Aluminium – Copper – Magnesium

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Literature Data

This system was previously evaluated by [1991Eff]. Their evaluation has been used by two groups as the basis for thermodynamic assessments and phase diagram calculations [1993Zuo, 1996Zuo, 1997Che] and [1998Buh, 2003Jan]. Some experiments have been performed to support these calculations [1995Hua, 1995Kim, 1995Soa, 1998Fau] and [1999Fau]. The equilibria in the Al-Cu-Mg system are complicated by the existence of four ternary phases. There is need for experiments to clarify the ternary equilibria involving the three Laves phases, $\lambda_{1\text{-}3}$, which have clearly been identified as three separate phases. The λ_1 phase with a Cu_2Mg type structure is a solution phase of the binary Cu_2Mg compound with replacement of the Cu atoms by Al along the 33.3 at.% Mg section. At a composition close to the Cu_3Mg_2Al formula, the λ_1 phase melts congruently at ~910°C. Further replacement of Cu by Al stabilizes the λ_2 phase with a $MgNi_2$ type structure and then the λ_3 phase with a $MgZn_2$ type structure. A variety of polytype structures with different atom layer stacking sequences have been observed between the $MgNi_2$ and $MgZn_2$ type phases. The $\lambda_{2\text{-}3}$ phases appear to be formed by peritectic reaction and each Laves phase is associated with a region in which it forms as the primary phase on solidification of melts. Four additional ternary compounds have also been studied extensively. The S phase is based on the $CuMgAl_2$ composition, V on $Cu_6Mg_2Al_5$ and Q on $Cu_3Mg_6Al_7$. These three phases exist over very limited homogeneity ranges. The T phase has a broad range of homogeneity. A formula $(Cu_{1-x}Al_x)_{49}Mg_{32}$ is derived from the crystal structure [1952Ber], but also some mutual replacement between Mg and Cu+Al takes place.
The liquidus projection, presented by [1952Ura], does not include the monovariant curves associated with the $L + \lambda_1 \rightleftharpoons \lambda_2$ and $L + \lambda_2 \rightleftharpoons \lambda_3$ peritectic reactions. The Laves phase λ_1 is the predominant primary phase, but also the regions for primary solidification of (Al) and (Mg) are relatively large. Six pseudobinary reactions have been identified experimentally, and the pseudobinary reaction e_3 (Table 2b) has been suggested. The invariant reactions associated with the primary (Al) phase region are well characterized by numerous workers. The invariant reactions associated with the primary V, Q and T phase regions have been elucidated by Russian workers, summarized by [1952Ura]. The liquidus surface across the Mg_2Al_3, T and $Mg_{17}Al_{12}$ phase regions is exceptionally flat and ranges in temperature from 420 to 475°C. [1952Ura] gave a complete reaction scheme. The thermodynamic calculations referred to above in principle reproduce this reaction scheme, but differ in some details.

Binary Systems

Assessments of the Al-Cu system by [2003Gro], of the Al-Mg system by [2003Luk] and of the Cu-Mg system by [2002Iva] are accepted. They are based on [1994Mur, 1998Liu] for Al-Cu, [1982Mur, 1998Lia1] for Al-Mg and [1994Nay] for Cu-Mg. The thermodynamic data set of the COST 507 action [1998Ans, 1998Buh] was updated recently in some details [2003Jan]. It was used for the calculated figures and the reaction scheme presented in this assessment. The homogeneity ranges of the phases Mg_2Al_3, ζ and δ were simplified to stoichiometric phases. η_1 and η_2 were treated as a single phase, η. ζ_1 and ζ_2 were also not distinguished and called ζ.

Solid Phases

There are four well-defined ternary phases, designated in the literature as Q, S, T and V phases. It is quite interesting to note that all ternary compounds in the Al-Cu-Mg system are formed at maxima of three-phase equilibria involving the liquid phase, except the V phase, which is formed in a four-phase peritectic reaction (P_1). In addition the section at 33.3 at.% Mg contains a complex series of ternary Laves-Friauf phases that are designated as λ_1, λ_2, λ_3, 5L, 6L, 9L and 16L in this assessment, Table 1. The Q phase is based on the chemical formula $Cu_3Mg_6Al_7$ [1947Str, 1951Mir1] and has a very limited homogeneity range. The S phase

has been extensively studied [1936Lav1, 1937Nis1, 1938Pet1, 1938Pet2, 1940Kuz, 1941Obi, 1943Per, 1944Lit, 1946Pet, 1946Ura, 1947Str, 1949Mir]. It also has a limited homogeneity range, based on the chemical formula $CuMgAl_2$. Its structure was determined by [1943Per] and confirmed by [1949Mir]. The T phase has been equally thoroughly investigated [1919Vog, 1923Gay, 1935Lav, 1937Nis1, 1940Kuz, 1943Gue, 1944Lit, 1946Pet, 1946Ura, 1948Str, 1949Ura1, 1949Ura2, 1950Phr, 1952Ber, 1966Aul, 2000Tak] and a variety of chemical formulae assigned to it. From the crystal structure determined by [1952Ber], the formula $(Cu_{1-x}\ Al_x)_{49}Mg_{32}$ is adequate. It is found that very few Al atoms occupy site A, which is the center of an isochahedral cluster being almost empty [2000Tak]. The V phase has a small region of homogeneity centered on the $Cu_6Mg_2Al_5$ formula [1936Lav1, 1936Lav2, 1937Sch, 1943Gue, 1947Str, 1948Str, 1949Sam, 1949Ura1, 1951Mir3, 1952Ura] although other chemical formulae have been quoted in the literature. Its structure was determined by [1949Sam] with the ideal formula $Cu_6Mg_2Al_5$. New recent results using DSC and EDS/WDX techniques [2001Fau] confirmed small solubility ranges of the Q and S phases. Moreover, the solubility domain of the V phase seems to be parallel to the Al-Cu binary edge [2001Fau]. Addittional experiments are needed to confirm it.

The Laves-Friauf phases, although well studied, have not been integrated experimentally into the ternary equilibria in a satisfactory manner. The λ_1 phase with a Cu_2Mg type structure is based on the Cu_2Mg binary compound with a substitution of Al atoms for Cu to form a solid solution series. At a composition close to Cu_3Mg_2Al, the λ_1 phase melts congruently [1936Lav1, 1952Ura]. With further replacement of Cu by Al on the 33.3 at.% Mg section, an $MgNi_2$ type phase is stable, λ_2. There is general agreement between [1953Kle, 1965Sli, 1977Kom, 1981Mel1] and [1981Mel2] on the extent of the λ_2 phase region. Earlier work did not detect λ_2 [1934Lav, 1943Gue, 1949Ura1] or regarded it as stable at high temperature only [1936Lav1]. The $MgZn_2$ type structure, λ_3, is formed with further substitution of Cu atoms by Al. The results from the different workers are summarized in Fig. 1. Polytype structure Laves phases with variations in the layer stacking sequences have been studied by [1962Kom, 1977Kit, 1977Kom] and [1981Mel1]. They are located between λ_1 and λ_2, but their ranges of stability could not exactly be separated from those of λ_1 and λ_2. [1998Che] proposed a "new intermetallic compound $Mg_{1.75}Cu_{1.0}Al_{0.4}$" at a composition, where [1991Eff, 2000Fau] and the calculations [1997Che, 1998Buh, 2003Jan] assume two phases, λ_1 and (Mg). The characteristics of this "new phase", however, clearly identify it as the λ_1 phase [2000Fau]. The presence of (Mg) and λ_1 phases were confirmed by [2000Fau] who made XRD experiments on alloys having the same composition as those reported by [1998Che]. Most probably the also present (Mg) phase was not detected in the X-ray patterns of [1998Che] due to line broadening by cold deformation.

Pseudobinary Systems

A number of pseudobinary systems have been reported. The calculation [2003Jan] found 13 maxima of three-phase equilibria, but some of them are less than 1 K above an adjacent four-phase equilibrium and must be taken as tentative only. The (Mg)-λ_1 section is a pseudobinary eutectic [1932Por, 1933Bas, 1934Por, 1949Ura2], e_{13}, Table 2. The (Al)-S section contains a pseudobinary eutectic e_{14} [1937Nis1, 1946Ura, 1948Bro, 1952Han]. The calculated temperatures [2003Jan] of both equilibria are far below those given by [1946Ura] and accepted by [1991Eff]. The sections Mg_2Al_3-T, e_{19}, and $Mg_{17}Al_{12}$-T, e_{16}, are also pseudobinary eutectic sections at Cu contents below the beginning of the primary Q phase region. [1943Gue, 1949Ura1, 1949Ura2, 1951Mir2] and [2003Jan] are in agreement on the nature of these two sections, Table 2. The investigation [1951Mir2] of the region of primary solidification of Q led to the conclusion that the T phase is formed by peritectic reaction with Q at p_{13}, Fig. 2. A pseudobinary reaction was indicated by [1946Ura] who found a maximum on the curve U_8U_{11} corresponding with the peritectic formation of S by reaction of liquid with a Laves phase. [1949Ura1, 1949Ura2] and [1952Ura] refer to the cubic Cu_2Mg type phase λ_1 or to a composition CuMgAl. They take no account of the λ_2 and λ_3 Laves phases. The calculation of [2003Jan] gives λ_2 as the Laves phase participating in this reaction, p_{10}, which is also favoured by [1991Eff]. [1938Pet1] regarded the $CuAl_2$-S section as a pseudobinary, but later work has disproved this assumption.

