

Cerium – Copper – Germanium

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Introduction

There is much information available on the crystal structure and lattice parameters of the ternary compounds in the Ce–Cu–Ge system, but only two investigations [1996Sal, 2002Nak] on the phase equilibria. The experimental studies are summarized in Table 1. [1996Sal] constructed isothermal sections for the concentration range from 0 to 50 at.% Ge (600°C) and from 50 to 100 at.% Ge (400°C). Eight ternary compounds have been found (Fig. 1). Two of them (CeCuGe and CeCu_{0.6-0.8}Ge_{1.4-1.2}) along 33.3 at.% Ce section have the AlB₂ structure. On the other hand, [1969Rie1] found a compound with the AlB₂ type structure in the composition range between CeCuGe and CeCu_{0.67}Ge_{1.33}. This information was obtained on as-cast samples following arc-melting, and according to [2002Ria], probably corresponds to a high temperature phase. [1993Ian] annealed samples at 750°C for 7 to 10 days and found the AlB₂ type structure at the stoichiometric composition. At the same time, according to [1991Yan, 2004Che], the CeCuGe compound annealed at 800 or 700°C crystallizes with a hexagonal structure with a doubled *c* axis indicating an ordered ternary structure of the ZrBeSi type.

[2002Nak] studied the phase equilibria at 800°C along the sections Ce(Cu_{*x*}Ge_{*y*})₂ with *x* + *y* = 1; 0.95 and 0.90 at 0.15 ≤ *x* ≤ 0.3. The alloys belong to the sections at 33.3 at.% Ce (1), at 34.5 at.% (0.95) and at 35.6 at.% Ce (0.9); the contents of Cu and Ge correspond to ~10 to 20 and ~55 to 45 at.%, respectively. Two ternary compounds with the AlB₂ and ThSi₂ type structures have been established along the section at 34.5 at.% Ce. Moreover, [2002Nak] determined that the compounds at Ce:Cu:Ge = 2:1:3 and 2:1:2 are not formed. However, [2000Tie] indicated the formation of the Ce₂CuGe₃ compound with an orthorhombic structure.

[1997Was] investigated the effect of hydrostatic pressure up to 15 GPa on the crystal structure of the CeCu₂Ge₂ compound, and [2002Gil] studied the effect of low temperature on the crystal and magnetic structure of the CeCu_{0.86}Ge compound.

[2002Ria] summarized and discussed the constitutional data of the Ce–Cu–Ge system, including the crystal structures of the binary and ternary phases, the phase equilibria observed in this system and some magnetic and electrical properties.

Binary Systems

The Ce–Ge binary system is taken from [Mas2]. The Ce–Cu and Cu–Ge binary systems are accepted from [2002Fer] and [2002Per], respectively.

Solid Phases

Crystallographic data of the unary, binary and ternary compounds are listed in Table 2.

Eleven ternary compounds have been found in the Ce–Cu–Ge system. The compound τ_1 (CeCu₂Ge₂) with the ThCr₂Si₂ (or CeGa₂Al₂) type structure was reported by [1969Rie2, 1997Kri, 1996Sal]. This phase has been described as a “point” compound. The crystal structures of the Ce₂CuGe₆ (τ_2) and Ce₂Cu₃Ge₃ (τ_4) compounds (having their own structure types) have been found and refined using a powder method [1988Kon1, 1988Kon2] and more recently confirmed by [1995Sol] for τ_2 and [1996Sal] for τ_2 and τ_4 . The ternary CeCu_{*x*}Ge₂ (τ_3) compound was described by [1990Fra]. It is non-stoichiometric and has a homogeneity range of 0.86 ≤ *x* ≤ 1. The stoichiometric CeCuGe (τ_5) compound crystallizes with an AlB₂ structure [1969Rie1, 1993Ian, 1996Sal] or a ZrBeSi structure [1991Yan, 2004Che] depending on heat treatment. The ternary compound τ_6 with the AlB₂ structure has a homogeneity range. According to [1996Sal] it lies in the 33.3 at.% Ce section at Cu contents from 20 to 26 at.% and is described as CeCu_{0.6-0.8}Ge_{1.4-1.2}. According to [2002Nak], this ternary compound lies along the 34.5 at.% Ce section at Cu contents from ~17 to ~19 at.% and is described as Ce(Cu_{*x*}Ge_{*y*})₂ with (*x* + *y*) = 0.95 at 0.25 ≤ *x* ≤ 0.275.

