I $\parallel$ ab							
	2.4	-0.1		~1	0.06-1[159]			
$CeAuSb_2$[160]	$B_c(T_N\to0)$ = 5.4 T, B $\parallel$ c							
at 5.5 T, B $\parallel$ c	4.8	**12**	**0.16**	**0.5**	**0.5-10**			
URu_2Si_2[161-162]	B_c = 37 ± 1 T, B $\parallel$ c							
at 38 T, B $\parallel$ c	23			1.1	0.6-3			
YbPtIn[163]	at $B_c(T_N\to0)$ = 6 T, B $\parallel$ ab							
	7.2	**4.3**	**3.2**	**0.45**	**0.4-5**			

References for Table II (Note: If a reference is cited for one property for a given system, e. g. for ρ, and no reference is cited for the other properties listed, this reference also applies to the other data.)

96. Zapf, et al. (2003).
97. E. Bauer, et al. (2004).
98. E. Bauer, et al. (2005).
99. E. Bauer, priv. comm.
100. Light, et al. (2004).
101. Killer, et al. (2004).
102. E. D. Bauer, C. Capan, et al. (2005).
103. E. D. Bauer, N. Moreno, et al. (2005).
104. Stewart, et al. (2005).
105. Kawae, et al. (2005).
106. Slebarski and Spalek (2005).
107. Radu (2005).
108. E. Bauer, et al. (1998).
109. Gomez Berisso, et al. (1998).
110. Trovarelli, et al. (1998).
111. Gomez Berisso, et al. (1999).
112. Kim and Stewart, unpublished.
113. Kalvius, et al. (2000).
114. Nakano, et al. (2002).
115. J. S. Kim, et al. unpublished.
116. Gu, et al. (2002).
117. Graf, et al. (1997).
118. Pedrazzini, et al. (2002).
119. D. Y. Kim, et al. (2005).
120. Hong, et al. (2003).
121. Jung and Kwon, (2005).
122. Nishigori, et al. (2003).
123. Sereni, et al. (2004).
124. Slebarski, et al. (2004).
125. Gegenwart, et al. (2005).
126. Ferstl, et al. (2005).
127. Nakamura, et al. (2005).
128. Montfrooij, et al. (2003).
129. Montfrooij, priv. comm.
130. Troc, et al. (2001).
131. Tran, et al. (1999).
132. Steiner, et al. (2003).
133. E. D. Bauer, V. A. Sidorov, et al. (2005).
134. E. D. Bauer, V. S. Zapf, et al. (2005).

TABLE II. (*Continued.*)

$C/T = -R[(0.25/T_0)\ln(T/0.41T_0)]$			$C/T\sim T^{-1+\lambda}$		S_{elec}(10 K)/mol U/Ce
T_0 (K)	C/T at 1 K/ (mJ/molU/Ce K^2)	T range/ scaling β (K)	λ	T range (K)	(fraction of Rln2) ($S_{elec}=S_{measured}-S_{lattice}$)
5.8	800	**0.7*-4**			
$B_c(T_N\rightarrow0)=3.5$ T					
12	600	0.8*-11			
28	530	0.4*-2.5			
	$B_{ab}=8$ T/$B_c=14$ T	scaling β			
13/15	550/530	0.9*-10/0.9*-20 / 1.15/1.15			
B(|| c)=8 T					
23	420	0.2*-2			
B_c(|| c)=5.4 T					
6	400	3.5*-20			

135. Baranov, et al. (2003).
136. Khalifah, et al. (2004).
137. Geibel, et al. (1996).
138. Mitamura, et al. (2002).
139. Cichorek, et al. (2003).
140. Kaczorowski, et al. (2004).
141. Chen, et al. (2004).
142. Michor, et al. (2004).
143. Sasakawa, et al. (2005).
144. M. S. Kim, et al. (2003).
145. Shimizu, et al. (2001).
146. Holmes, et al. (2004).
147. Forro, et al. (2000).
148. Wilhelm and Jaccard (2002).
149. Umeo, et al. (2002).
150. Larrea, et al. (2004).
151. Goto, et al. (2002).
152. Hane, et al. (2000).
153. Sereni, et al. (1999).
154. Gegenwart, et al. (2002).
155. Burkov, et al. (2003).
156. Capan, et al. (2004).
157. Bud'ko, et al. (2004).
158. Zhou, et al. (2004).
159. Perry, et al. (2004).
160. Balicas, et al. (2005).
161. K. H. Kim, et al. (2003).
162. K. H. Kim, et al. (2004).
163. Morosan, et al. (2005).