Invariant Equilibria

Table 2 lists the invariant reactions following from the thermodynamic calculation of [2003Jan] for the Al-Cu-Mg ternary system and may be read in conjunction with Fig. 2. The reaction scheme, following from this calculation is given in Fig. 3. In this calculation, η_1 and η_2 as well as ζ_1 and ζ_2 were considered as single phases and called η and ζ, respectively. The ternary eutectic reaction E_5 has been widely studied, Table 3. The flat nature of the liquidus surface near to E_7 has led to a considerable scatter in quoted compositions and temperatures, Table 4. The reaction has normally been quoted as a ternary eutectic reaction and this is accepted. The transition reaction U_{16} has also been widely studied, Table 5. The work of [1946Ura, 1949Ura2] and [1948Bro] rests on an examination of a greater number of alloys than other work and allowed a more precise determination of the liquid composition at U_{16}. Ternary eutectic reactions in Mg-rich alloys occur at E_6 and E_9. The reaction temperature at E_6 is 1°C [1932Por, 1933Bas, 1934Por] or 2°C [1949Ura2] below the binary Cu-Mg eutectic temperature. The ternary eutectic E_9, Table 6, was initially regarded as involving a Laves phase, but the work of [1951Mir2] indicates that this eutectic involves the Q phase, which was not detected by the previous workers. Faudot et al. [1998Fau, 1999Fau] confirmed the eutectic, Table 6. The ternary eutectic reaction at E_9 was found by [1949Ura2] at 423°C, what agrees well with that calculated by [2003Jan], 424°C. The reaction at U_{13} was regarded as a transition reaction by [1937Nis1, 1952Han], as calculated by [2003Jan], whereas [1946Ura] and [1949Ura2] considered it to be a ternary peritectic reaction, $L+\lambda_1+S \rightleftharpoons T$. [1951Mir2] gives it as $L+\lambda_1+S \rightleftharpoons Q$. There is doubt about this reaction on two counts. The Q phase lies virtually on the L-λ_1 tie line [1952Ura] and it is unlikely that the Laves phase is λ_1. For the reactions U_{15} and U_{18} [2003Jan] reproduced those given by [1951Mir2] with 3°C deviation. For U_{18} Faudot et al. [1998Fau] gave 427°C as calculated by [1998Buh, 2003Jan]. But later [1999Fau] found it at 451°C with a more Al-rich liquid, Table 6. The transition reaction at U_{17} was given by [1951Mir2] as $L+\lambda_1 \rightleftharpoons (Mg)+Q$, but the work of [1981Mel2] indicates λ_3 as the reactant rather than λ_1, whereas [1998Fau, 1999Fau, 2003Jan] assume λ_2. The reactions in the Cu-rich corner have been little studied. In Table 2 are given those calculated by [2003Jan]. [1949Ura2] assumed an eutectic instead of U_2 and a transition reaction instead of E_4. The temperatures of the invariant equilibrium in this area calculated by the two groups [1997Che] and [1998Buh, 2003Jan] deviate up to 20°C. The regions of primary solidification of the Laves phases λ_1, λ_2 and λ_3 have not been experimentally defined, but the calculation [2003Jan] gives them as shown in Fig. 2. [1997Che] did not distinguish these Laves phases.

Liquidus Surface

A liquidus projection, Fig. 2b, is taken from the calculation of [2003Jan] with some minor modifications on the edges according to the binary systems accepted in this assessment. It should be compared with the projection, Figs. 2 and 2a, deduced also from the calculations of [2003Jan]. The liquidus in the ternary diagram was also calculated by [2001Che, 2002Che] using the multicomponent phase diagram calculation software PANDAT. [1999Xie] also studied the liquidus projection in the Al rich corner. Results are in agreemnt with those calculated by [2003Jan]. According to the liquidus of the binary systems accepted in this assessment, the liquidus projection was modified at the edge boundaries. The liquidus isotherms reproduce fairly well those assessed by [1991Eff]. The primary (Al) region has been widely studied with general agreement on the form of the liquidus. The isotherms for the region of primary solidification of the series of Cu-rich Al-Cu phases are uncertain.

Isothermal Sections

The calculated 400°C isothermal section calculated by [2003Jan], Fig. 4, agrees with Fig. 4 of [1991Eff] except the broadening of the homogeneity range of λ_1 near 25 at.% Al, which in calculation needs to model an anomaly in the Gibbs energy description at that composition, but there is no other evidence for an anomaly. The phase Mg_2Al_3 is simplified as a stoichiometric phase as well as the $CuMg_2$, η, ζ and δ phases. The solubility of Cu and Mg in Al-rich alloys at 460°C was determined by [1944Lit] and [1947Str], Fig. 5. [1944Lit] also produced data for 375°C. The results of [1932Dix] agree with the solubilities given in Fig. 5. [1946Pet] found lower Mg solubilities but used fewer alloys. [1955Zam] published solubility curves with a

series of cusps that cannot be reconciled with the alloy constitution. The solubilities of Mg and Cu in (Al) reported in the accepted binary systems have also been taken into account in Fig. 5. The calculated solvus isotherms of [1986Cha] and [2003Jan], Fig. 6, are in good agreement with [1944Lit] and [1947Str]. [1957Rog] reported the solubility of Al and Mg in (Cu), Fig. 7. No comparable work has appeared. In this area the calculation is less reliable, as it cannot be based on adjacent experimental data. More extensive isothermal sections were determined by [1946Pet] at 400°C in the region from Al to S and T. [1949Mir] reported on the S phase region at 420°C, [1949Ura1] on the T and λ_1 phase region at 400°C, [1951Mir1] on the Q phase region at 400°C, [1952Ura] on an almost complete isothermal section at 400°C and [1981Mel2] on the region from 33.3 to 100 at.% Mg at 400°C. [1944Lit] and [1947Str] studied the 460°C isothermal section from Al to the θ, S, Q and T phases.

Temperature – Composition Sections

The liquidus and solidus of the Al rich alloys along the isopleth Al-$Cu_{0.5}Mg_{0.5}$ were calculated by [1997Che, 1999Xie, 2000Lia] using thermodynamic descriptions. The measured solidus data found by [1988Mur] was found to be ~ 0.5 at.% higher than the model-calculated values, while the measured liquidus is in good agreement with the model-calculation. The inaccuracy for the solidus is explained by microsegregations occuring in ternary Al-Cu-Mg alloys [1999Xie].
Several isopleths were calculated by [1997Che, 2003Jan] from thermodynamic descriptions. Figs. 8 and 9a, 9b, 9c show isopleth sections at 33.3 at.% Mg and *x* mass% Al (*x* =60, 70 and 95.5) respectively. The calculated isopleth, taken from [2003Jan] and reported on Fig. 8, is in agreement with the experimental data reported by [1936Lav1] and [1953Kle]. The calculated isopleths reported on Figs. 9a, 9b and 9c are taken from [1998Buh] and describe quite well the experimental information reported by [1937Nis1, 1937Nis2, 1952Han] and [1946Ura]. The calculated isopleths at 37 at.% Al (Fig. 10a) and 43.75 at.% Al (Fig. 10b) show the λ_2 and the Q phases formations respectively [2003Jan].

Thermodynamics

[1972Pre] studied the enthalpy of formation of alloys on the 33.3 at.% Mg section. Substitution of Cu by Al increases the stability of the λ_1 phase although there is a decrease of stability at a valency electron concentration of 1.5 (76.9Cu, 17.3Mg). [1987Hoc] calculated the enthalpy of a ternary alloy containing 33.3% "$MgAl_2$"; agreement with [1972Pre] is fair. [1985Kuz] applied a thermodynamic model to predict the ternary solidus from the ternary liquidus and the binary solidus-liquidus for Al-rich alloys. [1973Dav] used quasi-chemical regular solution theory to calculate the monovariant curve e_2E_5 of Fig. 2a. With the introduction of a ternary interaction parameter the calculated ternary eutectic point E_5, Table 3, shows reasonable agreement with the assessed composition. [1987Lac] calculated the Al-rich region of the phase diagram using an extended Redlich-Kister formalism. Excellent agreement was obtained with the assessed liquidus, Fig. 2b. [1985Far] calculated the composition of the ternary eutectic E_5, Fig. 2a and Table 2, assuming both ideal solution behaviour and regular solution behaviour. The calculated eutectic compositions, 34.4Cu-8.8Mg (mass%) for ideal solutions and 30.3Cu-7.5Mg (mass%) for regular solutions, approximate to the assessed values. The calculated eutectic temperatures are surprisingly low at 273°C and 271°C, respectively. Recently two groups [1997Che] and [1998Buh, 2003Jan] calculated the whole ternary system, describing the Gibbs energies of all phases involved by the compound energy formalism. Both calculations show very similar results, only in the Cu-rich part there is some disagreement of the invariant temperatures (up to 20°C). The first group also calculated solidification paths using the model of Scheil [1993Zuo, 1996Zuo].
[1986Che] measured the enthalpy of fusion of the ternary eutectic E_5 as 365 $J \cdot g^{-1}$ corresponding to 11.8 $kJ \cdot mol^{-1}$ of atoms. [1986Not] measured the enthalpy of formation of the S phase as -63.2 ± 4.0 $kJ \cdot mol^{-1}$ of $CuMgAl_2$. [1995Kim] measured the enthalpy of mixing of ternary liquids by a high temperature calorimeter at 713°C along three lines with constant Al/Mg ratios up to 40 at.% Cu and along Al/Cu = 13/7 up to 27 at.% Mg. [1995Soa] measured the chemical potential of Mg in ternary melts by an isopiestic method.

Notes on Materials Properties and Applications

The mechanical properties such as tensile strengh were investigated by [2002Dav] on 0.02Zn-0.05Ti-0.42Mn-0.27Fe-4.5Cu-1.5Mg-Al-0.17Si alloys.
[2002Zhu] reported that a small addition of Ag (< 0.1 at.%) to an Al-Cu-Mg alloy with a high content of Al promote an increasing strength and creep resistance when compared to Al-Cu-Mg alloys that contain only the $CuAl_2$ precipitate.

Miscellaneous

[1940Kuz] and [1946Kuz] measured lattice spacings of the (Al) phase along sections from Al with various Cu:Mg ratios. [1951Poo] measured the lattice spacings of the (Al) phase along sections from 99 at.% Al, 1 at.% Mg to 99.5 at.% Al, 0.5 at.% Cu and from 98 at.% Al, 2 at.% Mg to 99 at.% Al, 1 at.% Cu, Table 7.
A small addition of Mg to Al-Cu alloys accelerates the formation of Guinier-Preston (GP) zones through the Mg/Cu/vacancy complexes mechanism [2000Hir, 2002Hir].
The crystal structure of a metastable variant of S on aging Al alloys was studied by [1950Bag]. Aging studies of single crystals of an alloy containing 1.2 at.% Cu, 1.2 at.% Mg [1978Ale] showed S particles to be coherent with the Al matrix. The effect of aging on mechanical properties of Al-rich alloys have been reported by [1939Han, 1941Mec] and [1948Sha]. More recent studies on metastable precipitates in (Al) are from [1990Gar] and [1991Jin].
[1959Pal] prepared thin film Al-rich ternary alloys by evaporation on to Al substrates. The constitution is claimed to correspond with bulk samples. There is a growing literature on the formation of a non-equilibrium icosahedral quasicrystalline phase by rapid solidification of alloys in the T phase region. [1986Cas] tentatively outlined the phase region that produces quasicrystals on rapid solidification as containing 10 to 13.5 at.% Cu, 35 to 37 at.% Mg. This composition range is on the low Mg side of the equilibrium T phase region. Annealing a rapidly solidified alloy with 1 at.% Cu, 5 at.% Mg for 100 h at 190°C gave both the icosahedral phase and the equilibrium T phase at the grain boundaries of the Al matrix. For anneals of 24 h at 250°C only the T phase was observed at the grain boundary [1986Cas, 1987Cas] with precipitation of the S phase in the Al matrix. [1987San1] and [1987San2] rapidly solidified an alloy corresponding to $CuMg_4Al_6$. This composition lies in the T phase region. DSC measurements gave a melting point of 474.9°C which is in good agreement with the assessed temperature of the pseudobinary reaction p_6, L+Q⇌T, Fig. 3. A polymorphic transformation of the T phase, reported at 356.5°C, has not been noted by other workers. [1988She] rapidly solidified an alloy containing 12.5Cu-36.5Mg-51Al (at.%) and found it to be a single phase icosahedral quasicrystal. This composition is within the phase region given by [1986Cas]. A wider, but less exact, delineation of the icosahedral quasicrystal phase region was given by [1988Shi]. They quote the composition as typically $CuMg_4Al_5$, as proposed by [1937Nis1] for the stable T phase. [1988San] rapidly solidified the composition $CuMg_4Al_6$ and carried out a detailed X-ray study of the quasicrystalline phase and its transformation to the crystalline T phase by annealing for 1 h at 340°C. [1989She] used high resolution X-ray diffraction to study atomic distribution in quasicrystalline phases as well as differential scanning calorimetry (DSC) to get thermodynamic properties. [1991Wit] prepared and studied an icosahedral alloy with composition $Cu_{12.5}Mg_{36.5}Al_{51}$ by electrical resistivity measurements and DSC.

