Cerium – Copper – Indium

Oksana Bodak†, Nataliya Bochvar

Introduction

The Ce-Cu-In ternary system was investigated and isothermal sections were constructed at 600°C in the concentration range from 0 to 33.3 at.% Ce and at 400°C in the concentration range from 33.3 to 100 at.% Ce [1991Bar]. Crystal structures and lattice parameters of the ternary compounds of the Ce-Cu-In system were determined by [1976Dwi, 1984Kal, 1985Fel, 1988Bar, 1988Kal, 1988Tak1, 1989Sys, 1990Bar, 1990Kal, 1991Bar, 1996Kac, 1998Kam, 1999Tak, 2005Bob]. Almost all investigators prepared alloys using pure compacted metals, arc-melted under argon or helium. After melting, the samples were sealed in evacuated silica capsules and annealed at different temperatures for prolonged times followed by quenching into water or slow cooling in the furnace. [2005Bob] used another method of alloys preparation. Mixtures of the elements were loaded into evacuated alumina crucibles, which were heated at a temperature of 1100°C for 4 h, followed by slow cooling (3 $K \cdot h^{-1}$) to 800°C. At this temperature, the molten flux (Cu-In eutectic) was removed by centrifuge. The recovered product consisted of relatively large and well defined crystals which were later identified as a ternary compound.
Information concerning investigations of phase relations, structures and thermodynamics in the Ce-Cu-In system is summarized in Table 1.
[1998Kal, 2005Kal] reviewed literature data and the results of their own experimental investigations of the R-Cu-In systems and presented the isothermal sections of the Ce-Cu-In system and crystal structures of ternary Ce-Cu-In compounds. [2003Luk] has reviewed the crystal chemistry, chemical bonding and physical properties of the tetragonal U_3Si_2 type compounds, in particular, Ce_2Cu_2In. A series of works were devoted to the investigation of the magnetic and electrical characteristics of the different ternary compounds. This information is summarized in Table 3.

Binary Systems

The Ce-In binary system is accepted from [Mas2]. Cu-In is from [2000Goe], based mainly on [1972Jai]. The Ce-Cu system is accepted from [2002Per].

Solid Phases

Crystallographic data of the binary and ternary compounds that are formed in the ternary Ce-Cu-In system are shown in Table 2. There are ten ternary compounds [1991Bar, 1998Kal].
[1990Bar] discovered the compound τ_1 $\{Ce_{1-x}(Cu_{0.68}In_{0.32})_{12}Cu_{1-y}$ at $x = 0.22$; $y = 0.36\}$ and estimated its crystal structure in a sample annealed at temperature 600°C and subsequently quenched. [1989Sys] determined the crystal structure of the compound τ_2 ($CeCu_{5.1}In_{6.9}$) in as-cast samples. [1991Bar] found the compounds τ_3 ($CeCu_9In_2$) and τ_4 (~$CeCu_{4.2}In_{4.8}$) in the isothermal section for 600°C. [1991Bar] determined the crystal structure of τ_3 and found that the compound has a homogeneity range from ~16 to 25 at.% In along 8.3 at.% Ce section. The crystallographic characteristics of the τ_4 compound have not been determined. [1988Kal] investigated the crystal structure of the compound τ_5 ($CeCu_{4.38}In_{1.62}$) and estimated that this compound crystallizes with the space group *Pnnm* and belongs to a new structure type derived from the parent $CeCu_6$ compound through the doubling the *a* axis of the unit cell. On the other hand, [2005Bob] carried out detailed structural studies of this compound and showed that it belongs to the orthorhombic $CeCu_6$ structure type (space group *Pnma*). [2005Bob] considered that such differences could arise from the differences in samples production - arc-melting and subsequent annealing [1998Kal] or growth in a Cu-In flux [2005Bob]. The $CeCu_6$ structural type of the τ_5 compound was expected by [1995Kas, 1998Kam]. The τ_5 compound has a homogeneity range from 13 to 26 at.% In [1991Bar] or from 8 to 29 at.% [1995Kas] along the 14.3 at.% Ce section. Further investigations are required in order to obtain more exact information about the crystal structure and the homogeneity range of this compound. The crystal structure of the τ_6