parameters for known non-Fermi-liquid materials will allow experimentalists to gain insights as to what future experimental directions to take and theorists to pose tough questions (e.g., how does the residual resistivity behave with tuning via field or pressure near a quantum critical point?) whose answers can at least begin to be answered with the data and references thereto contained herein.

The author gratefully acknowledges the help of J. S. Kim with analyzing the published data for this updated compilation, the generosity of numerous colleagues who provided data and results ahead of publication, including E. Bauer, E. D. Bauer, K. H. Kim, W. Montfrooij, H. Wilhelm, V. Zapf, and numerous presenters of posters at the SCES2005 conference in Vienna, the assistance of J. Sereni who provided a long list of new experimental references, and K. Ingersent for helpful discussions on the theoretical references. Work in Florida was performed under the auspices of the U.S. Department of Energy, Contract No. DE-FG05-86ER45268.

REFERENCES

Balicas, L., S. Nakatsuji, H. Lee, P. Schlottmann, T. P. Murphy, and Z. Fisk, 2005, Phys. Rev. B **72**, 064422.

Baranov, N. V., A. A. Yermakov, and A. Podlesnyak, 2003, J. Phys.: Condens. Matter **15**, 5371.

Bauer, E., 2006, private communication.

Bauer, E., R. Hauser, A. Galatanu, A. Lindbaum, G. Hilscher, H. Sassik, H. Kirchmayr, J. G. Sereni, and P. Rogl, 1998, J. Appl. Phys. **83**, 6423.

Bauer, E., G. Hilscher, H. Michor, Ch. Paul, Y. Aoki, H. Sato, D. T. Adroja, J.-G. Park, P. Bonville, C. Godart, J. Sereni, M. Giovanni, and A. Saccone, 2005, J. Phys.: Condens. Matter **17**, S999.

Bauer, E., G. Hilscher, H. Michor, Ch. Paul, Y. Aoki, H. Sato, M. Giovannini, and A. Saccone, 2004, J. Magn. Magn. Mater. **272-276**, 237.

Bauer, E. D., C. Capan, F. Ronning, R. Movshovich, J. D. Thompson, and J. L. Sarrao, 2005, Phys. Rev. Lett. **94**, 047001.

Bauer, E. D., N. O. Moreno, D. J. Mixson, J. L. Sarrao, J. D. Thompson, M. F. Hundley, R. Movshovich, and P. G. Pagliuso, 2005, Physica B **359-361**, 35.

Bauer, E. D., V. A. Sidorov, S. Bobev, D. J. Mixson, J. D. Thompson, J. L. Sarrao, and M. F. Hundley, 2005, Phys. Rev. B **71**, 014419.

Bauer, E. D., V. S. Zapf, P.-C. Ho, N. P. Butch, E. J. Freeman, C. Sirvent, and M. B. Maple, 2005, Phys. Rev. Lett. **94**, 046401.

Belitz, D., T. R. Kirkpatrick, and J. Rollbuehler, 2004, Phys. Rev. Lett. **93**, 155701.

Bud'ko, S. L., E. Morosan, and P. C. Canfield, 2004, Phys. Rev. B **69**, 014415.

Burkov, A. T., A. Yu. Zyuzin, T. Nakama, K. Yagasaki, J. Schumann, and H. Vinzelberg, 2003, Physica B **329-333**, 543.

Capan, C., A. Bianchi, F. Ronning, A. Lacerda, J. D. Thompson, M. F. Hundley, P. G. Pagliuso, J. L. Sarrao, and R. Movshovich, 2004, Phys. Rev. B **70**, 180502(R).

Castro Neto, A. H., and B. A. Jones, 2005, Europhys. Lett. **71**, 790.