References

[1919Vog] Vogel, R., "Ternary Alloys of Al with Mg and Cu" (in German), *Z. Anorg. Chem.*, **107**, 265-307 (1919) (Equi. Diagram, Experimental, 10)

[1923Gay] Gayler, M.L.V., "The Constitution and Age-Hardening of the Ternary Alloys of Al with Mg and Cu", *J. Inst. Met.*, **29**, 507-528 (1923) (Equi. Diagram, Experimental, 8)

[1931Pre] Preston, G.D., "An X-ray Investigation of some Copper-Aluminium Alloys", *Philos. Mag.*, **12**, 980-993 (1931) (Crys. Structure, Experimental, 11)

[1932Dix] Dix, E.H., Sager, G.F., Sager, B.P., "Equilibrium Relations in Al-Cu-Mg and Al-Cu-Mg_2Si of High Purity", *Trans. AIME*, **99**, 119-131 (1932) (Equi. Diagram, Experimental, 8)

[1932Por] Portevin, A., Bastien, P., "Contribution to the Study of the Mg-Al-Cu Ternary System" (in French), *Compt. Rend.*, **195**, 441-443 (1932) (Equi. Diagram, Experimental, 6)

[1933Bas] Bastien, P., "Study of the Ultra-Light Alloys of Mg-Al-Cu" (in French), *Rev. Met.*, **6**, 478-501 (1933) (Equi. Diagram, Experimental, 22)

[1934Lav] Laves, F., Löhberg, K., "The Crystal Structure of Intermetallic Compounds with the Formula AB_2" (in German), *Nachr. Ges. Wiss. Goettingen*, **1**, 59-66 (1934) (Crys. Structure, Experimental, 11)

[1934Por] Portevin, A., Bastien, P., "Constitution and Properties of Alloys of Mg with Al and Cu" (in French), *Chim. et Ind. Paris*, Special No. (April), 490-519 (1934) (Equi. Diagram, Experimental, 24)

[1935Lav] Laves, F., Löhberg, K., Witte, H., "The Isomorphism of the Ternary Compounds $Mg_3Zn_2Al_2$ and Mg_4CuAl_6" (in German), *Metallwirtschaft*, **14**, 793-794 (1935) (Crys. Structure, Experimental, 5)

[1936Lav1] Laves, F., Witte, H., "Investigations in the Mg-Cu-Al System, Especially on the $MgCu_2$-$MgAl_2$ Section" (in German), *Metallwirtschaft*, **15**, 15-22 (1936) (Crys. Structure, Equi. Diagram, Experimental, 6)

[1936Lav2] Laves, F., Werner, S., "The Crystal Structure of Mg_2Zn_{11} and its Isomorphy with $Mg_3Cu_7Al_{10}$" (in German), *Z. Kristallogr.*, **95**, 114-128 (1936) (Crys. Structure, Equi. Diagram, Experimental, 11)

[1937Nis1] Nishimura, H., "The Al Corner of the Al-Cu-Mg System" (in Japanese*), Nippon Kinzoku Gakkai-Shi*, **1**, 8-18 (1937) (Equi. Diagram, Experimental, 8)

[1937Nis2] Nishimura, H., "Investigation of the Al-rich Al-Cu-Mg Alloy System", *Mem. Coll. Eng. Kyoto Imp. Univ.*, **10**, 18-33 (1937 (Experimental, Equi. Diagram, 7)

[1937Sch] Schütz, W., "The Ternary Compound $Mg_4Cu_{11}Al_{11}$" (in German), *Metallwirtschaft*, **16**, 949-950 (1937) (Equi. Diagram, Experimental, 3)

[1938Pet1] Petrov, D.A., "On the Importance of the Ternary Phase in the Aging of Al-Cu-Mg Alloys" (in Russian), *Metallurgia*, **3**, 88-91 (1938) (Experimental, 4)

[1938Pet2] Petrov, D.A., "On the Problem of the Age-Hardening of Duralumin", *J. Inst. Met.*, **62**, 81-100 (1938) (Experimental, 31)

[1939Han] Hansen, M., Dreyer, K.L., "The Influence of the Cu and Mg Contents on the Age-Hardening of Al-Cu-Mg Alloys" (in German), *Z. Metallkd.*, **31**, 204-209 (1939) (Experimental, 6)

[1940Han] Hanemann, H., "A Note on the System Al-Cu-Mg" (in German), *Z. Metallkd.*, **32**, 114 (1940) (Equi. Diagram, Experimental, 1)

[1940Kuz] Kuznetsov, V.G., Guseva, L.N., "X-Ray Investigation of Al-rich Al-Mg-Cu Alloys" (in Russian), *Izv. Akad. Nauk SSSR, Ser. Khim.*, **6**, 905-928 (1940) (Crys. Structure, Equi. Diagram, Experimental, 17)

[1941Mec] Mechel, R., "Contribution to the Metallography of Precipitated $CuAl_2$ Phase in Commercial Al-Cu-Mg Alloys" (in German), *Luftfahrtforschung*, **18**, 107-110 (1941) (Experimental, 7)

[1941Obi] Obinata, I., Mutuzaki, K., "On the Composition and Crystal Structure of the "S" Compound, the Main Hardening Element of Duralumin" (in Japanese), *Nippon Kinzoku Gakkai-Shi*, **5**, 121-123 (1941) (Crys. Structure, Experimental, 6)

[1943Gue] Guertler, W., Rassmann, G., "The Application of the X-Ray Fine Structure Diagram for the Recognition of the Phase Equilibria of Ternary Systems in the Crystalline State" (in German), *Metallwirtschaft*, **22**, 34-42 (1943) (Crys. Structure, Equi. Diagram, Experimental, 30)

[1943Per] Perlitz, H., Westgren, A., "The Crystal Structure of Al_2CuMg", *Arkiv Kemi, Mineral. Geol.*, **B16**, 13, 1-5 (1943) (Crys. Structure, Experimental, 4)

[1944Lit] Little, A.T., Hume-Rothery, W., Raynor, G.V., "The Constitution of Al-Cu-Mg Alloys at 460°C", *J. Inst. Met.*, **70**, 491-506 (1944) (Equi. Diagram, Experimental, 7)

[1946Kuz] Kuznetsov, V.G., "X-Ray Investigation of Al-Base Ternary Alloys" (in Russian), *Izv. Sekt. Fiz.-Khim. Anal.*, **16**, 232-250 (1946) (Equi. Diagram, Crys. Structure, Experimental, 29)

[1946Pet] Petrov, D.A., Berg, G.S., "Investigation of the Region of Solid Solution of Cu and Mg in Al" (in Russian), *Zh. Fiz. Khim*., **20**, 1475-1488 (1946) (Crys. Structure, Equi. Diagram, Experimental, 21)

[1946Ura] Urazov, G.G., Petrov, D.A., "Investigation of the Al-Cu-Mg Phase Diagram" (in Russian), *Zh. Fiz. Khim*., **20**, 387-398 (1946) (Equi. Diagram, Experimental, 10)

[1947Str] Strawbridge, D.J., Hume-Rothery, W., Little, A.T., "The Constitution of Al-Cu-Mg-Zn Alloys at 460C", *J. Inst. Met*., **74**, 191-225 (1947-48) (Crys. Structure, Equi. Diagram, Experimental, 11)

[1948Bro] Brommelle, N.S., Phillips, H.W.L., "The Constitution of Al-Cu-Mg Alloys", *J. Inst. Met.*, **75**, 529-558 (1948-49) (Equi. Diagram, Experimental, 39)

[1948Sha] Sharma, A.S., "The Metallography of Commercial Alloys of the Duralumin Type", *Trans. Indian Inst. Met*., **1**, 11-44 (1948) (Experimental, 11)

[1948Str] Strawbridge, D.J., "Correspondence on the Paper by N.S. Brommelle and H.W.L. Phillips, The Constitution of Al-Cu-Mg Alloys", *J. Inst. Met*., **75**, 1116-1119 (1948-49) (Review, 4)

[1949Mir] Mirgalovskaya, M.S., Makarov, E.S., "The Crystal Structure and Properties of the S Phase in the Al-Cu-Mg System" (in Russian), *Izv. Sekt. Fiz.-Khim. Anal*., **18**, 117-127 (1949) (Crys. Structure, Equi. Diagram, Experimental, 16)

[1949Sam] Samson, S., "The Crystal Structure of $Mg_2Cu_6Al_5$" (in German), *Acta Chem. Scand.*, **3**, 809-834 (1949) (Crys. Structure, Experimental, 11)

[1949Ura1] Urazov, G.G., Mirgalovskaya, M.S., "Ternary Intermetallic Phases in the Al-Cu-Mg System" (in Russian), *Izv. Sekt. Fiz.-Khim. Anal*., **19**, 514-521 (1949) (Crys. Structure, Equi. Diagram, Experimental, 20)

[1949Ura2] Urazov, G.G., Mirgalovskaya, M.S., Nagorskaya, N.D., "Phase Diagram of the Al-Mg-Cu System" (in Russian), *Izv. Sekt. Fiz.-Khim. Anal*., **19**, 522-530 (1949) (Equi. Diagram, Experimental, 19)

[1950Bag] Bagaryatsky, Yu.A., "Structural Changes on Aging Al-Cu-Mg Alloys" (in Russian), *Zh. Tekhn. Fiz*., **20**, 424-427 (1950) (Crys. Structure, Experimental, 7)