($CeCu_2In$) compound was reported by [1985Fel]. The lattice parameters of τ_6 were determined by [1985Fel, 1987Lah, 1988Tak1]. The crystal structure of the τ_7 (CeCuIn) compound was estimated by [1976Dwi] and the lattice parameters were given by [1991Bar]. The crystal structure of the τ_8 ($CeCu_{0.5}In_{1.5}$) was determined by [1988Bar]. According to [1991Bar], this compound has a homogeneity range from 40 to 55 at.% In along the 33 at.% Ce section. The crystal structures of the τ_9 ($Ce_2Cu_{5.1}In_{6.9}$) and τ_{10} ($CeCu_{2-x}In_{2-y}$) compounds were described by [1990Kal] and [1990Bar], respectively. [1990Bar] showed that the compound τ_{10} is found only after casting but not after subsequent annealing at 600°C.

Isothermal Sections

[1991Bar] constructed isothermal sections of the Ce-Cu-In system at 600°C in the concentration range 0 to 33.3 at.% Ce and at 400°C in the concentration range 33.3 to 100 at.% Ce, on the basis of experimental data. Information of these sections is also reported in [1998Kal] and [2005Kal]. The isothermal sections of Ce-Cu-In system shown in Fig. 1 were constructed on the basis of data from [1991Bar] with the addition of the $CeCu_4$ compound taken from the accepted Ce-Cu binary system [2002Per].

Thermodynamics

Specific heat investigation of the $CeCu_2In$ compound (Heusler phase) was reported in [1987Lah, 1988Tak1, 1988Tak2, 1992Sat, 1995Kas]. $CeCu_2In$ is a heavy fermion compound. It has a large specific heat coefficient indicating a large effective mass. According to [1987Lah], no magnetic transition is visible for $CeCu_2In$, and the C/T variation only shows a broad maximum of 2 $J \cdot mol^{-1} \cdot K^{-1}$ near $T = 2.5$ K. According to [1988Tak1], the low-temperature specific heat of $CeCu_2In$ has an enormous electronic contribution, with $C/T = 1.2$ $J \cdot mol^{-1} \cdot K^{-2}$ below 1.2 K and shows a broad maximum at around 2.2 K. In [1992Sat], the magnetic specific heat of the $CeCu_2In$ compound and its entropy changes were recorded. Anomalous behavior due to a dense Kondo effect was observed. This indicates that $CeCu_2In$ undergoes an antiferromagnetic phase transition at $T_N = 2.3$ K. Similar results were obtained by [1988Tak2]: the low temperature specific heat coefficient C/T shows a maximum at 0.9 K; the maximum value is 1.4 $J \cdot mol^{-1} \cdot K^{-2}$. [1995Kas] measured specific heat *vs* T for the $CeCu_{6-x}In_x$ compound at $x = 0.5$, 1.0, 1.25, 1.5 and 1.75. The specific heat measurements revealed that the samples with x up to 1.0 did not show any anomaly owing to magnetic ordering within the temperature range investigated (from 1.7 to 15 K). The specific heat coefficient for $CeCu_5In$ ($x = 1.0$) was 0.2 $J \cdot mol^{-1} \cdot K^{-2}$. However, $C(T)$ curves for the samples with x above 1.0 suggested the onset of magnetic order: T_N is 2.2 K for $x = 1.5$ and ~1.5 K for $x = 1.75$.

Notes on Materials Properties and Applications

Measurement of the magnetic and electrical properties of the $CeCu_2In$ compound, specifically the temperature and pressure dependencies of magnetic susceptibility and electrical resistivity were made by [1985Fel, 1987Lah, 1988Tak1, 1988Tak2, 1989Oom, 1992Oom, 1992Kag, 1996Kac, 2000Sio, 2002Mil]. Information regarding investigations of material properties is summarized in Table 3.