Chen, G. F., I. Sakamoto, S. Ohara, T. Takami, H. Ikuta, and U. Mizutani, 2004, Phys. Rev. B **69**, 014420.

Cichorek, T., C. Geibel, N. Carocca-Canales, T. Luehmann, P. Gegenwart, and F. Steglich, 2003, Acta Phys. Pol. B **34**, 371.

Coleman, P., C. Pepin, Q. Si, and R. Ramazashvili, 2001, J. Phys.: Condens. Matter **13**, R723.

Fenton, J., and A. J. Schofield, 2005, Phys. Rev. Lett. **95**, 247201.

Ferstl, J., C. Geibel, F. Weickert, P. Gegenwart, T. Radu, T. Luehmann, and F. Steglich, 2005, Physica B **359-361**, 26.

Forro, L., R. Gaal, H. Berger, P. Fazekas, K. Penc, I. Kezsmarki, and G. Mihaly, 2000, Phys. Rev. Lett. **85**, 1938.

Gegenwart, P., J. Custers, C. Geibel, K. Neumaier, T. Tayama, K. Tenya, O. Trovarelli, and F. Steglich, 2002, Phys. Rev. Lett. **89**, 056402.

Gegenwart, P., J. Custers, Y. Tokiwa, C. Geibel, and F. Steglich, 2005, Phys. Rev. Lett. **94**, 076402.

Geibel, C., U. Klinger, B. Buschinger, M. Weiden, G. Olesch, F. Thomas, and F. Steglich, 1996, Physica B **223&224**, 370.

Gomez Berisso, M., P. Pedrazzini, J. G. Sereni, O. Trovarelli, C. Geibel, and F. Steglich, 1999, Physica B **259-261**, 68.

Gomez Berisso, M., O. Trovarelli, P. Pedrazzini, G. Zwicknagl, C. Geibel, F. Steglich, and J. G. Sereni, 1998, Phys. Rev. B **58**, 314.

Goto, T., S. Hane, K. Umeo, T. Takabatake, and Y. Isikawa, 2002, J. Phys.: Condens. Matter **63**, 1159.

Graf, T., J. D. Thompson, M. F. Hundley, R. Movshovich, Z. Fisk, D. Mandrus, R. A. Fisher, and N. E. Phillips, 1997, Phys. Rev. Lett. **78**, 3769.

Gu, H. W., J. Tang, A. Matsushita, T. Taniguchi, Y. Tabata, and Y. Miyako, 2002, Physica B **312-313**, 248.

Hane, S., T. Goto, T. Abe, and Y. Ishikawa, 2000, Physica B **281&282**, 391.

Holmes, A. T., D. Jaccard, G. Behr, Y. Inada, and Y. Onuki, 2004, J. Phys.: Condens. Matter **16**, S1121.

Hong, S. O., E. D. Mun, N. Takeda, M. Ishikawa, and Y. S. Kwon, 2003, Physica B **329-333**, 518.

Jung, M. H., and Y. S. Kwon, 2005, Physica B **359-361**, 59.

Kaczorowski, D., O Tougait, A. Czopnik, Cz. Marucha, and H. Noel, 2004, J. Magn. Magn. Mater. **272-276**, 239.

Kalvius, G. M., A. Kratzer, G. Grosse, D. R. Noakes, R. Waeppling, H. v. Loehneysen, T. Takabatake, and Y. Echizen, 2000, Physica B **289-290**, 256.

Kawae, T., K. Kinoshita, C. Li, Y. Nakaie, Y. Yoshida, M. Hidaka, N. Tateiwa, K. Takeda, and T. Kitai, 2006, J. Alloys Compd. **408-412**, 47.

Khalifah, P., I. Ohkubo, H. M. Christen, and D. G. Mandrus, 2004, Phys. Rev. B **70**, 134426.

Killer, U., E.-W. Scheidt, G. Eickerling, H. Michor, J. Sereni, Th. Pruschke, and S. Kehrein, 2004, Phys. Rev. Lett. **93**, 216404.

Kim, D. Y., M. H. Jung, and Y. S. Kwon, 2005, Physica B **359-361**, 302.