Additional investigation is required to establish the composition of the τ_6 compound. Also, [2002Nak] found the ternary τ_9 compound in the 34.5 at.% Ce section. This compound was described as $\text{Ce}(\text{Cu}_x\text{Ge}_y)_2$ with $(x + y) = 0.95$ at $0.12 \leq x \leq 0.14$. Two other ternary compounds, τ_7 ($\text{Ce}_{0.60}\text{Cu}_{0.25}\text{Ge}_{0.15}$) and τ_8 ($\text{Ce}_{0.60}\text{Cu}_{0.05}\text{Ge}_{0.35}$), were found by [1996Sal] but their crystal structures were not determined. The compound τ_{10} (Ce_2CuGe_2) as determined by [2000Tie] is included in the present assessment, although [2002Nak] indicated that this compound does not exist in the Ce–Cu–Ge system. This needs to be confirmed. The crystal structure of the ternary compound τ_{11} ($\text{Ce}_3\text{Cu}_4\text{Ge}_4$) was determined by [2002Zah] after annealing at 800°C for 2 weeks and subsequent quenching into water. The binary compound CeGe_{2-x} dissolves up to 10 at.% Cu at 600°C according to [1996Sal].

Liquidus Surface

There is only one reference to the melting temperature of the CeCu_2Ge_2 compound. Using high temperature differential thermal analysis [1997Mor] determined the melting temperature of CeCu_2Ge_2 to be 1384°C.

Isothermal Sections

The isothermal section of the Ce–Cu–Ge system at 600°C in Ge and Cu corner, and at 400°C in the Ce corner is shown in Fig. 1, taken from [1996Sal]. Locations of the τ_3 and τ_4 phases which were interchanged in [1996Sal] have been corrected in Fig. 1. The phase equilibria shown by dashed lines were introduced speculatively because of two additional phases at the Cu–Ge side according to the accepted binary phase diagram from [2002Fer]. The partial isothermal section in the region of the phases with the AlB_2 and αThSi_2 type structures (phases τ_6 and τ_9) at 800°C is presented in Fig. 2 taken from [2002Nak].

Thermodynamics

[2000Tie] studied the specific heat and the entropy of Ce_2CuGe_3 . The specific heat of Ce_2CuSi_3 exhibits a peak at ~4 K. Since the magnetic entropy between 2 and 4 K is much smaller than $2R\ln 2$, the peak in the specific heat is unlikely to be related to long-range magnetic ordering. This 4 K peak might be due to a Schottky anomaly with a spin-glass contribution. The coefficient of the linear temperature dependent term in the specific heat of Ce_2CuGe_3 is $249.86 \text{ mJ}\cdot\text{mol}^{-1}\cdot\text{K}^{-2}$, which is much larger than that of normal metals [2000Tie].

Notes on Materials Properties and Applications

Studies of electrical, magnetic and other properties of the Ce–Cu–Ge compounds are summarized in Table 3. The temperature dependence of the resistivity of CeCu_2Ge_2 was determined by [1985Rau]. Elastic and inelastic neutron scattering studies of the Kondo lattice of CeCu_2Ge_2 were performed by [1989Kno]. At $T_N = 4.1 \text{ K}$, an incommensurate magnetic order develops with an ordering wave vector $\mathbf{q}_0 = (0.28, 0.28, 0.54)$ and an ordered $\mu_s = 0.74 \mu_B$ [1989Kno]. The temperature dependence of the width of the quasielastic line for CeCu_2Ge_2 is characteristic of a heavy-fermion system with a high temperature square root dependence and a limiting low temperature value, yielding a Kondo temperature $T_K \approx 10 \text{ K}$ [1989Kno]. A close correlation between the unit cell volume and the 4f-local spin / conduction electron hybridization for the CeCu_2Ge_2 compound was demonstrated in [1989Loi]. The width of the quasielastic line of the Lorentzian component in the magnetic neutron scattering spectrum revealing the magnetic relaxation rate and the strength of the hybridization between the 4f- and the conduction electrons were determined by [1989Loi]. The temperature-magnetic field phase diagram of $\text{Ce}(\text{Cu}_{1-x}\text{Ni}_x)_2\text{Ge}_2$ was discussed in [1990Ste]. The magnetic properties of the CeCuGe compound have been studied by [1991Yan]. Ferromagnetic ordering in CeCuGe has been found below 8.6 K. A T_N of 15.8 K and μ_{eff} of $2.5 \mu_B$ has been determined for Ce_2CuGe_6 by [1995Sol]. CeCu_2Ge_2 orders antiferromagnetically below $T_N = 4.15$ in an incommensurate sinusoidal amplitude modulated structure [1997Kri]. Enhancement of the superconducting transition temperature T_C is confirmed at around 16 GPa in the pressure-induced superconductor CeCu_2Ge_2 [1998Kob]. The superconducting HC–TC phase diagrams in low- T_C and high- T_C pressure regions are presented in Fig. 3 [1998Kob]. With increasing pressure, the compound CeCu_2Ge_2 evolves from