The magnetic behavior of the $CeCu_2In$ compound was studied by [1985Fel] over the temperature range from 2 to 300 K. $CeCu_2In$ exhibited normal paramagnetic behavior and adhered closely to the Curie-Weiss law of over the major portion of the measured temperatures.

[1987Lah] constructed magnetic isotherms for a $CeCu_2In$ single crystal along the {100} axis at $T = 1.5$, 4.2 and 8 K. The magnetization anisotropy was found to be extremely small. The reciprocal susceptibilities for the $CeCu_2In$ were constructed by [1987Lah], also in the temperature range from 1.5 to 100 K. [1988Tak2] reported that for $CeCu_2In$, the ground state is antiferromagnetic. There exists disordering between the Ce atoms and the In atoms in the Heusler structure. The order parameter is 0.8. $CeCu_2In$ undergoes an antiferromagnetic phase transition at $T_N = 2.3$ K [1988Tak1].

The thermal expansion coefficient, α, of single crystalline $CeCu_2In$ has been measured between 4.2 and 300 K [1989Oom]. α along the {110} direction is very large at temperatures below 100 K. There is a large contribution from the 4f electron in $CeCu_2In$.

The effect of the magnetic field on the electrical resistivity of $CeCu_2In$ at pressures up to 2 GPa was measured over the temperature range from 2 to 60 K [1992Oom]. The coherent temperature was found to increase with pressure.
[1992Kag] reported the dependence of the lattice parameters of the $CeCu_2In$ compound as a function of pressure at room temperature. The temperature dependence of electrical resistivity was also determined in [1992Kag]. It was found that the maximum in the ρ(T) curve due to Kondo effect disappears at high pressure.
The magnetic behavior of the Ce_2Cu_2In and Ce_2CuIn_3 compounds were shown in [1996Kac] and [2000Sio], respectively. The magnetic susceptibility of Ce_2CuIn_3 was measured in [2000Sio]. It shows that compound does not have any ordering temperature down to 4.2 K and remains paramagnetic. The Ce_2Cu_2In compound was found to order antiferromagnetically below T_N = 5.5 K [1996Kac]. The temperature dependence of the electrical resistivity for this compound has a metallic character. [2002Mil] has shown that hydrogenation weakens the magnetic exchange interactions in Ce_2Cu_2In, which turns from an antiferromagnet with T_N = 5.5 K, into a paramagnet.

Miscellaneous

[1997Ple] studied the effects of Al, Ga, Sn or Fe, Ni, Pd and Pt doping of the cubic $CeCu_2In$ compound. At least 20% In or 10% Cu can be replaced by respective metalloid or transition metal atoms without changing the crystal structure. The main influence of the substitutions on the physical properties of $CeCu_2In$ is to change the Kondo temperature and crystalline electric field splitting. Using X-ray diffraction, [1999Tak] detected residual short-range order in the $CeCu_2In$ compound. In spite of the long-range order of this substance, diffuse scattering exhibiting short-range order was observed at room temperature. [2002Mil] investigated the interaction of the Ce_2Cu_2In compound with hydrogen. The synthesis of the hydrides was performed at a hydrogen pressure of 0.8 bar and temperature of 593 K. The formation of the $Ce_2Cu_2InH_{1.5}$ hydride was estimated. It has the structure type Mo_2FeB_2 (space group *P4/mbm*) with lattice parameters a = 780.50 ± 0.20 pm and c = 410.40 ± 0.11 pm.

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

Reference	Method/Experimental Technique	Temperature/Composition/Phase Studied
[1976Dwi]	X-ray diffraction Debye-Scherrer method	Annealing at 800°C / CeCuIn/Crystal structure and lattice parameter
[1984Kal]	X-ray powder diffraction/ DRON-2.0	Annealing at 800°C for 700 h / $CeCu_2In$/ Lattice parameters
[1985Fel]	X-ray powder diffraction	As-cast samples / $CeCu_2In$ / Lattice parameters