Kim, J. S., D. J. Mixson, D. Burnette, B. Andraka, K. Ingersent, G. R. Stewart, and E.-W. Scheidt, 2006, unpublished.

Kim, J. S., and G. R. Stewart, 2006, unpublished.

Kim, K. H., N. Harrison, M. Jaime, G. S. Boebinger, and J. A. Mydosh, 2003, Phys. Rev. Lett. **91**, 256401.

Kim, K. H., N. Harrison, M. Jaime, G. S. Boebinger, and J. A.

Mydosh, 2004, J. Magn. Magn. Mater. **272-276**, 50.

Kim, M. S., Y. Echizen, K. Umeo, S. Kobayashi, M. Sera, P. S. Salamakha, O. L. Sologub, and T. Takabatake, 2003, Phys. Rev. B **68**, 054416.

Kim, Y. B., and A. J. Millis, 2003, Phys. Rev. B **67**, 085102.

Kuechler, R., N. Oeschler, P. Gegenwart, T. Cichorek, K. Neumaier, O. Tegus, C. Geibel, J. A. Mydosh, F. Steglich, L. Zhu, and Q. Si, 2003, Phys. Rev. Lett. **91**, 066405.

Larrea, J., T. Burghardt, A. Eichler, M. B. Fontes, A. D. Alvarenga, E. Baggio-Saitovitch, 2004, J. Magn. Magn. Mater. **272-276**, 54.

Light, B. E., Ravhi S. Kumar, A. L. Cornelius, P. G. Pagliuso, and J. L. Sarrao, 2004, Phys. Rev. B **69**, 024419.

Malinowski, A., M. F. Hundley, C. Capan, F. Ronning, R. Movshovich, N. O. Moreno, J. L. Sarrao, and J. D. Thompson, 2005, Phys. Rev. B **72**, 184506.

Michor, H., E. Bauer, C. Dusek, G. Hilscher, P. Rogl, B. Chevalier, J. Etourneau, G. Giester, U. Killer, and E.-W. Scheidt, 2004, J. Magn. Magn. Mater. **272-276**, 227.

Millis, A. J., D. K. Morr, and J. Schmalian, 2002, Phys. Rev. B **66**, 174433.

Millis, A. J., A. J. Schofield, G. G. Lonzarich, and S. A. Grigera, 2002, Phys. Rev. Lett. **88**, 217204.

Miranda, E., and V. Dobrosavljevic, 2005, Rep. Prog. Phys. **68**, 2337.

Mitamura, H., Y. Karaki, R. Masutomi, N. Takeshita, A. Yamaguchi, Y. Uwatoko, T. Goto, H. Ishimoto, and N. Mori, 2002, J. Magn. Magn. Mater. **239**, 31.

Montfrooij, W., 2006, private communication.

Montfrooij, W., M. C. Aronson, B. D. Rainford, J. A. Mydosh, A. P. Murani, P. Haen, and T. Fukuhara, 2003, Phys. Rev. Lett. **91**, 087202.

Morosan, E., S. L. Bud'ko, Y. A. Mozharivskyj, and P. C. Canfield, 2006, Phys. Rev. B **73**, 174432.

Nakamura, S., H. Yamamoto, M. Endo, H. Aoki, T. Nojima, and S. Kunii, 2005, Physica B **359-361**, 71.

Nakano, T., K. Fujita, Y. Ohmori, S. Murayama, K. Hoshi, H. Amitsuka, Y. Onuki, M. Ocio, and J. Hammann, 2002, Physica B **312-313**, 440.

Nishigori, S., M. Katsube, T. Ito, and A. Matsushita, 2003, Physica B **329-333**, 593.

Norman, M. R., Q. Si, Ya. B. Bazaliy, and R. Ramazashvili, 2003, Phys. Rev. Lett. **90**, 116601.

Paschen, S., T. Luehmann, S. Wirth, P. Gegenwart, O. Trovarelli, C. Geibel, F. Steglich, P. Coleman, and Q. Si, 2004, Nature (London) **432**, 881.