antiferromagnetically ordered Kondo to intermediate valence behavior as the Kondo temperature increases by about two orders of magnitude [1998Var]. The pressure dependence of the temperatures of magnetic ordering is presented in Fig. 4 according to [1998Var]. The differential thermopower of Ce_2CuGe_6 was investigated in the range 78–380 K [2000Kon]. Below 6 K, Ce_2CuGe_3 shows spontaneous magnetic ordering [2000Tie]. The results of heat capacity measurements in the presence of an external magnetic field and the measurement of resistivity for the compound CeCu_xGe_2 with $x = 0.86$ are reported in [2001Raw]. The ordered Ce magnetic moment is 2.05(2) μB at the 2d site and 1.10(2) μB at the 4e site for $\text{Ce}_3\text{Cu}_4\text{Ge}_4$ [2002Zah]. Below the Neel temperature of 16.5 K for $\text{CeCu}_{0.86}\text{Ge}_2$ compound, a collinear antiferromagnetic ordering is present with the Ce magnetic moment aligned along the c -axis [2002Gil]. The magnetic structure of the $\text{CeCu}_{0.86}\text{Ge}_2$ compound does not change over the temperature interval between 1.5 K and the Neel temperature of 16.5 K [2002Gil]. A transition from ferromagnetism to non-magnetic ordering above 1.8 K is evident during the hydrogenation of CeCuGe [2004Che]. Cu containing alloys (CeCu_xGe_2 , $0 \leq x \leq 1$) order antiferromagnetically at a high temperature (~ 17 K) and shows strong metamagnetic behavior as a function of externally applied magnetic field [1992Das].

Miscellaneous

[1997Was] investigated the effect of hydrostatic pressure on the crystal structure of CeCu_2Ge_2 . Up to pressures of 15 GPa, the lattice parameters and unit cell volume for CeCu_2Ge_2 compound decrease continuously, whereas the c/a ratio increases. A comparison of the structural parameters of CeCu_2Ge_2 under pressure with those at $p = 0$ indicates that the 4f-hybridization strength is determined by Ce–Cu hybridization. Non-hydrostatic pressure has a strong influence on the behavior of the structural parameters. The ternary germanide CeCuGe absorbs hydrogen in the temperature range 393–473 K [2004Che]. The structural characteristics of $\text{CeCuGeH}_{1.0(1)}$ are shown in Table 2.

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Table 1: Investigations of the Ce-Cu-Ge Phase Relations, Structures and Thermodynamics

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1965Gla]	X-ray diffraction	Annealing at 800°C/ $\text{Ce}(\text{Cu},\text{Ge})_2$ /Crystal structure
[1969Rie1]	X-ray powder diffraction	As-cast samples after arc melting at room temperature/ CeCuGe and $\text{CeCu}_{0.67}\text{Ge}_{1.33}$ /Crystal structure
[1969Rie2]	X-ray powder diffraction	Annealing at 900°C for 100 h / CeCu_2Ge_2 /Crystal structure
[1985Rau]	X-ray diffraction	As-cast samples after arc melting / CeCu_2Ge_2 /Crystal structure
[1988Kon1]	X-ray powder diffraction / DRON –3.0 / HZG-4a	Annealing at 600°C for 720 h / Ce_2CuGe_6 /Crystal structure
[1988Kon2]	X-ray powder diffraction / DRON –3.0 / HZG-4a	Annealing at 600°C / $\text{Ce}_2\text{Cu}_3\text{Ge}_3$ /Crystal structure
[1989Kno]	X-ray powder diffraction, neutron powder diffraction / multidetector diffractometer	As-cast samples after arc melting at room temperature / CeCu_2Ge_2 /Crystal structure
[1990Fra]	X-ray powder diffraction, electron microprobe	Homogenizing at 900°C/ $\text{CeCu}_{0.86}\text{Ge}_2$ /Lattice parameters
[1991Yan]	X-ray powder diffraction	Annealing at 800°C for 1 week / CeCuGe /Crystal structure
[1993Ian]	X-ray diffraction	Annealing at 750°C for 7 to 10 days / CeCuGe /Crystal structure