Reference	Method/Experimental Technique	Temperature/Composition/Phase Studied
[1987Lah]	Specific-heat measurements Neutron scattering experiments/ IN4 spectrometer	1.5-300 K / $CeCu_2In$ / Specific heat, lattice parameters at room temperature
[1988Tak1]	X-ray powder diffraction Specific-heat/adiabatic calorimeters and Cu NMR measurements/phase-coherent NMR spectrometer	As-cast samples, 0.22-20 K / $CeCu_2In$ / Specific heat, latter parameters at room temperature
[1988Tak2]	X-ray powder diffraction	As-cast samples / $CeCu_2In$ / Crystal structure and lattice parameters
[1988Bar]	X-ray single crystal and powder diffraction/HZG-4A Laue's method Weissenberg method	Annealing at 600°C for 750 h / $CeCu_{0.5}In_{1.5}$ (single crystal) / Crystal structure and lattice parameters
[1988Kal]	X-ray single crystal diffraction/Syntex *P*1 Laue's method Weissenberg method	Annealing at 600°C / $CeCu_{4.38}In_{1.62}$ (single crystal) / Crystal structure and lattice parameters
[1989Sys]	X-ray single crystal and powder diffraction/DRON-3.0 Laue's method Weissenberg method	Annealing at 600°C /$CeCu_{5.1}In_{6.9}$ / Crystal structure and lattice parameters
[1990Bar]	X-ray single crystal diffraction/Syntex *P*1 Laue's method Weissenberg method X-ray powder diffraction/ DRON-3.0	Annealing at 1030°C for 24 h / $CeCu_{2-x}In_{2-y}$ ($x = y = 0.50$) (single crystal) / Crystal structure and lattice parameters Annealing at 600°C for 750 h / $Ce_{1-x}(Cu_{0.68}In_{0.32})_{12}Cu_{1-y}$ ($x = 0.22$; $y = 0.36$) / Crystal structure and lattice parameters
[1990Kal]	X-ray analysis	Annealing at 600°C / Ce_2Cu_2In / Lattice parameters
[1991Bar]	X-ray powder diffraction Debye-Scherrer method/APOC DRON-2.0, DRON-3.0 Microstructural analysis/Neophot-30	Annealing at 600°C for 750 h and quenching / Ce-Cu-In at 0 to 33.3 at.% Ce/ Annealing to 400°C for 1500 h/ Ce-Cu-In at 33.3 to 100 at.% Ce/ Isothermal sections at 600 and 400°C, crystal structure and lattice parameters
[1992Kag]	X-ray diffraction	Single crystal (Czochralski method)/ $CeCu_2In$/ Lattice parameters at room temperature and pressure up to 15 GPa
[1992Sat]	Specific-heat measurements Adiabatic standard method	Single crystal (Czochralski method)/ $CeCu_2In$/ Specific heat
[1995Kas]	X-ray analysis	Single crystal and polycrystalline samples/ $CeCu_{6-x}In_x$ (x =0.5, 1.0, 1.25, 1.38, 1.5, 1.75, 2.0), annealing at 530°C for 5 days / Crystal structure and lattice parameters

Reference	Method/Experimental Technique	Temperature/Composition/Phase Studied
[1996Kac]	X-ray single crystal/STOE Nicolet four-circle diffractometer and powder diffraction/Guinier camera, Siemens D5000 diffractometer	Annealing at 650°C for 2 weeks / Ce_2Cu_2In / Lattice parameters
[1997Ple]	X-ray powder diffraction	As-cast samples, at room temperature / $CeCu_2In$ / Lattice parameters
[1998Kam]	Neutron powder diffraction/TOF versatile diffractometer	Annealing at 530°C for 5 days / $CeCu_5In$/ Crystal structure and lattice parameters
[1999Tak]	X-ray single crystal diffraction/four-circle diffractometer (Photon Factory at the National Laboratory for High Energy Physics) Czochralski crystal-pulling method	Single crystal (Czochralski method) / $CeCu_2In$ / Crystal structure
[2000Sio]	X-ray analysis	Annealing at 480°C for 30 days / Ce_2CuIn_3 / Lattice parameters
[2002Mil]	X-ray powder diffraction/Siemens D500, DRON-4.0, HZG-4a	Annealing at 600°C / Ce_2Cu_2In / Lattice parameters
[2005Bob]	X-ray analysis	Cooling with 800°C/ $CeCu_{5-x}In_{1+x}$ ($0 \le x \le 0.75$)/ Crystal structure and lattice parameters