Pedrazzini, P., M. Gomez Berisso, N. Caroca-Canales, M. Deppe, C. Geibel, and J. G. Sereni, 2002, Physica B **312-313**, 406.

Pepin, C., 2005, Phys. Rev. Lett. **94**, 066402.

Perry, R. S., K. Kitagawa, S. A. Grigera, R. A. Borzi, A. P. MacKenzie, K. Ishida, and Y. Maeno, 2004, Phys. Rev. Lett. **92**, 166602.

Radu, T., 2005, Ph.D. thesis, Technische Hochschule Dresden.

Ronning, F., C. Capan, A. Bianchi, R. Movshovich, A. Lacerda, M. F. Hundley, J. D. Thompson, P. G. Pagliuso, and J. L. Sarrao, 2005, Phys. Rev. B **71**, 104528.

Sasakawa, T., K. Shigetoh, D. Hirata, K. Umeo, and T. Takabatake, 2005, Physica B **359-361**, 111.

Sereni, J. G., P. Pedrazzini, E. Bauer, A. Galatanu, Y. Aoki, and H. Sato, 2004, e-print cond-mat/0403154.

Sereni, J. G., O. Trovarelli, G. Schmerber, and J. P. Kappler, 1999, Physica B **259-261**, 405.

Sessions, S. L., and D. Belitz, 2003, Phys. Rev. B **68**, 054411.

Shimizu, K., T. Kimura, S. Furomoto, K. Takeda, K. Kontani, Y. Onuki, and K. Amaya, 2001, Nature (London) **412**, 316.

Si, Q., S. Rabello, K. Ingersent, and L. Smith, 2001, Nature (London) **413**, 804.

Si, Q., S. Rabello, K. Ingersent, and L. Smith, 2003, Phys. Rev. B **68**, 115103.

Slebarski, A., A. Czopnik, A. Zygmunt, and T. Zawada, 2004, J. Phys.: Condens. Matter **16**, 4897.

Slebarski, A., and J. Spalek, 2005, Phys. Rev. Lett. **95**, 046402.

Steiner, M. J., F. Beckers, P. G. Niklowitz, and G. G. Lonzarich, 2003, Physica B **329-333**, 1079.

Stewart, G. R., 2001, Rev. Mod. Phys. **73**, 797.

Stewart, G. R., J. S. Kim, R. E. Sykora, and R. G. Haire, 2006, Physica B **378-380**, 40.

Sun, P., and G. Kotliar, 2005, Phys. Rev. Lett. **95**, 016402.

Tran, V. H., R. Troc, R. Pietri, and B. Andraka, 1999, Phys. Rev. B **60**, 4696.

Troc, R., V. H. Tran, B. Andraka, R. Pietri, and T. Cichorek, 2001, J. Magn. Magn. Mater. **226-230**, 118.

Trovarelli, O., M. Gomez Berisso, P. Pedrazzina, D. Bosse, C. Geibel, J. G. Sereni, and F. Steglich, 1998, J. Alloys Compd. **275-277**, 569.

Umeo, K., T. Takabatake, S. Hane, H. Mitamura, and T. Goto, 2002, Physica B **312-313**, 403.

Vojta, T., 2003, Phys. Rev. Lett. **90**, 107202.

Vojta, T., and J. Schmalian, 2005, Phys. Rev. Lett. **95**, 237206.

Wilhelm, H., 2005, private communication.

Wilhelm, H., and D. Jaccard, 2002, Phys. Rev. B **66**, 064428.

Zapf, V. S., N. A. Frederick, K. L. Rogers, K. D. Hof, P.-C. Ho, E. D. Bauer, and M. B. Maple, 2003, Phys. Rev. B **67**, 064405.

Zhou, Z. X., S. McCall, C. S. Alexander, J. E. Crow, P. Schlottmann, A. Bianchi, C. Capan, R. Movshovich, K. H. Kim, M. Jaime, N. Harrison, M. K. Haas, R. J. Cava, and G. Cao, 2004, Phys. Rev. B **69**, 140409(R).

Zhu, L., M. Garst, A. Rosch, and Q. Si, 2003, Phys. Rev. Lett. **91**, 066404.