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1995Sol]	Guinier-Huber X-ray powder diffraction	Annealing at 600°C for 150 h and quenching/ Ce ₂ CuGe ₆ /Crystal structure
[1996Sal]	X-ray powder diffraction / DRON-3.0, HZG-4a	Annealing at 600°C and 400°C for 2 weeks and quenching / Isothermal sections
[1997Kri]	neutron powder diffraction, Czochralsky technique, microprobe analysis, X-ray diffraction / triple-axis spectrometers IN3 at the high-flux reactor, E7 located at the BERII reactor	At room temperature and between 1.5 and 300 K /CeCu ₂ Ge ₂ /Lattice parameter and magnetic structure
[1997Mor]	X-ray diffraction / DRON-3.0, high temperature differential thermal analysis / VDTA-8M2	CeCu ₂ Ge ₂ /Melting point
[1997Was]	X-ray powder diffraction / ID30, ID9, Fluorescence method	At pressures up to 15 GPa/CeCu ₂ Ge ₂ /Lattice parameters
[2000Tie]	X-ray diffraction	After melting at room temperature / Ce ₂ CuGe ₃ /Crystal structure
[2001Raw]	X-ray diffraction	Homogenizing at 900°C for 5 days / CeCu _{0.86} Ge ₂ /Crystal structure
[2002Nak]	X-ray diffraction	Heat treatment at 800°C for 7days/ Ce(Cu _x Ge _y) ₂ $x = 0.15$ to 0.3 , $x + y = 1$; 0.95 ; 0.90 / Crystal structure
[2002Zah]	X-ray diffraction, neutron powder diffraction / DMC diffractometer at SINQ	Annealing at 800°C for 2 weeks and quenching / Ce ₃ Cu ₄ Ge ₄ /Crystal structure
[2002Gil]	X-ray diffraction, neutron powder diffraction / E6 diffractometer	Homogenizing at 900°C for 6 days / CeCu _{0.86} Ge ₂ /Lattice parameters at room and low temperatures
[2004Che]	X-ray powder diffraction / Philips 1050-diffractometer, automated Sievert's-type apparatus (HERA), electron microscopy experiments (JEOL 2000FX)	Annealing at 700°C for 1 month / CeCuGe/Crystal structure