Table 2: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Cu) < 1084.62	*cF*4 $Fm\bar{3}m$ Cu	 a = 361.46	dissolves up to ~11 at.% In at 574°C [Mas2] at 25°C [Mas2]
		a = 367.27	for 5.9 at.% In [V-C2]
		a = 370.665	for 10 at.% In [V-C2]
(δCe) 798 - 726	*cI*2 $Fm\bar{3}m$ W	 	dissolves up to 0.55 at.% Cu at 708°C [2002Per] and ~10 at.% In at 730°C [Mas2]
		a = 412	[Mas2]
(γCe) 726 - 61	*cF*4 $Fm\bar{3}m$ Cu	 	dissolves up to 0.4 at.% Cu at 708°C [2002Per] and 4 at.% In at 650°C [Mas2]
		a = 510.10	[Mas2]
(βCe) 61 - (–177)	*hP*4 $P6_3/mm$ αLa	a = 308.10 c = 1185.7	at 24°C [2002Per]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(αCe) < –177	*cF*4 *Fm*$\bar{3}$*m* Cu	*a* = 485	at –196°C [2002Per]
(In) < 156.634	*tI*2 *I*4/*mmm* In	*a* = 324.5 ± 0.6 *c* = 494.2 ± 0.6	[Mas2], [V-C2]
CeCu < 516	*oP*8 *Pnma* FeB	*a* = 737.0 *b* = 462.3 *c* = 564.8	[2002Per]
$CeCu_2$ < 817	*oI*12 *Imma* KHg_2	*a* = 442.9 *b* = 706.1 *c* = 747.4	[2002Per]
$CeCu_4$ < 796	*oP*20 *Pnnm* $CeCu_4$	*a* = 458 *b* = 810 *c* = 935	[2002Per]
$CeCu_5$ < 798	*hP*6 *P*6/*mmm* $CaCu_5$	*a* = 514.8 *c* = 410.8	[2002Per]
β$CeCu_6$ 938 - (–43)	*oP*28 *Pnma* β$CeCu_6$	*a* = 810.88 *b* = 510.04 *c* = 1016.21 *a* = 810.09 *b* = 509.78 *c* = 1015.48	at 22°C [2002Per] at –23°C [2002Per]
α$CeCu_6$ < –43	*mP*28 $P2_1/c$ α$LaCu_6$	*a* = 509.5 *b* = 1014.66 *c* = 809.31 β = 90.485° *a* = 508.92 *b* = 1013.26 *c* = 807.89 β = 91.148° *a* = 508.41 *b* = 1012.79 *c* = 807.31 β = 91.442°	at –73°C [2002Per] at –173°C [2002Per] at –263°C [2002Per]
Ce_3In < 910	*cP*4 *Pm*$\bar{3}$*m* $AuCu_3$	*a* = 506.1	24 to ~25 at.% In [Mas2] [V-C2]
Ce_2In < 960	*hP*6 $P6_3/mm$ $InNi_2$	*a* = 555.7 *c* = 690.8	32 to 33.3 at.% In [Mas2] [V-C2]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$Ce_{1+x}In$ < 1140	-	-	43 to 47 at.% In [Mas2]
$CeIn_{1+y}$ ~ 1070 - ~ 890	-	-	[Mas2]
Ce_3In_5 < 1170	*oC*32 *Cmcm* Pd_5Pu_3	*a* = 1025 *b* = 831 *c* = 1054	60 to 63 at.% In [Mas2] [V-C2]
$CeIn_2$ < 1130	*oI*12 *Imma* $CeCu_2$	*a* = 474.0 *b* = 761.0 *c* = 901.8	[Mas2] [V-C2]
$CeIn_3$ < 1180	*cP*4 $Pm\bar{3}m$ $AuCu_3$	*a* = 468.93 ± 0.02	[Mas2] [V-C2]
α, Cu_4In 710 - 574	*cI*2 $Im\bar{3}m$ W	*a* = 301.40 *a* = 304.61	20.50 at.% In at 625°C [1994Sub] 18.64 at.% In at 672°C [1941And]
β, Cu_7In_3 < 631	*aP*40 $P\bar{1}$ Cu_7In_3	*a* = 107.1 *b* = 913.1 *c* = 672.6 α = 90.2° β = 90.4° γ = 106.82° *a* = 1000 *b* = 910 *c* = 672 α = 89.9° β = 82.6° γ = 106.9°	30.0 at.% In [1980Vro] 29.6 at.% In [1994Sub]
γ, Cu_9In_4 684 - 631	*cP*52 $P\bar{4}3m$ $InMn_3$ or Al_4Cu_9	*a* = 925.03	29.6 at.% In at 650°C [1951Rey]
δ_1, Cu_2In 667 - 440	*hP*6 $P6_3/mmc$ Ni_2In	*a* = 412.0 *c* = 526.3	[V-C2]
δ_2, $Cu_7In_4(h_2)$ 480 - 350	*oP*55 ?	*a* = 2137.5 *b* = 740.5 *c* = 521.8	[1972Jai] superstructure of the Ni_2In type
δ_3, $Cu_7In_4(h_1)$ 450 - 298	*oP*88 ?	*a* = 3419.4 *b* = 739.5 *c* = 526.2	[1972Jai] superstructure of the Ni_2In type