[1950Phr] Phragmen, G., "On the Phases Occurring in Alloys of Al with Cu, Mg, Mn, Fe and Si", *J. Inst. Met*., **77**, 489-552 (1950) (Crys. Structure, Equi. Diagram, Experimental, 67)

[1951Mir1] Mirgalovskaya, M.S., "The Q Phase in the Al-Cu-Mg System" (in Russian), *Dokl. Akad. Nauk SSSR*, **77**, 289-292 (1951) (Crys. Structure, Equi. Diagram, Experimental, 7)

[1951Mir2] Mirgalovskaya, M.S., "The Region of Primary Solidification of the Q Phase in the Al-Cu-Mg System" (in Russian), *Dokl. Akad Nauk SSSR*, **77**, 1027-1030 (1951) (Equi. Diagram, Experimental, 5)

[1951Mir3] Mirgalovskaya, M.S., "On Similar Crystallochemical Characteristics in the Mg-Zn and Mg-Al-Cu Systems" (in Russian), *Dokl. Akad. Nauk SSSR*, **78**, 909-911 (1951) (Crys. Structure, Experimental, Theory, 7)

[1951Poo] Poote, O.M., Axon, H.J., "Lattice-Spacing Relationships in Al-rich Solid Solutions of the Al-Mg and Al-Mg-Cu Systems", *J. Inst. Met*., **80**, 599-604 (1951) (Crys. Structure, Experimental, 11)

[1952Ber] Bergman, G., Waugh, J.L.T., Pauling, L., "Crystal Structure of the Intermetallic Compound $Mg_{32}(Al,Zn)_{49}$ and Related Phases", *Nature*, **169**, 1057-1058 (1952) (Crys. Structure, Experimental, 4)

[1952Han] Hanemann, H., Schrader, A., "Ternary Alloys of Al", in "*Atlas Metallographicus*", (in German), Verlag Stahleisen M.R.H. Dsseldorf, **3**(2), 73-81 (1952) (Equi. Diagram, Experimental, Review, 9)

[1952Ura] Urazov, G.G., Mirgalovskaya, M.S., "The Al-Cu-Mg System" (in Russian), *Dokl. Akad. Nauk SSSR*, **83**, 247-250 (1952) (Equi. Diagram, Experimental, 8)

[1953Kle] Klee, H., Witte, H., "Magnetic Susceptibilities of Ternary Mg Alloys and their Significance from the Standpoint of the Electron Theory of Metals" (in German), *Z. Phys. Chem*. (Leipzig), **202**, 352-378 (1953) (Experimental, 32)

[1955Zam] Zamotorin, M.I., "Solubility of Cu and Mg in the Solid State in Al at Various Temperatures" (in Russian), *Tr. Leningrad. Polytekhn. Inst*., **180**, 32-37 (1955) (Equi. Diagram, Experimental, 12)

[1957Rog] Rogel'berg, I.L., "Solubility of Mg in Cu and Combined Solubility of Mg and Al in Cu" (in Russian), *Tr. Gosud. N.-I. Pr. Inst. Obrab. Tsvetn. Met*., **16**, 82-89 (1957) (Equi. Diagram, Experimental, 12)

[1959Pal] Palatnik, L.S., Fedorov, G.V., Gladkikh, N.T., "Study of Al Alloys of the Al-Cu-Mg System in Samples of Variable Compositions" (in Russian), *Fiz. Met. Metalloved.*, **8**, 378-386 (1959) (Experimental, 14)

[1962Kom] Komura, Y., "Stacking Faults and Two New Modifications of the Laves phase in the Mg-Cu-Al System", *Acta Crystallogr*., **15**, 770-778 (1962) (Crys. Structure, Experimental, 15)

[1965Sam] Samson, S., "The Crystal Structure of the Phase βMg_2Al_3", *Acta Crystallogr*. **19**, 401-413 (1965) (Experimental, Crys. Structure, 16)

[1965Sli] Slick, P.I., Massena, C.W., Craig, R.S., "Electronic Specific Heats of Alloys of the $MgCu_{2-x}Al_x$ System", *J. Chem. Phys.*, **43**, 2788-2794 (1965) (Experimental, 13)

[1966Aul] Auld, J.H., Willians, B.E., "X-Ray Powder Data of T Phases Composed of Al and Mg with Ag, Cu or Zn", *Acta Crystallogr*., **21**, 830-831 (1966) (Crys. Structure, Experimental, 4)

[1967Coo] Cooksey, D.J.S., A. Hellawell, A., "The Microstructures of Ternary Eutectic Alloys in the Systems Cu-Sn-(Pb, In, Tl), Al-Cu-(Mg, Zn, Ag) and Zn-Sn-Pb", *J. Inst. Met.*, **95**, 183-187 (1967) (Experimental, 17)

[1968Sam] Samson, S., Gordon, E.K., "The Crystal Structure of $\epsilon Mg_{23}Al_{30}$", *Acta Crystallogr., B* **B24**, 1004-1013 (1968) (Experimental, Crys. Structure, 32)

[1972Gar] Garmong, G., Rhodes, C.G., "Structure and Mechanical Properties of the Directionally Solidified Al-Cu-Mg Eutectic", *Metall. Trans*., **3**, 533-544 (1972) (Experimental, 26)

[1972Pre] Predel, B., Ruge, H., "Investigation of Enthalpies of Formation in the Mg-Cu-Zn, Mg-Cu-Al and Mg-Cu-Sn Systems as a Contribution to the Clarification of the Bonding Relationships in Laves Phases" (in German), *Mater. Sci. Eng*., **9**, 141-150 (1972) (Thermodyn., Experimental, 61)

[1973Dav] Davison, J.E., Rice, D.A., "Application of Computer Generated Phase Diagrams to Composite Synthesis", in "*In-Situ Composites. III-Physical Properties*", 33-60 (1973) (Equi. Diagram, Thermodyn., Experimental, 10)

[1976Mon] Mondolfo, L.F., *Aluminium Alloys: Structure and Properties*, Butter Worths, London-Boston, 497-505 (1976) (Equi. Diagram, Review, 70)

[1977Kit] Kitano, Y., Komura, Y., Kajiwara, H., "Electron-Microscope Observations of Friauf-Laves Phase $Mg(Cu_{1-x}Al_x)_2$ with $x = 0.465$", *Trans. Japan Inst. Met*., **18**, 39-45 (1977) (Crys. Structure, Experimental, 9)

[1977Kom] Komura, Y., Kitano, Y., "Long-Period Stacking Variants and their Electron-Concentration Dependence in the Mg-Base Friauf-Laves Phases", *Acta Crystallogr*., **33B**, 2496-2501 (1977) (Crys. Structure, Experimental, 16)

[1978Ale] Alekseev, A.A., Ber, L.B., Klimovich, L.G., Korohov, O.S., "The Structure of the Zones in an Al-Cu-Mg Alloy" (in Russian), *Fiz. Metall. Metalloved*., **46**, 548-556 (1978) (Crys. Structure, Experimental, 17)

[1980Bir] Birchenall, B.E., Riechman, A.F., "Heat Storage in Eutectic Alloys", *Metall. Trans.A*, **11A**, 1415-1420 (1980) (Experimental, 13)

[1981Mel1] Mel'nik E.V., Kinzhibalo, V.V., "Compounds with Laves Phase Structures in the Systems Mg-Al-Cu, Mg-Ga-Cu and Mg-Ga-Ni" (in Russian), *Vestn. L'vov. Univ. Khim.*, **23**, 40-43 (1981) (Crys. Structure, Experimental, 4)

[1981Mel2] Mel'nik, E.V., Kinzhibalo, V.V., "Investigation of the Mg-Al-Cu and Mg-Ga-Cu Systems from 33.3 to 100 at.% Mg", *Russ. Metall*., **3**, 154-158 (1981), translated from *Izv. Akad. Nauk SSSR, Met.*, **3**, 154-158 (1981) (Crys. Structure, Equi. Diagram, Experimental, 5)

[1982Mur] Murray, J.L., "The Al-Mg (Aluminum-Magnesium) System", *Bull. Alloy Phase Diagrams*, **3**, 60-74 (1982) (Equi. Diagram, Review, 132)

[1985Kuz] Kuznetsov, G.M., Konovalov, Yu.V., "Prediction of the Solidus Surface of the Al-Cu-Mg System from Data on the Liquidus Surface" (in Russian*), Izv. V.U.Z., Tsvetn. Metall.*, **6**, 72-76 (1985) (Theory, 15)

[1985Far] Farkas, D., Birchenall, C.E., "New Eutectic Alloys and Their Heats of Transformation", *Metall. Trans. A*, **16A**, 323-328 (1985) (Thermodyn., 18)

[1985Mur] Murray, J.L., "The Al-Cu System", *Int. Met. Rev.*, **30** (5), 211-233 (1985) (Equi. Diagram, Review, 230)

[1986Cas] Cassada, W.A., Shen, Y., Poon, S.J., Shiflet, G.J., "$Mg_{32}(Zn,Al)_{49}$-Type Icosahedral Quasicrystals Formed by Solid-State Reaction and Rapid Solidification", *Phys. Rev. B, Condens. Matter*, **34**, 7413-7416 (1986) (Crys. Structure, Experimental, 17)

[1986Cha] Chakrabarti, D.J., "Interactive Computer Graphics of Phase Diagrams in Al-Based Systems, Computer Modelling of Phase Diagrams", *Proc. Symp. Met. Soc. A.I.M.E.*, Bennett, L.H. (Ed.), 399-416 (1985) (Equi. Diagram, Theory, 6)

[1986Che] Cherneeva, L.I., Rodionova, E.K., Martynova, N.M., "Determination of the Energy Capacity of Metallic Alloys as Promising Heat-Storage Materials" (in Russian), *Izv. Vyss.Uchebn.Zaved. Energia*, (12), 78-82 (1986) (Thermodyn., Experimental, 7)

[1986Not] Notin, M., Dirand, M., Bouaziz, D., Hertz, J., "Determination of the Partial Molar Enthalpy at Infinite Dilution of Liquid Mg and Solid Cu in Pure Liquid Al and of the Enthalpy of Formation of the S-Phase (Al_2CuMg)" (in French), *Compt. Rend. Acad. Sci., Paris, Ser. II*, **302**, 63-66 (1986) (Thermodyn., Experimental, 3)

[1987Cas] Cassada, W.A., Shiflet, G.J., Poon, S.J., "Quasicrystalline Grain Boundary Precipitates in Al Alloys Through Solid-Solid Transformations", *J. Microsc.*, **146**, 323-335 (1987) (Crys. Structure, Experimental, 26)