Table 2: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Cu) < 1084.62	<i>cF4</i> <i>Fm$\bar{3}m$</i> Cu	$a = 361.46$	dissolves up to 12 at.% Ge at 824°C [2002Fer] and 0.1 at.% Ce at 876°C [2002Per] at 25°C [Mas2]
(δ Ce) 798 - 726	<i>cI2</i> <i>Im$\bar{3}m$</i> W	$a = 412$	dissolves up to 0.55 at.% Cu at 708°C [2002Per] [2002Per]
(γ Ce) 726 - 61	<i>cF4</i> <i>Fm$\bar{3}m$</i> Cu	$a = 510.10$	dissolves up to 0.37 at.% Cu at 708°C [2002Per] [2002Per]
(β Ce) 61 - (–177)	<i>hP4</i> <i>P6$_3$/mmn</i> α La	$a = 308.10$ $c = 1185.7$	at 24°C [2002Per]
(α Ce) < –177	<i>cF4</i> <i>Fm$\bar{3}m$</i> Cu	$a = 485$	at –196°C [2002Per]
(Ge) < 938.3	<i>cF8</i> <i>Fd$\bar{3}m$</i> C (diamond)	$a = 565.74$	at 25°C [Mas2]
CeCu < 516	<i>oP8</i> <i>Pnma</i> FeB	$a = 737.0$ $b = 462.3$ $c = 564.8$	[2002Per]
CeCu ₂ < 817	<i>oI12</i> <i>Imma</i> KHg ₂	$a = 442.9$ $b = 706.1$ $c = 747.4$	[2002Per]
CeCu ₄ < 796	<i>oP20</i> <i>Pnnm</i> CeCu ₄	$a = 458$ $b = 810$ $c = 935$	[2002Per]
CeCu ₅ < 798	<i>hP6</i> <i>P6/mmm</i> CaCu ₅	$a = 514.8$ $c = 410.8$	[2002Per]
β CeCu ₆ 938 - (–43)	<i>oP28</i> <i>Pnma</i> β CeCu ₆	$a = 810.88$ $b = 510.04$ $c = 1016.21$	at 22°C [2002Per]
		$a = 810.09$ $b = 509.78$ $c = 1015.48$	at –23°C [2002Per]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
αCeCu_6 < –43	<i>mP</i> 28 <i>P</i> 2 ₁ / <i>c</i> αLaCu_6	$a = 509.5$ $b = 1014.66$ $c = 809.31$ $\beta = 90.485^\circ$	at –73°C [2002Per]
		$a = 508.92$ $b = 1013.26$ $c = 807.89$ $\beta = 91.148^\circ$	at –173°C [2002Per]
		$a = 508.41$ $b = 1012.79$ $c = 807.31$ $\beta = 91.442^\circ$	at –263°C [2002Per]
Cu_3Ge < 790	<i>hP</i> 8 <i>P</i> 6 ₃ / <i>mmc</i> <i>AsNa</i> ₃	$a = 417$ $c = 696$	[V-C2] [Mas2]
ϵ , $\sim\text{Cu}_3\text{Ge}(\text{h}_2)$ 747 – 549.5	<i>hP</i> 8 <i>P</i> 6 ₃ / <i>mmc</i> <i>AsNa</i> ₃	$a = 416.9$ $c = 749.9$	at 76 at.% Cu [2002Fer]
ϵ_2 , $\sim\text{Cu}_3\text{Ge}(\text{h}_1)$ 698 – 614	<i>cF</i> 16 <i>Fm</i> $\bar{3}m$ <i>BiF</i> ₃	$a = 590.6$	at 71.4 at.% Cu (Cu_5Ge_2) [2002Fer]
ϵ_1 , $\sim\text{Cu}_3\text{Ge}(\text{r})$ < 636	<i>oP</i> 8 <i>Pmmn</i> $\beta\text{Cu}_3\text{Ti}$	$a = 528$ $b = 422$ $c = 454$	74.9 to 76.9 at.% Cu [2002Fer]
Cu_5Ge	<i>hP</i> 2 <i>P</i> 6 ₃ / <i>mmc</i> <i>Mg</i>	$a = 261.2$ $c = 423.1$	[V-C2]
Ce_5Ge_3 < 1500	<i>hP</i> 16 <i>P</i> 6 ₃ / <i>mmc</i> <i>Mn</i> ₅ <i>Si</i> ₃	$a = 890$ $c = 663$	[Mas2] annealing at 600°C [V-C2]
		$a = 884$ $c = 672$	after melting [V-C2]
		$a = 885.9$ $c = 662.8$	annealing at 1000°C [V-C2]
Ce_4Ge_3 < 1293	<i>cI</i> 28 <i>I</i> $\bar{4}3d$ <i>Th</i> ₃ <i>P</i> ₄	-	[Mas2]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
Ce_5Ge_4 < 1345	<i>oP36</i> <i>Pnma</i> Sm_5Ge_4	$a = 796$ $b = 1521$ $c = 804$	[Mas2] [V-C2]
CeGe < 1433	<i>oP8</i> <i>Pnma</i> FeB	$a = 835.4 \pm 0.5$ $b = 408.2 \pm 0.3$ $c = 603.3 \pm 0.3$	[Mas2] [V-C2]
αCeGe_{2-x} < 560	<i>o*</i> <i>Imma</i> αCdSi_2	$a = 436 \pm 0.1$ $b = 426 \pm 0.1$ $c = 1407 \pm 0.1$	61.1 to 62.12 [Mas2] [V-C2]
		$a = 428.2$ $b = 419.9$ $c = 1408.1$	[V-C2]
βCeGe_{2-x} 1513 - 490	<i>tI12</i> <i>I4₁/amd</i> ThSi_2	$a = 421.0 \pm 0.2$ $c = 1418.2 \pm 0.5$	61.1 to 62.12 [Mas2] [V-C2]
		$a = 426$ $c = 1422$	[V-C2]
* τ_1 , CeCu_2Ge_2	<i>tI10</i> <i>I4/mmm</i> ThCr_2Si_2 or CeGa_2Al_2	$a = 417$ $c = 1021$ $a = 418.6$ $c = 1027.8$	after melting at room temperature [1989Kno] [1997Kri]