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
δ_4, Cu_7In_4(r) < 389	-	-	[1972Jai]
δ_5, $Cu_{15}In_8$ < 350	-	-	[1972Jai]
* τ_1, $Ce_{1-x}(Cu_{0.68}In_{0.32})_{12}Cu_{1-y}$	*cF*112 *Fm*$\bar{3}$*c* $NaZn_{13}$		*x* = 0.22; *y* = 0.36 [1990Bar] at 5.8Ce-65.5Cu-28.7In (at.%) after annealing at 600°C
		a = 1248.2 ± 0.1	at *x* = 0.22; *y* = 0.36 [1990Bar] after annealing at 600°C
		a = 1248.3 ± 0.1	at *x* = 0.22; *y* = 0.36 [1991Bar]
* τ_2, $CeCu_{5.1}In_{6.9}$	*tI*26 *I*4/*mmm* $ThMn_{12}$	 *a* = 926.3 ± 0.2 *c* = 542.3 ± 0.1	at 7.7Ce-39.2Cu-53.1In (at.%) for as-cast [1989Sys] and annealed at 600°C samples [1991Bar]
* τ_3, $CeCu_{9.0-8.0}In_{2.0-3.0}$	*tP*24 *P*4/*mbm* YNi_9In_2	*a* = 847.6 to 863.1 ± 0.2 *c* = 498.8 to 511.7 ± 0.2	after annealing at 600°C at 8.3 at.% Ce 75.0 to 66.7 at.% Cu 16.7 to 25 at.% In [1991Bar]
* τ_4, ~$CeCu_{4.2}In_{4.8}$	?	?	after annealing at 600°C [1991Bar, 1998Kal]
* τ_5, $CeCu_{5.1-4.2}In_{0.9-1.8}$	*oP*56 *Pnnm* $CeCu_{4.38}In_{1.62}$	 *a* = 1716.9 ± 0.6 *b* = 1090.8 ± 0.4 *c* = 520.2 ± 0.2	[1988Kal] single crystal, after annealing at 600°C for $CeCu_{4.38}In_{1.62}$ at 14.3Ce-62.6Cu-23.1In (at.%) [1988Kal]
	or		
		a = 1672.0 to 1701.9 *b* = 1060.0 to 1080.9 *c* = 507.4 to 518.9	after annealing at 600°C for $CeCu_{4.38}In_{1.62}$ at 14.3 at.% Ce, 72.8 to 60.1 at.% Cu, 12.8 to 25.7 at.% In [1991Bar]
	*oP*28 *Pnma* $CeCu_6$	*a* = 837.605 ± 0.015 *b* = 506.975 ± 0.009 *c* = 1062.490 ± 0.019	after annealing at 530°C for $CeCu_5In$ at 14.3Ce-71.4Cu-14.3In (at.%) [1998Kam]