[1987Hoc] Hoch, M., "Application of the Hoch-Arpshofen Model to the Thermodynamics of the Cu-Ni-Sn, Cu-Fe-Ni, Cu-Mg-Al and Cu-Mg-Zn Systems", *Calphad*, **11**, 237-246 (1987) (Thermodyn., 16)

[1987Lac] Lacaze, J., Lesoult, G., Relave, O., Ansara, I., Riquet, J.-P., "Thermodynamics and Solidification of Al-Cu-Mg-Si Alloys", *Z. Metallkd.*, **78**, 141-150 (1987) (Equi. Diagram, Thermodyn., 10)

[1987San1] Sanyal, M.K., Sahni V.C., Dey, G.K., "Evidence for Endothermic Quasicrystalline - Crystalline Phase Transitions in Al_6CuMg_4", *Nature*, 328, 704-706 (1987) (Crys. Structure, Experimental, 10)

[1987San2] Sanyal, M.K., Sahni, V.C., Dey, G.K., "Endothermic Quasicrystalline Phase Transition in Al_6CuMg_4", *Pramna - J. Phys.*, **28**, L709-712 (1987) (Crys. Structure, Experimental, 7)

[1988Mur] Murray, J.L., Private Communication, Alcoa Laboratory, Aluminium Co. of America, Alcoa, PA (1988)

[1988San] Sanyal, M.K., Sahni, V.C., Chidambaram, R., "X-Ray Structural Study of Crystalline and Quasicrystalline Al_6CuMg_4", *Solid State Commun.*, **66**, 1043-1045 (1988) (Crys. Structure, Experimental, 19)

[1988She] Shen, Y., Dmowski, W., Egami, T., Poon, S.J., Shiflet, G.J., "Structure of Al-(Li,Mg)-Cu Icosahedral Alloys Studied by Pulsed Neutron Scattering", *Phys. Rev. B, Condens. Matter*, **37**, 1146-1154 (1988) (Crys. Structure, Experimental, 14)

[1988Shi] Shibuya, T., Kimura, K., Takeuchi, S., "Compositional Regions of Single Icosahedral Phase in Ternary Nontransition Metal Systems", *Japan. J. Appl. Phys.*, **27**, 1577-1579 (1988) (Crys. Structure, Experimental, 14)

[1989Mee] Meetsma, A., De Boer, J.L.,Van Smaalen, S., "Refinement of the Crystal Structure of Tetragonal Aluminum-Copper (Al_2Cu)", *J. Solid State Chem.*, **83**(2), 370-372 (1989) (Crys. Structure, Experimental, 17)

[1989She] Shen, Y., "The Formation and Structure of Al-Cu-(Li,Mg) Icosahedral Alloys", *Thesis*, University of Virginia, (1989) (Crys. Structure, Experimental)

[1990Gar] Garg, A., Chang, Y.C., Howe, J.M., "Precipitation of the Omega Phase in an Al-4.0Cu-0.5Mg Alloy", *Scr. Metall. Mater.*, **24**, 677-680 (1990) (Crys. Structure, Experimental, 12)

[1991Eff] Effenberg, G., Prince, A., "Aluminium-Copper-Magnesium", MSIT Ternary Evaluation Program, in *MSIT Workplace*, Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; Document ID: 10.12587.1.20, (1991) (Crys. Structure, Equi. Diagram, Assessment, 80)

[1991Ell] Ellner, M., Kolatschek, K., Predel, B., "On the Partial Atomic Volume and the Partial Molar Enthalpy of Aluminium in some Phases with Cu and Cu_3Au Structures", *J. Less-Common Met.*, **170**, 171-184 (1991) (Experimental, Crys. Structure, 57)

[1991Jin] Jin, Y., Li, C., Yan, M., "A Precipitate Phase in AA2124", *J. Mater. Sci.*, **26**, 3244-3248 (1991) (Crys. Structure, Experimental, 6)

[1991Wit] Wittmann, R., Löbl, P., Lüscher, E., Fritsch, G., Wollgarten, M., Urban, K., "Electrical Resistivity and Crystallization Behaviour of Icosahedral $Al_{51}Cu_{12.5}Mg_{36.5}$", *Z. Phys. B - Condens. Matter.*, **83**, 193-198 (1991) (Crys. Structure, Experimental, 30)

[1993Gin] Gingl, F., Selvam, P., Yvon, K., "Structure Refinement of Mg_2Cu and a Composition of the Mg_2Cu, Mg_2Ni and Al_2Cu Structure Types", *Acta Crystallogr., Sect. B: Struct. Crystallogr. Crys. Chem.,* **B49**, 201-203 (1993) (Crys. Structure, Experimental, *, 15)

[1993Zuo] Zuo, Y., Chang ,Y.A., "Calculation of Phase Diagram and Solidification Paths of Al-rich Al-Mg-Cu Ternary Alloys", *Light Met.(Warrendale Pa)*, 935-942 (1993) (Equi. Diagram, Thermodyn., Assessment, 29)

[1994Mur] Murray, J.L., "Al-Cu (Aluminium-Copper)", in "*Phase Diagrams of Binary Copper Alloys*", Subramanian, P.R., Chakrabarti, D.J., Laughlin, D.E., (Eds.), ASM International, Materials Park, OH, 18-42 (1994) (Equi. Diagram, Crys. Structure, Thermodyn., Review, #, *, 226); similar to [1985Mur]

[1994Nay] Nayeb-Nashemi, A.A., Clark J.B., "Cu-Mg (Copper-Magnesium)" in "*Phase Diagrams of Binary Copper Alloys*", Subramanian, P.R., Chakrabarti, D.J., Laughlin, D.E., (Eds.), ASM International, Materials Park, OH, 245-252 (1994) (Equi. Diagram, Crys. Structure, Thermodyn., Review, #, 44)

[1995Hua] Huang, C., Chen, S., "Phase Equilibria of Al-rich Al-Cu-Mg Alloys", *Metall. Mater. Trans. A*, **26A**, 1007-1011 (1995) (Equi. Diagram, Experimental, 18)

[1995Kim] Kim, Y.B., Sommer, F., Predel, B., "Determination of the Enthalpy of Mixing of Liquid Aluminum-Copper-Magnesium Alloys", *Z. Metallkd.*, **86**, 597-602 (1995) (Thermodyn., Experimental, 15)

[1995Soa] Soares, D., Malheiros, L.F., Hämäläinen, M., Castro, F., "Isopiestic Determination of the Coefficients of Activity of Magnesium in Al-Cu-Mg Liquid Alloys", *J. Alloys Comp.*, **220**, 179-181 (1995) (Thermodyn. Experimental, 3)

[1996Zuo] Zuo, Y., Chang, Y.A., "Calculation of Phase Diagram and Solidification Paths of Ternary Alloys: Al-Mg-Cu", *Mater. Sci. Forum*, **215-216**, 141-148 (1996) (Equi. Diagram, Thermodyn, Assessment, 32)

[1997Che] Chen, S., Zuo, Y., Liang, H., Chang, Y.A., "A. Thermodynamic Description for the Ternary Al-Cu-Mg System", *Metall. Mater. Trans. A*, **28A**, 435-446 (1997) (Equi. Diagram, Thermodyn., Assessment, 48)

[1998Ans] Ansara, I., Dinsdale, A.T., Rand, M.H., *COST 507, Thermochemical Database for Light Metal Alloys*, Vol. 2, European Communities, Luxembourg, 311-315 (1998) (Equi. Diagram, Thermodyn., Calculation)

[1998Buh] Buhler, T., Fries, S.G., Spencer, P.J., Lukas, H.L., "A Thermodynamic Assessment of the Al-Cu-Mg Ternary System", *J. Phase Equilib.*, **19**, 317-333 (1998) (Equi. Diagram, Thermodyn., Assessment, 38)

[1998Che] Chen, Y., "A New Intermetallic Compound $Mg_{1.75}Cu_{1.0}Al_{0.4}$", *J. Mater. Sci. Lett.*, **17**, 1271-1272 (1998) (Crys. Structure, Experimental, 7)

[1998Don] Donnadieu, P., Harmelin, M.G., Seifert, H.J., Aldinger, F., "Commensurately Modulated Stable States Related to the γ Phase in Mg-Al Alloys", *Philos. Mag. A*, **78**(4), 893-905 (1998) (Experimental, Crys. Structure, 21)

[1998Fau] Faudot, F., P. Ochin, M.G., Harmelin, S.G., Fries, T., Jantzen, Spencer, P.J., Liang, P., Seifert, H.J., "Experimental Investigation of Ternary Invariant Reactions Predicted by Thermodynamic Calculations for the Al-Cu-Mg System", *Proceedings of the JEEP'98*, 173-176, Nancy 1998 (Equi. Diagram, Experimental, 14)

[1998Lia1] Liang, P., Su, H.L., Donnadieu, P., Harmelin, M.G., Quivy, A., Effenberg, G., Seifert, H.J., Lukas, H.L., Aldinger, F., "Experimental Investigation and Thermodynamic Calculation of the Central Part of the Mg-Al Phase Diagram", *Z. Metallkd.*, **98**, 536-540 (1998) (Equi. Diagram, Experimental, 33)

[1998Lia2] Liang, P., Tarfa, T., Robinson, J.A., Wagner, S., Ochin, P., Harmelin, M.G., Seifert, H.J., Lukas, H.L., Aldinger, F., "Experimental Investigation and Thermodynamic Calculation of the Al-Mg-Zn System", *Thermochim. Acta*, **314**, 87-110 (1998) (Experimental, Calculation, Thermodyn., Equi. Diagram, 69)

[1998Liu] Liu, X.J., Ohnuma, I., Kainuma, R., Ishida, K., "Phase Equilibria in the Cu-rich Portion of the Cu-Al Binary System", *J. Alloys Compd.*, **264**, 201-208 (1998) (Equi. Diagram, Experimental, #, *, 25)

[1999Fau] Faudot, F., Harmelin, M.G., Fries, S.G., Jantzen, T., Liang, P., Seifert, H.J., Aldinger, F., "DSC Investigation of Invariant Equilibria in the Mg-Rich Side of the Al-Cu-Mg System", *Proceedings of the JEEP'99*, in press, Annecy, 1999 (Equi. Diagram, Experimental, 14)

[1999Xie] Xie, F.Y., Kraft, T., Zuo, Y., Moon, C.H., Chang, Y.A., "Microstructure and Microsegregation in Al-rich Al-Cu-Mg Alloys", *Acta Mater.*, **47**, 489-500 (1999) (Experimental, Calculation, Equi. Diagram, 42)

[2000Fau] Faudot, F., Dallas, J.P., Harmelin, M.G., "Comment on the Paper a New Intermetallic Compound $Mg_{1.75}Cu_{1.0}Al_{0.4}$", *J. Mater. Sci. Letter.*, **19**, 539-540 (2000) (Experiment, Crys. Structure, 9)