		$a = 417.2$ $c = 1021.2$	after annealing at 600°C and quenching [1996Sal]
* τ_2 , Ce_2CuGe_6	<i>oC18</i> <i>Cmm2</i> Ce_2CuGe_6	$a = 421.52 \pm 0.01$ $b = 407.56 \pm 0.02$ $c = 2154.08 \pm 0.07$	after annealing at 600°C and quenching [1988Kon1,1996Sal]
		$a = 421.16 \pm 0.05$ $b = 407.25 \pm 0.05$ $c = 2158.4 \pm 0.4$	after annealing at 600°C and quenching [1995Sol]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_3 , CeCu_xGe_2	<i>oC16</i>		$0.86 \leq x < 1$ [1990Fra]
	<i>Cmcm</i>		
	CeNiSi_2	$a = 429.9 \pm 0.2$ $b = 1732.2 \pm 0.6$ $c = 416.4 \pm 0.1$	at $x = 1$, after annealing at 600°C and quenching [1996Sal]
		$a = 427.6 \pm 0.4$ $b = 1729 \pm 1$ $c = 4145 \pm 4$	at $x = 0.86$, after homogenization at 900°C [1990Fra]
		$a = 428.67 \pm 0.07$ $b = 1430.20 \pm 0.14$ $c = 415.17 \pm 0.03$	at $x = 0.86$, after homogenization at 900°C [2002Gil]
		$a = 425.90 \pm 0.11$ $b = 1720.89 \pm 0.52$ $c = 412.58 \pm 0.10$	at $x = 0.86$ and 1.5 K [2002Gil]
		$a = 426.09 \pm 0.11$ $b = 1721.90 \pm 0.50$ $c = 412.76 \pm 0.10$	at $x = 0.86$ and 5 K [2002Gil]
* τ_4 , $\text{Ce}_2\text{Cu}_3\text{Ge}_3$	<i>oC16</i>	$a = 416.8$	after annealing at 600°C and quenching [1988Kon1]
	<i>Cm2m</i>	$b = 1740.9 \pm 0.2$	
	$\text{Ce}_2\text{Cu}_3\text{Ge}_3$	$c = 421.1$	
		$a = 416.80 \pm 0.04$ $b = 1740.9 \pm 0.2$ $c = 421.08 \pm 0.05$	after annealing at 600°C and quenching [1996Sal]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_5 , CeCuGe	<i>hP3</i> <i>P6mmm</i> AlB ₂	$a = 429.6$ $c = 398.8$	[1965Gla]
		$a = 429.6$ $c = 398.8$	for as-cast sample [1969Rie2]
		$a = 430.8 \pm 0.2$ $c = 396.6 \pm 0.2$	after annealing at 750 °C [1993Ian]
		$a = 431.6 \pm 0.1$ $c = 396.7 \pm 0.1$	after annealing at 600°C and quenching [1996Sal]
	or		
	<i>hP6</i> <i>P6₃/mmc</i> ZrBeSi	$a = 431.1$ $c = 793.3$	after annealing at 800°C [1991Yan]
		$a = 430.2 \pm 0.1$ $c = 791.9 \pm 0.2$	annealing at 700°C [2004Che]
* τ_6 , CeCu _{0.6-0.8} Ge _{1.4-1.2} or Ce(Cu _x Ge _y) ₂	<i>hP3</i> <i>P6mmm</i> AlB ₂		annealing at 600°C and quenching [1996Sal] for CeCu _{0.67} Ge _{1.33} after melting [1969Rie]
		$a = 421.4 \pm 0.2$ to 418.8 ± 0.1 $c = 420.6 \pm 0.3$ to 426.4 ± 0.2	at $0.25 \leq x \leq 0.275$ and $0.675 \leq y \leq 0.70$ after annealing at 800°C [2002Nak] ^o
		$a = 419.7$ $c = 424.5$	at $x = 0.275$ and $y = 0.675$ after annealing at 800°C [2002Nak]
		$a = 419.1$ $c = 423.4$	at $x = 0.25$ and $y = 0.70$ after annealing
		$a = 418.3$ $c = 424.5$	at 800°C [2002Nak]
* τ_7 , Ce _{0.60} Cu _{0.25} Ge _{0.15}	-	-	annealing at 600°C and quenching [1996Sal]
* τ_8 , Ce _{0.60} Cu _{0.05} Ge _{0.35}	-	-	annealing at 600°C and quenching [1996Sal]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_9 , $\text{Ce}(\text{Cu}_x\text{Ge}_y)_2$	$tI12$ $I4_1/amd$ αThSi_2	$a = 424.6$ $c = 1449.4$	at $0.175 \leq x \leq 0.20$ and $0.75 \leq y \leq 0.775$ after annealing at 800°C [2002Nak]
		$a = 422.1$ $c = 1438.1$	at $x = 0.20$ and $y = 0.75$ after annealing 800°C [2002Nak]
* τ_{10} , Ce_2CuGe_3	o^*	$a = 726.2$ $b = 459.1$ $c = 423.1$	as-cast samples at room temperature / [2000Tie]
* τ_{11} , $\text{Ce}_3\text{Cu}_4\text{Ge}_4$	$oI22$ $Immm$ $\text{Gd}_3\text{Cu}_4\text{Ge}_4$	$a = 1489.4 \pm 0.4$ $b = 692.3 \pm 0.2$ $c = 453.4 \pm 0.1$	annealing at 800°C and quenching [2002Zah]
$\text{CeCuGeH}_{1.0(1)}$	$hP6$ $P6_3/mmc$ ZrBeSi	$a = 424.4 \pm 0.1$ $c = 831.1 \pm 0.2$	[2004Che]