		a = 840.56 ± 0.07 *b* = 509.39 ± 0.04 *c* = 1073.80 ± 0.08	for $CeCu_{4.83}In_{1.17}$ at 14.3Ce-69.0Cu-16.7In (at.%) [2005Bob]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_6, $CeCu_2In$	*cF*16 $Fm\bar{3}m$ $MnCu_2Al$	a = 678.5 ± 0.1	after annealing at 600°C [1984Kal]
		a = 679.8	for as-cast sample [1985Fel]
		a = 678.4	for as-cast sample at room temperature [1987Lah]
		a = 679.1	for as-cast sample at room temperature [1988Tak1]
		a = 679.06	for as-cast sample [1988Tak2]
		a = 678.9 ± 0.3	for as-cast sample [1997Ple]
* τ_7, CeCuIn	*hP*9 $P\bar{6}2m$ ZrNiAl	a = 749 c = 424	after annealing at 800°C [1976Dwi]
		a = 749.0 ± 0.1 c = 424.9 ± 0.1	after annealing at 600°C [1991Bar, 1998Kal]
* τ_8, $CeCu_{0.8\text{-}0.4}In_{1.2\text{-}1.6}$	*hP*3 *P*6/*mmm* AlB_2	a = 481.8 ± 0.1 c = 389.9 ± 0.1	after annealing at 600°C for $CeCu_{0.5}In_{1.5}$ at 33.3Ce-16.7Cu-50.0In (at.%) [1988Bar]
		a = 480.4 to 483.5 ± 0.1 c = 383.7 to 391.7 ± 0.1	after annealing at 600°C at 33.3 at.% Ce 26.7 to 13.3 at.% Cu 40.0 to 53.1 at.% In [1991Bar, 1998Kal]
		a = 482.1 c = 385.2	after annealing at 470°C for $CeCu_{0.5}In_{1.5}$ at 33.3Ce-16.7Cu-50.0In (at.%) [2000Sio]
* τ_9, Ce_2Cu_2In	*tP*10 *P*4/*mbm* Mo_2FeB_2	a = 773.34 ± 0.17 c = 392.91 ± 0.01	after annealing at 600°C [2002Mil]
	(ordered U_3Si_2 type)	a = 773.5 ± 0.3 c = 392.4 ± 0.2	Polycrystalline sample [1996Kac, 2003Luk]
		a = 773.68 ± 0.06 c = 392.40 ± 0.03	Single crystal sample [1996Kac]
		a = 772.8 ± 0.1 c = 391.6 ± 0.2	after annealing at 600°C [1990Kal, 1991Bar, 1998Kal, 2003Luk]
* τ_{10}, $CeCu_{2-x}In_{2-y}$	*tP*10-2.0 *P*4/*nmm* $CaBe_2Ge_2$	a = 424.5 ± 0.1 c = 1055.0 ± 0.2	x = 50, y = 0.50, at 25Ce-37.5Cu-37.5In (at.%) only in cast alloys [1990Bar, 1991Bar, 1998Kal]