[2000Hir] Hirosawa, S., Sato, T., Kamio, A., Flower, H.M., "Classification of the Role of Microalloying Elements in Phase Decomposition of Al Based Alloys", *Acta Mater.*, **48**, 1797-1806 (2000) (Experimental, Calculation, 35)

[2000Lia] H. Liang, T. Kraft, Y.A. Chang, "Importance of Reliable Phase Equilibria in Studying Microsegregation in Alloys Al-Cu-Mg", *Mater. Sci. Eng. A*, **A292**, 96-103 (2000) (Experimental, Equi. Diagram, 31)

[2000Tak] Takeuchi, T., Mizuno, T., Banno, E., Mizutani, U., "Magic Number of Electron Concentration in the Isocahedral Cluster of $Al_xMg_{40}X_{60-x}$ (X=Zn, Cu, Ag and Pd) 1/1-Cubic Approximants", *Mater. Sci.Eng. A*, **294-296**, 522-526 (2000) (Experiment, Crys. Struct., 14)

[2001Che] Chen, S.L., Daniel, S., Zhang, F., Chang, Y.A., Oates, W.A., Schmid-Fetzer, R., "On the Calculation of Multicomponent Stable Phase Diagrams", *J. Phase Equilib.*, **22**, 373-378 (2001) (Calculation, Equi. Diagram, 26)

[2001Fau] Faudot, F., Harmelin, M., Liang, P., Seifert, H., Private communication (2001)

[2002Che] Chen, S.L., Daniel, S., Zhang, F., Chang, Y.A., Yan, X.Y., Xie, F.Y., Schmid-Fetzer, R., Oates, W.A., "The PANDAT Software Package and its Applications", *Calphad*, **26**, 175-188 (2002) (Calculation, Equi. Diagram, 24)

[2002Cze] Czeppe, T., Zakulski, W., Bielanska, E., "Determination of the Thermal Stability of ϵ Phase in the Mg-Al System by the Application of DSC Calorimetry", *J. Phase Equilib.*, **23**, in press (2002) (Experimental, Equi. Diagram, 10)

[2002Dav] Davydov, V.G., Ber, L.B., "TTT and TTP Ageing Diagrams of Commercial Aluminum Alloys and Their use for Ageing Acceleration and Properties Improvement", *Mater. Sci. Forum*, **396-402**, 1169-1174 (2002) (Equi. Diagram, Phys. Prop., Experimental, 10)

[2002Gul] Gulay, L.D, Harbrecht, B., "The Crystal Structures of the ζ_1 and ζ_2 Phases in the Al-Cu System", in *"Crystal Chemistry of Intermetallic Compounds*", Abstr. VIII Int. Conf, Lviv, P139, 73 (2002) (Crys. Structure, Experimental, 5)

[2002Iva] Ivanchenko, V., Ansara, I., "Cu-Mg (Copper-Magnesium)", MSIT Binary Evaluation Program, in *MSIT Workplace*, Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; Document ID: 20.10551.1.20, (2002) (Crys. Structure, Equi. Diagram, Assessment, 13)

[2002Hir] Hirosawa, S., Sato, T., "Atomistic Behavior of Microalloying Elements in Phase Decomposition of Al Based Alloys", *Mater. Sci. Forum*, **396-402**, 649-654 (2002) (Calculation, 7)

[2002Zhu] Zhu, A.W., Gable, B.M., Shiflet, G.J., Starke Jr., E.A., "The Intelligent Design of the High Strength, Creep-Resistant Aluminium Alloys", *Mater. Sci. Forum*, **396-402**, 21-30 (2002) (Experimental, Calculation, Phys. Prop., 23)

[2003Gro] Groebner, J., "Al-Cu (Aluminium-Copper)", MSIT Binary Evaluation Program, in *MSIT Workplace,* Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; to be published, (2003) (Crys. Structure, Equi. Diagram, Assessment, 68)

[2003Jan] Jantzen, T., Fries, S.G., Harmelin, M.G., Faudot, F., Lukas, H.L., Liang, P., Seifert, H.J., Aldinger, F., Private Communication (1999)

[2003Luk] Lukas, H.L., "Al-Mg (Aluminium-Magnesium)", MSIT Binary Evaluation Program, in *MSIT Workplace,* Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; to be published, (2003) (Crys. Structure, Equi. Diagram, Assessment, 49)

Table 1: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Al) < 660.452	*cF*4 $Fm\bar{3}m$ Cu	a = 404.88	at 24°C [V-C] 100 to 81.4 at.% Al at 450°C [1982Mur]
(Cu) < 1084.62	*cF*4 $Fm\bar{3}m$ Cu	a = 361.46	at 25°C [Mas2] 0 to 19.7 at.% Al [Mas2] melting point [1994Mur]
$Cu_{1-x}Al_x$		a = 361.52 a = 365.36	[1991Ell], x=0,quenched from 600°C [1991Ell], x=0.152,quenched from 600°C, linear da/dx
(Mg) < 650	*hP*2 $P6_3/mmc$ Mg	a = 320.94 c = 521.01	at 25°C [V-C2] 0 to 11.5 at.% Al at 437°C [1982Mur]
θ, $CuAl_2$ < 591	*tI*12 *I4/mcm* $CuAl_2$	a = 606.7 c = 487.7	31.9 to 33.0 at.% Cu [1994Mur] single crystal [V-C2, 1989Mee]
η_1, CuAl(h) 624-560	*o**32	a = 408.7 b = 1200 c = 863.5	49.8 to 52.4 at.% Cu, [V-C, Mas2, 1985Mur] Pearson symbol: [1931Pre]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
η_2, CuAl(r) < 569	*mC*20 *C2/m* CuAl(r)	*a* = 1206.6 *b* = 410.5 *c* = 691.3 β = 55.04°	[1985Mur] 49.8 to 52.3 at.% Cu, [V-C2]
ζ_1, ~$Cu_{47.8}Al_{35.5}$(h) 590-530	*oF*88 - 4.7 *Fmm2* $Cu_{47.8}Al_{35.5}$	*a* = 812.67 *b* = 1419.85 *c* = 999.28	55.2 to 59.8 at.% Cu [Mas2, 1994Mur] structure: [2002Gul]
ζ_2, $Cu_{11.5}Al_9$(r) < 570	*oI*24 - 3.5 *Imm2* $Cu_{11.5}Al_9$	*a* = 409.72 *b* = 703.13 *c* = 997.93	55.2 to 56.3 at.% Cu [Mas2, 1985Mur] structure: [2002Gul]
ε_1, $Cu_{100-x}Al_x$ 958-848	cubic (?)		37.9 ≤ *x* ≤ 40.6 59.4 to 62.1 at.% Cu, [Mas2, 1985Mur]
ε_2, $Cu_{2-x}Al$ 850-560	*hP*6 *P6$_3$/mmc* Ni_2In	*a* = 414.6 *c* = 506.3	0.47 ≤ *x* ≤ 0.78 55.0 to 61.1 at.% Cu, [Mas, 1985Mur, V-C2], NiAs in [Mas2, 1994Mur]
δ, $Cu_{100-x}Al_x$ < 686	*hR** *R*3*m*	 *a* = 1226 *c* = 1511	38.1 ≤ *x* ≤ 40.7 [Mas2, 1985Mur] 59.3 to 61.9 at.% Cu at *x* = 38.9 [V-C]
γ_0, $Cu_{100-x}Al_x$ $Cu_{\sim 2}Al$ 1022-780	*cI*52 *I$\bar{4}$3m* Cu_5Zn_8	-	31 ≤ *x* ≤ 40.2 [Mas2], 62 to 68 at.% Cu [1998Liu]
γ_1, Cu_9Al_4 ≤ 890	*cP*52 *P$\bar{4}$3m* Cu_9Al_4	 *a* = 870.23 *a* = 870.68	62 to 68 at.% Cu, [Mas2, 1998Liu]; powder and single crystal [V-C2] from single crystal [V-C2]
β, Cu_3Al(h) 1049-559	*cI*2 *Im$\bar{3}$m* W	*a* = 295.64	70.6 to 82 at.% Cu [1985Mur][1998Liu] at 672°C in β+(Cu) alloy
$CuMg_2$ < 568	*oF*48 *Fddd* $CuMg_2$	*a* = 907 *b* = 528.4 *c* = 1825 *a* = 905 *b* = 528.3 *c* = 1824.7 *a* = 904.4 ± 0.1 *b* = 527.5 ± 0.1 *c* = 1832.8 ± 0.2	[Mas2, V-C2] [1994Nay] [1993Gin]
Cu_2Mg < 797	*cF*24 *Fd$\bar{3}$m* Cu_2Mg	*a* = 702.1	64.7 to 69 at.% Cu [Mas2, V-C2]
Mg_2Al_3 ≤ 452	*cF*1168 *Fd$\bar{3}$m* Mg_2Al_3	*a* = 2823.9	[1982Mur] 60-62 at.% Al [1982Mur, 2002Cze] 1168 atoms on 1704 sites per unit cell [1965Sam, 1982Mur]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$Mg_{17}Al_{12}$ ≤ 458	*cI*58 $I\bar{4}3m$ αMn	*a* = 1054.38	[1982Mur] At 41.4 at.% Al, [V-C2] 39.5 to 51.5 at.% Al, [1998Lia11] 40 to 52 at.% Al, [2002Cze] Space group from [1998Don]
$Mg_{23}Al_{30}$ 410-250	*hR*159 $R\bar{3}$ $Mn_{44}Si_9$	*a* = 1282.54 *c* = 2174.78	54.5-56.5 at.% Al [1998Lia1, 1998Lia2, 2002Cze] Structure : 159 atoms refer to hexagonal unit cell [1968Sam]
λ_1, $(Cu_{1-x}Al_x)_2Mg$ Cu_2Mg < 900	*cF*24 $Fd\bar{3}m$ Cu_2Mg	 *a* = 701.3 *a* = 715.42	0 ≤ *x* ≤ 0.433 [1936Lav1] space group from [1936Lav1] at *x* = 0 For $Mg_{1.75}Cu_{1.0}Al_{0.4}$ at 480°C [2000Fau]
* Q, $Cu_3Mg_6Al_7$	*cI*96 $Im\bar{3}m$ $CuFeS_2$	*a* = 1208.7	[1951Mir1] space group from [1991Eff]
* S, $CuMgAl_2$	*oC*16 *Cmcm* BRe_3	*a* = 401 *b* = 925 *c* = 715	[1943Per] space group from [1991Eff]
* T, $(Cu_{1-x}Al_x)_{49}Mg_{32}$	*cI*162 $Im\bar{3}$ $Mg_{32}(Al,Zn)_{49}$	 *a* = 1428 to 1435	[1952Ber] composition dependent space group from [1981Mel2]
* V, $Cu_6Mg_2Al_5$	*cP*39 $Pm\bar{3}$ Mg_2Zn_{11}	*a* = 827	[1949Sam] space group from [1991Eff]
* λ_2, $(Cu_{1-x}Al_x)_2Mg$ < 601.6	*hP*24 $P6_3/mmc$ $MgNi_2$	*a* = 509.8 to 510.2 *c* = 1664 to 1676	0.492 ≤ *x* ≤ 0.576 [1936Lav1] space group from [1936Lav1]
* λ_3, $(Cu_{1-x}Al_x)_2Mg$ < 537.8	*hP*12 $P6_3/mmc$ $MgZn_2$	*a* = 507 to 512 *c* = 829 to 839	0.598 ≤ *x* ≤ 0.613 [1936Lav1] space group from [1936Lav1]
* 5L, $(Cu,Al)_2Mg$	*hP*30	*a* = 514 *c* = 2105	stacking variation of Laves phases observed by electron diffraction [1962Kom]
* 6L, $(Cu,Al)_2Mg$	*hP*36 *P6m2*	*a* = 510 *c* = 2500 *a* = 514 *c* = 2530	stacking variation of Laves phases observed by electron diffraction [1977Kit] [1977Kom]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* 9L, $(Cu,Al)_2Mg$	*hR*18	*a* = 1297 α = 22.50°	[1962Kom], stacking variation of Laves phases observed by electron diffraction [1977Kom]
* 16L, $(Cu,Al)_2Mg$	*hP*96 *P6$_3$/mmc*	*a* = 510 *c* = 6670 *a* = 514 *c* = 6740	stacking variation of Laves phases observed by electron diffraction [1977Kit] [1977Kom]