Table 3: Investigations of the Ce-Cu-Ge Materials Properties

Reference	Method/Experimental Technique	Type of Property
[1985Rau]	standard techniques	Electrical resistivity, thermoelectric power, magnetic susceptibility, specific heat for CeCu_2Ge_2
[1989Kno]	time-of-flight spectrometers IN4 (located on a thermal neutron source),	Quasielastic line widths in CeCu_2Ge_2
[1989Loi]	time-of-flight spectrometers IN4 (located on a thermal neutron source), IN6 (located on a cold source) / high flux reactor at the Institute Laue-Langevin (Grenoble)	Quasielastic line in CeCu_2Ge_2
[1991Yan]	standard techniques	Magnetic susceptibility, magnetization, specific heat of CeCuGe
[1995Sol]	SQUID magnetometer	Magnetic susceptibility of Ce_2CuGe_6
[1998Kob]	Fluorescence method, four probes AC method for measurement of resistivity	Phase diagram in CeCu_2Ge_2 under high pressure, resistivity at low temperature and high pressure up to 21 GPa
[1998Var]	Bridgman technique	Pressure, CeCu_2Ge_2
[2000Kon]	Faraday balance	Magnetic susceptibility in the range 84 to 300 K, electrical resistivity in the range 78 to 300 K, differential thermopower for Ce_2CuGe_6

Reference	Method/Experimental Technique	Type of Property
[2000Tie]	SQUID magnetometer	Magnetic properties of Ce_2CuGe_3
[2001Raw]	four-probe method for the measurement of electrical resistivity, semiadiabatic heat pulse method	Resistivity of CeCu_2Ge_2 heat capacity measurements
[2002Zah]	quantum design physical property measurement system (PPMS)	DC susceptibility, specific heat of $\text{Ce}_3\text{Cu}_4\text{Ge}_4$
[2004Che]	Superconducting Quantum Interference Device magnetometer, dc four probe measurements, dynamic method	Magnetization measurements, electrical resistivity, thermoelectric power of $\text{CeCuGeH}_{11.0(1)}$

Fig. 1: Ce–Cu–Ge.
Isothermal section at
600°C (below 45 at.%
Ce) and 400°C (above
45 at.% Ce)