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

Reference	Method/Experimental Technique	Type of Property
[1985Fel]	Magnetic measurements	Magnetization and reciprocal susceptibility for $CeCu_2In$
[1987Lah]	Magnetic and electrical measurements Neutron scattering experiments/ IN4 spectrometer	Magnetic susceptibility and magnetic resistivity / 1.5 - 300 K / $CeCu_2In$
[1988Tak1]	Cu NMR measurements/phase-coherent NMR spectrometer	Magnetization for $CeCu_2In$ at low temperatures
[1988Tak2]	Magnetic and transport investigations	Magnetic susceptibility and electrical resistivity/ for $CeCu_2In$ at low temperatures
[1989Oom]	Thermal expansion measurements Strain gauge method	Thermal expansion coefficient of single crystalline $CeCu_2In$ at 4.2 to 300 K
[1991Kag]	Magnetic investigation	$CeCu_2In$
[1992Oom]	Magnetostriction and magnetoresistance measurements, thermal expansion and electrical resistance measurement Strain gauge method Standard four-probe method	Magnetostriction of single crystalline of $CeCu_2In$ up to 60 K. Magnetoresistance of $CeCu_2In$ at pressure up to 2 GPa and 2 to 60 K.
[1992Kag]	Electrical measurements Standard four-probe method	Resistivity of $CeCu_2In$ at high pressure up to 8 GPa
[1995Kas]	Magnetic and electrical measurements	Magnetic susceptibility and electrical resistivity/ for $CeCu_{6-x}In_x$ at 1.7 to 300 K
[1996Kac]	Magnetic and electrical measurements/Quantum Desing MPMS-5 superconducting quantum interference device magnetometer, Lake Shore ac susceptometer	Magnetic susceptibility and electrical resistivity of Ce_2Cu_2In at 1.7 to 300 K
[2000Sio]	Magnetic measurements/SQUID magnetometer	High and low temperature magnetic susceptibility at 4.2 to 160 K for Ce_2CuIn_3
[2002Mil]	Magnetic investigation/SQUID magnetometer	Magnetic susceptibility of Ce_2Cu_2In at 5 to 300 K

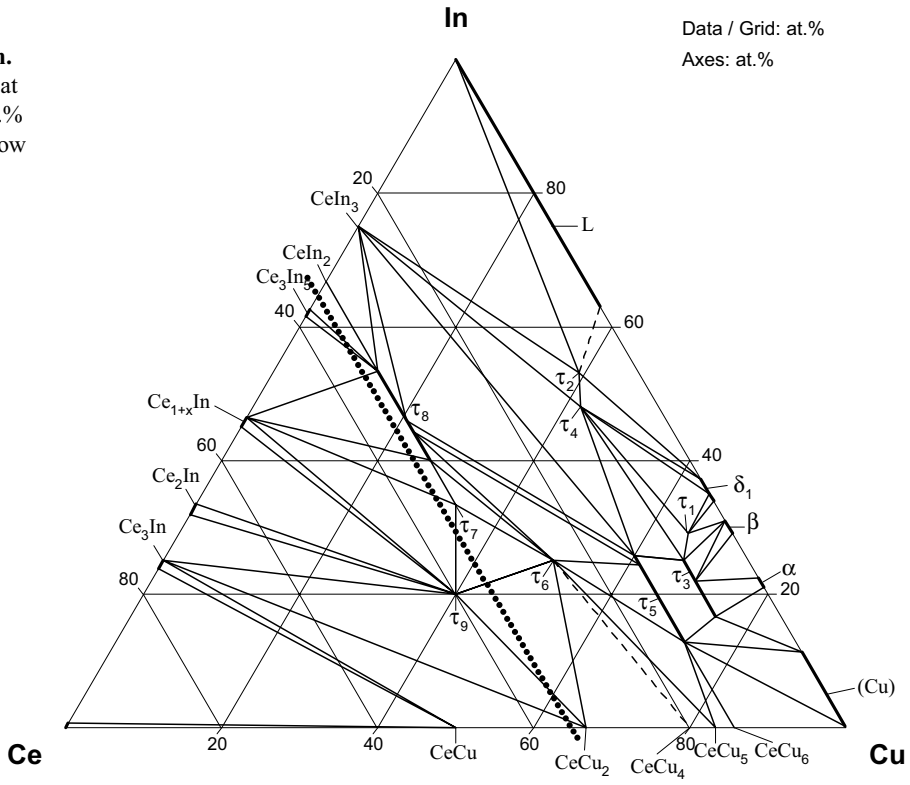

Fig. 1: Ce-Cu-In. Isothermal section at 400 (above 33.3 at.% Ce) and 600°C (below 33.3 at.% Ce)