Table 2a: Invariant Four-Phase Equilibria

Reaction	*T* [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
$\gamma_0 + \varepsilon_1 \rightleftharpoons L + \gamma_1$	876.4	U_1	γ_0	34.2	65.8	0.0
			ε_1	36.8	62.8	0.4
			L	39.2	56.4	4.4
			γ_1	35.0	65.0	0.0
$\varepsilon_1 \rightleftharpoons L + \gamma_1 + \varepsilon_2$	827.6	E_1	ε_1	39.7	59.9	0.4
			L	43.4	52.4	4.2
			γ_1	36.1	63.9	0.0
			ε_2	42.0	58.0	0.0
$L \rightleftharpoons \gamma_0 + \gamma_1 + \lambda_1$	804.0	E_2	L	25.1	59.6	15.3
			γ_0	31.8	68.2	0.0
			γ_1	32.7	67.3	0.0
			λ_1	16.3	50.6	33.1
$L \rightleftharpoons \beta + \gamma_0 + \lambda_1$	800.3	E_3	L	21.8	62.8	15.4
			β	27.5	71.4	1.1
			γ_0	31.3	68.7	0.0
			λ_1	14.2	52.8	33.0
$L + \beta \rightleftharpoons (Cu) + \lambda_1$	782.8	U_2	L	12.9	70.2	16.9
			β	20.7	78.3	1.0
			(Cu)	17.8	81.1	1.1
			λ_1	8.6	58.7	32.7
$\gamma_0 + \lambda_1 \rightleftharpoons \beta + \gamma_1$	782.1	U_3	γ_0	31.2	68.8	0.0
			λ_1	14.0	53.0	33.0
			β	27.2	71.7	1.1
			γ_1	31.4	68.6	0.0
$L + \gamma_1 \rightleftharpoons \varepsilon_2 + \lambda_1$	739.9	U_4	L	38.7	48.4	12.9
			γ_1	36.3	63.7	0.0
			ε_2	42.5	57.5	0.0
			λ_1	23.4	43.4	33.2

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
$\varepsilon_2 + \gamma_1 \rightleftharpoons \delta, \lambda_1$	690.2	D_1	ε_2	42.8	57.2	0.0
			γ_1	36.3	63.7	0.0
			δ	40.0	60.0	0.0
			λ_1	23.4	43.3	33.2
$L + \varepsilon_2 + \lambda_1 \rightleftharpoons V$	683.9	P_1	L	46.5	41.0	12.5
			ε_2	44.2	56.8	0.0
			λ_1	27.1	39.8	33.1
			V	38.5	46.1	15.4
$\varepsilon_2 + \lambda_1 \rightleftharpoons \delta + V$	641.8	U_5	ε_2	43.6	56.4	0.0
			λ_1	25.0	41.8	33.2
			δ	40.0	60.0	0.0
			V	38.5	46.1	15.4
$L + \varepsilon_2 \rightleftharpoons \eta + V$	601.5	U_6	L	58.3	33.5	8.1
			ε_2	45.8	54.2	0.0
			η	49.0	51.0	0.0
			V	38.5	46.1	15.4
$\varepsilon_2 \rightleftharpoons \delta + \zeta, V$	582.7	D_2	ε_2	44.4	55.6	0.0
			δ	40.0	60.0	0.0
			ζ	45.0	55.0	0.0
			V	38.5	46.1	15.4
$\varepsilon_2 \rightleftharpoons \eta + \zeta, V$	579.3	D_3	ε_2	47.5	54.3	0.0
			η	48.9	51.1	0.0
			ζ	45.0	55.0	0.0
			V	38.5	46.1	15.4
$\beta \rightleftharpoons (Cu) + \gamma_1 + \lambda_1$	564.6	E_4	β	22.8	76.9	0.3
			(Cu)	20.4	79.3	0.3
			γ_1	29.6	10.4	0.0
			λ_1	10.2	56.7	33.1
$L + \lambda_1 \rightleftharpoons \lambda_2 + V$	562.0	U_7	L	60.0	26.6	13.4
			λ_1	32.9	34.1	32.9
			λ_2	36.6	30.9	32.5
			V	38.5	46.1	15.4
$L + \lambda_2 \rightleftharpoons S + V$	561.2	U_8	L	60.1	26.5	13.4
			λ_2	36.6	30.9	32.5
			S	50.0	25.0	25.0
			V	38.5	46.1	15.4
$L + \eta \rightleftharpoons \theta + V$	559.4	U_9	L	62.5	29.4	8.1
			η	49.6	50.4	0.0
			θ	67.0	33.0	0.0
			V	38.5	46.1	15.4
$L + V \rightleftharpoons \theta + S$	543.8	U_{10}	L	63.0	28.9	8.1
			θ	67.0	33.0	0.0
			S	50.0	25.0	25.0
			V	38.5	46.1	15.4

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
$L + \lambda_2 \rightleftharpoons \lambda_3 + S$	534.7	U_{11}	L	58.4	10.7	30.9
			λ_2	39.0	28.0	33.0
			λ_3	40.4	26.3	33.3
			S	50.0	25.0	25.0
$L + \lambda_3 \rightleftharpoons \lambda_2 + Q$	524.9	U_{12}	L	46.7	7.7	45.6
			λ_3	40.1	26.5	33.4
			λ_2	38.5	28.3	33.2
			Q	43.8	18.7	37.5
$L + \lambda_3 \rightleftharpoons Q + S$	513.2	U_{13}	L	58.6	8.2	33.2
			λ_3	41.0	25.6	33.3
			Q	43.8	18.7	37.5
			S	50.0	25.0	25.0
$L \rightleftharpoons \theta + (Al) + S$	502.1	E_5	L	73.9	15.5	10.6
			θ	67.8	32.2	0.0
			(Al)	95.7	1.7	2.6
			S	50.0	25.0	25.0
$L + \lambda_1 \rightleftharpoons \lambda_2 + (Mg)$	497.3	U_{14}	L	18.6	7.1	74.3
			λ_1	31.0	35.5	33.5
			λ_2	34.6	32.0	33.4
			(Mg)	3.8	0.0	96.2
$L \rightleftharpoons \lambda_1 + CuMg_2 + (Mg)$	481.2	E_6	L	1.1	16.6	82.3
			λ_1	19.2	47.1	33.7
			$CuMg_2$	0.0	33.3	66.7
			(Mg)	0.1	0.1	99.8
$L + Q \rightleftharpoons T + S$	479.0	U_{15}	L	64.1	5.5	30.4
			Q	43.8	18.7	37.5
			T	52.0	8.3	39.7
			S	50.0	25.0	25.0
$L + S \rightleftharpoons T + (Al)$	469.2	U_{16}	L	67.0	4.9	28.1
			S	50.0	25.0	25.0
			T	52.4	8.1	39.5
			(Al)	89.2	0.3	10.5
$L + \lambda_2 \rightleftharpoons Q + (Mg)$	454.6	U_{17}	L	26.3	4.1	69.6
			λ_2	37.2	29.4	33.4
			Q	43.8	18.7	37.5
			(Mg)	7.5	0.0	92.5
$L \rightleftharpoons T + Mg_2Al_3 + (Al)$	447.6	E_7	L	63.5	0.5	36.0
			T	55.4	4.1	40.5
			Mg_2Al_3	61.1	0.0	38.9
			(Al)	83.6	0.0	16.4
$L \rightleftharpoons T + Mg_2Al_3 + Mg_{17}Al_{12}$	447.6	E_8	L	57.4	0.3	42.3
			T	55.1	3.4	41.5
			Mg_2Al_3	61.1	0.0	38.9
			$Mg_{17}Al_{12}$	51.9	0.0	48.1

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
L + Q ⇌ T + (Mg)	426.8	U_{18}	L	31.1	1.7	67.2
			T	47.8	9.3	42.9
			Q	43.8	18.7	37.5
			(Mg)	11.0	0.0	89.0
L ⇌ (Mg) + T + $Mg_{17}Al_{12}$	424.7	E_9	L	31.6	1.8	66.6
			(Mg)	11.1	0.0	88.9
			T	47.9	9.2	42.9
			$Mg_{17}Al_{12}$	40.0	0.0	60.0
Mg_2Al_3 + $Mg_{17}Al_{12}$ ⇌ $Mg_{23}Al_{30}$, T	409.8	D_4	Mg_3Al_2	61.1	0.0	38.9
			$Mg_{17}Al_{12}$	50.6	0.0	49.4
			$Mg_{23}Al_{30}$	56.6	0.0	43.4
			T	55.2	3.4	41.4
$Mg_{23}Al_{30}$ ⇌ Mg_2Al_3 + $Mg_{17}Al_{12}$, T	250.1	D_5	$Mg_{23}Al_{30}$	56.6	0.0	43.4
			Mg_3Al_2	61.1	0.0	38.9
			$Mg_{17}Al_{12}$	46.4	0.0	53.6
			T	55.8	3.5	40.7