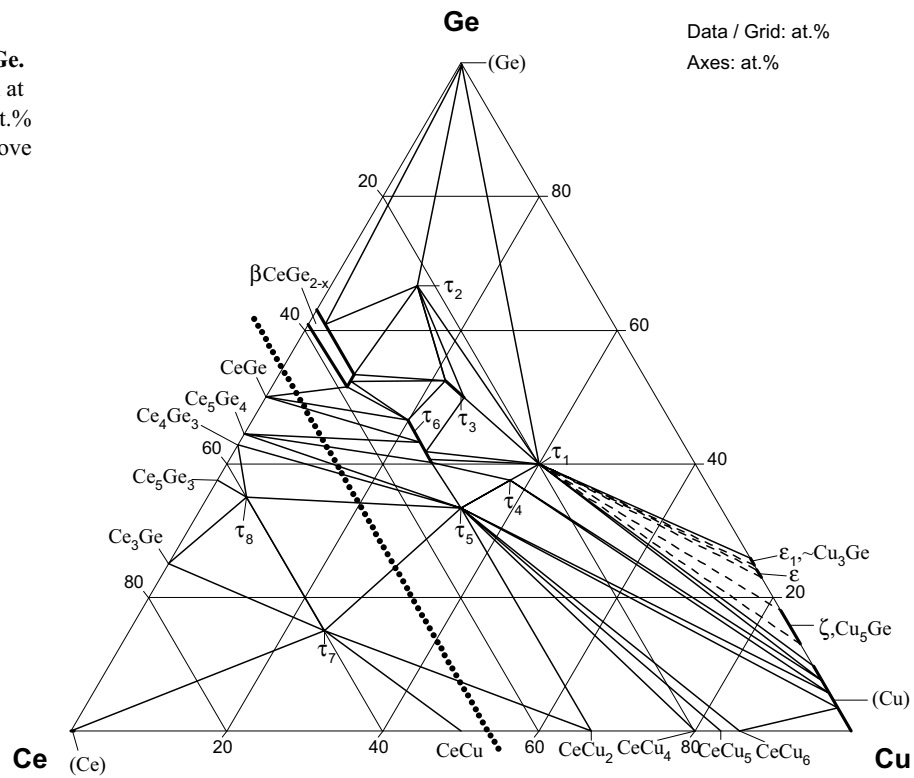


Fig. 2: Ce-Cu-Ge.
Partial isothermal
section at 800°C

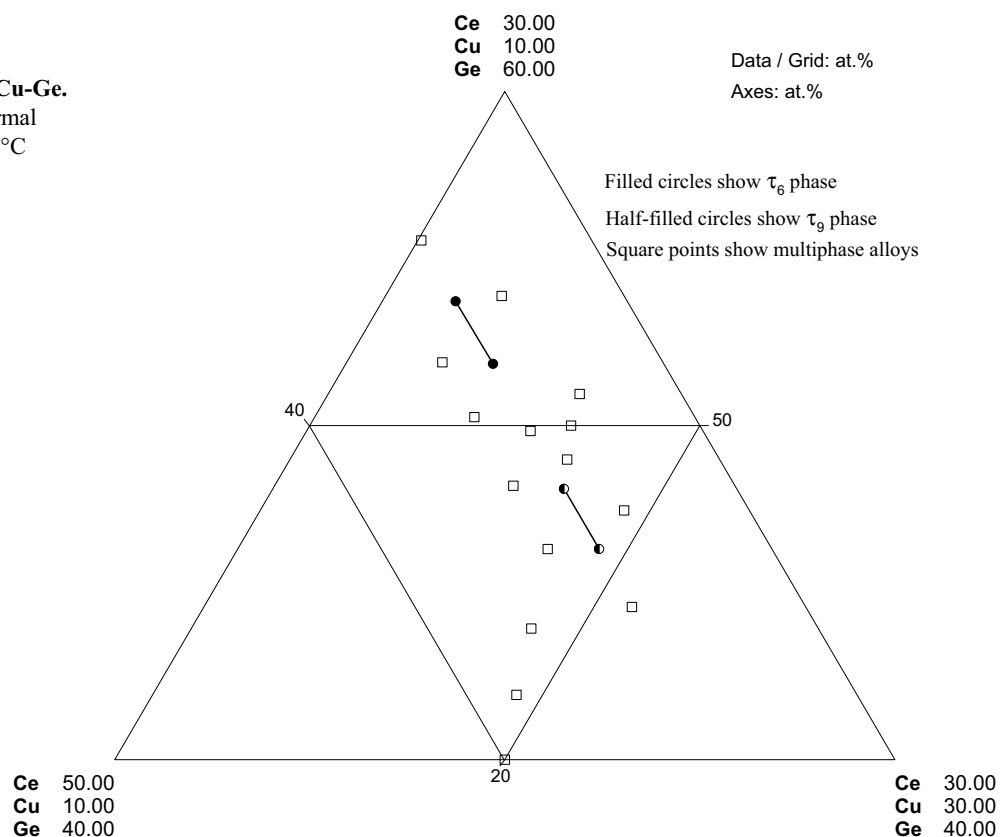


Fig. 3: Ce-Cu-Ge.
Phase diagram of
 CeCu_2Ge_3 under
high pressure.
M - magnetic phase,
SC - superconducting
phase, FL - the
temperature region
where the $p(T)$
follows
the AT^2 -law

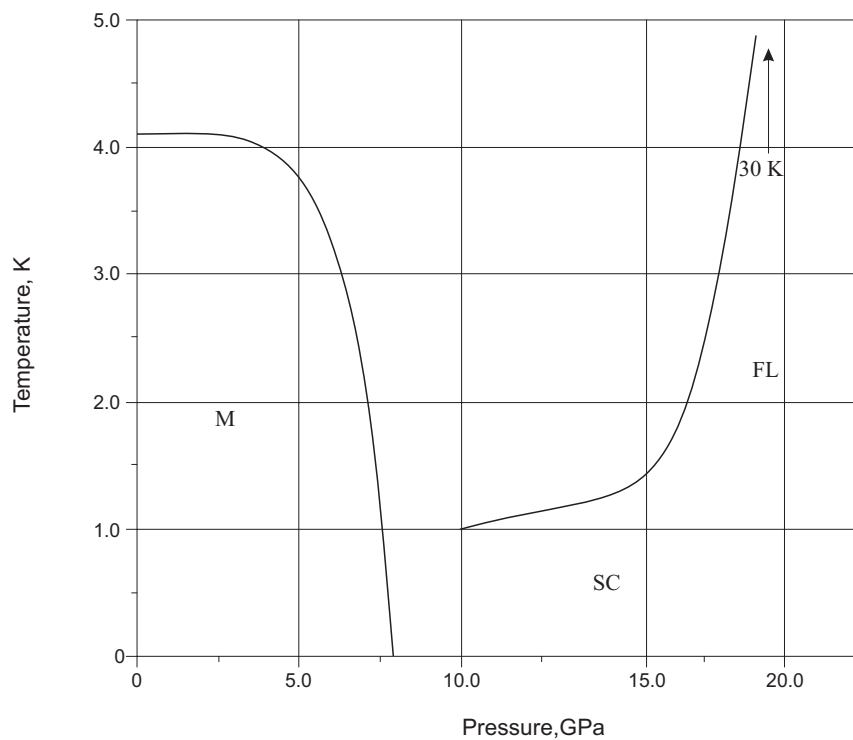


Fig. 4: Ce-Cu-Ge.

The pressure dependence of the temperatures of magnetic ordering