Table 2b: Invariant Maxima of Two- and Three-Phase Equilibria

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
L ⇌ λ_1	909.3	congruent	L	16.1	50.5	33.4
			λ_1	16.1	50.5	33.4
L ⇌ γ_0 + λ_1	804.4	e_3	L	24.2	60.4	15.4
			γ_0	31.6	68.4	0.0
			λ_1	15.8	51.1	33.1
L ⇌ γ_1 + λ_1	804.0	e_4	L	25.1	59.6	15.3
			γ_1	32.7	67.3	0.0
			λ_1	16.3	50.6	33.1
L ⇌ β + λ_1	800.4	e_5	L	20.9	63.5	15.6
			β	26.9	72.0	1.1
			λ_1	13.7	53.3	33.0
L+ λ_1 ⇌ λ_2	601.6	p_8	L	51.5	16.4	32.1
			λ_1	33.9	32.9	33.2
			λ_2	37.0	29.9	33.1
L ⇌ λ_1 + $CuMg_2$	566.5	e_{10}	L	0.2	33.9	65.9
			λ_1	9.3	56.6	34.1
			$CuMg_2$	0.0	33.3	66.7
L + λ_2 ⇌ S	570.9	p_{10}	L	60.2	20.8	19.0
			λ_2	37.5	29.8	32.7
			S	50.0	25.0	25.0
L + λ_2 ⇌ λ_3	537.8	p_{11}	L	54.4	9.7	35.9
			λ_2	38.8	28.1	33.1
			λ_3	40.3	26.4	33.3

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Al	Cu	Mg
$L \rightleftharpoons \lambda_1 + (Mg)$	528.2	e_{13}	L	7.8	10.7	81.5
			λ_1	26.3	40.1	33.6
			(Mg)	1.1	0.0	98.9
$L + \lambda_3 \rightleftharpoons Q$	527.5	p_{12}	L	49.1	7.9	43.0
			λ_3	40.3	26.3	33.4
			Q	43.8	18.7	37.5
$L \rightleftharpoons (Al) + S$	505.5	e_{14}	L	73.5	12.6	13.9
			(Al)	95.2	1.1	3.7
			S	50.0	25.0	25.0
$L + Q \rightleftharpoons T$	495.4	p_{13}	L	53.5	4.8	41.7
			Q	43.8	18.7	37.5
			T	51.1	8.3	40.6
$L \rightleftharpoons Mg_{17}Al_{12} + T$	457.2	e_{16}	L	48.0	0.9	51.1
			$Mg_{17}Al_{12}$	47.1	0.0	52.9
			T	52.4	5.4	42.2
$L \rightleftharpoons Mg_2Al_3 + T$	449.3	e_{19}	L	60.5	0.4	39.1
			Mg_2Al_3	61.1	0.0	38.9
			T	55.3	3.8	40.9

Table 3: Reported Data for the Invariant Reaction E_5, $L \rightleftharpoons (Al) + S + \theta$

Temperature [°C]	Liquid composition (mass%)		References	Comment
	Cu	Mg		
500	26.8	6.2	[1937Nis1]	-
500	29.7	7.2	[1946Ura, 1949Ura2]	-
507	33	6.1	[1948Bro]	-
-	29	6.5	[1950Phr]	scaled from figure
506.5	33.1	6.8	[1952Han]	-
506	33	7	[1967Coo]	unidirect solidification
506	33.1	6.25	[1972Gar]	unidirect solidification
507	33	7.1	[1973Dav]	-
507	34	7.6	[1973Dav]	calculated
507	30	6	[1976Mon]	-
506±1	-	-	[1980Bir]	d.s.c
506.6	33.4	7.2	[1987Lac]	calculated
503	32	7.2	[1995Hua]	DTA
503±2	33.4	6.95	[1997Che]	calculated
503	30.4	8	[1998Buh]	calculated
502.1	30.4	8	[2003Jan]	calculated

Table 4: Reported Data for the Invariant Reaction E_7, L ⇌ T + (Al) + Mg_2Al_3

Temperature [°C]	Liquid Composition (mass%)		References
	Cu	Mg	
451	~0.0	35	[1919Vog]
447	3	32	[1937Nis1]
445	1.5	33	[1946Ura, 1949Ura2]
451	~2.7	~ 32	[1948Bro]
450	~ 3.5	~ 32	[1952Han]
-	4	31.5	[1950Phr]
~ 450	2.8	32	[1951Mir2]
443	3.4	34	[1987Lac]
448±5	1.34	34.2	[1997Che]
448	1.5	33.3	[1998Buh]
447.6	1.3	33.4	[2003Jan]

Table 5: Reported Data for the Invariant Reaction U_{16}, L + S ⇌ T + (Al)

Temperature [°C]	Liquid Composition (mass%)		References	Comment
	Cu	Mg		
471	10	27	[1919Vog]	-
465	11	25	[1937Nis1]	-
465	10	25.6	[1946Ura]	-
462	10	25.6	[1949Ura2]	-
467	10	26	[1948Bro]	-
465	9.3	26.5	[1951Mir2]	-
472.3	11.3	25.7	[1952Han]	scaled from figure
467	10	26	[1976Mon]	-
468	11.4	25.5	[1987Lac]	assessment
467±4	10.7	26.1	[1997Che]	calculated
469	11.1	24.6	[1998Buh]	calculated
469.2	11.2	24.4	[2003Jan]	calculated

Table 6: Reported Data for the Mg-Rich Invariant Reactions E_9, U_{17} and U_{18}

Temperature [°C]	Liquid Composition (mass%)		References	Invariant Reaction
	Cu	Mg		
412	17	56.5	[1933Bas, 1934Por]	$L \rightleftharpoons (Mg) + Al_{11}Mg_{17} + \lambda$
419-420	6	62.2	[1940Han]	$L \rightleftharpoons (Mg) + Al_{11}Mg_{17} + \lambda$
423	4.6	67	[1949Ura2]	$L \rightleftharpoons (Mg) + Al_{11}Mg_{17} + \lambda$
425	6	63	[1951Mir2]	$L \rightleftharpoons (Mg) + Al_{12}Mg_{17} + Q$
423.6	5.4	62.6	[1997Che]	$L \rightleftharpoons (Mg) + Al_{12}Mg_{17} + Q$
426	4.4	63.2	[1998Buh]	$L \rightleftharpoons (Mg) + Al_{12}Mg_{17} + Q$
424.9	4.3	63.3	[2003Jan]	$L \rightleftharpoons (Mg) + Al_{12}Mg_{17} + Q$
452.0	11.3	62.7	[1997Che]	$L + \lambda_2 \rightleftharpoons (Mg) + Q$
456.6	9.9	63.7	[2003Jan]	$L + \lambda_2 \rightleftharpoons (Mg) + Q$
444.0	6.0	52.9	[1997Che]	$L + T \rightleftharpoons Al_{12}Mg_{17} + Q$
428	4.4	62.3	[1998Buh]	$L + T \rightleftharpoons Al_{12}Mg_{17} + Q$
426.8	4.4	62.6	[2003Jan]	$L + T \rightleftharpoons Al_{12}Mg_{17} + Q$

Table 7: Lattice Parameter, *a*, of the (Al) Phase [1951Poo] at 25°C

Analysed Composition (at.%)		Observed *a* [pm]	Intended Composition (at.%)		Corrected *a* [pm]
Mg	Cu		Mg	Cu	
0.189	0.367	404.8	0.25	0.375	404.81
0.456	0.247	404.97	0.5	0.25	404.99
0.655	0.119	405.1	0.75	0.125	405.14
0.202	0.88	404.58	0.25	0.875	404.6
0.414	0.75	404.72	0.5	0.75	404.76
0.637	0.628	404.9	0.75	0.625	404.95
0.927	0.5	405.07	1	0.5	405.1
1.247	0.362	405.24	1.25	0.375	405.24
1.311	0.246	405.32	1.5	0.25	405.4
1.608	0.127	405.5	1.75	0.125	405.56
0.356	0.302	404.91	0.375	0.313	404.91
0.578	0.179	405.05	0.625	0.188	405.07
1.058	0.422	405.12	1.125	0.438	405.14
0.57	0.659	404.77	0.625	0.688	404.78
0.804	0.521	404.9	0.875	0.563	404.91

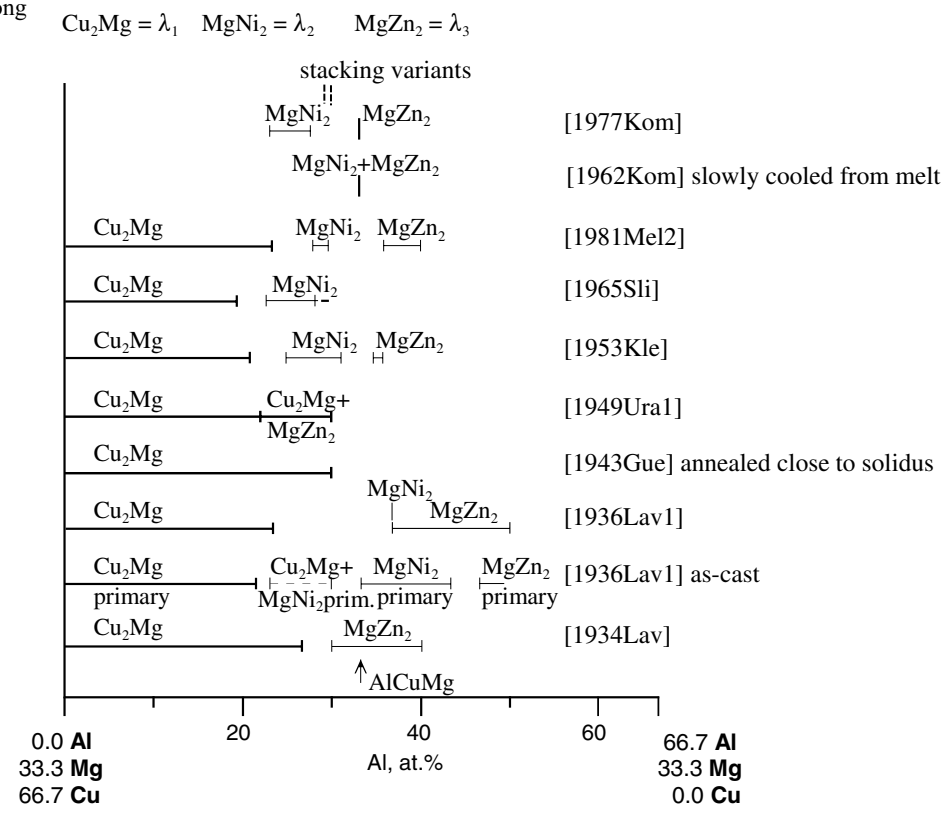

Fig. 1: Al-Cu-Mg. Phases detected along the 33.3 at.% Mg section

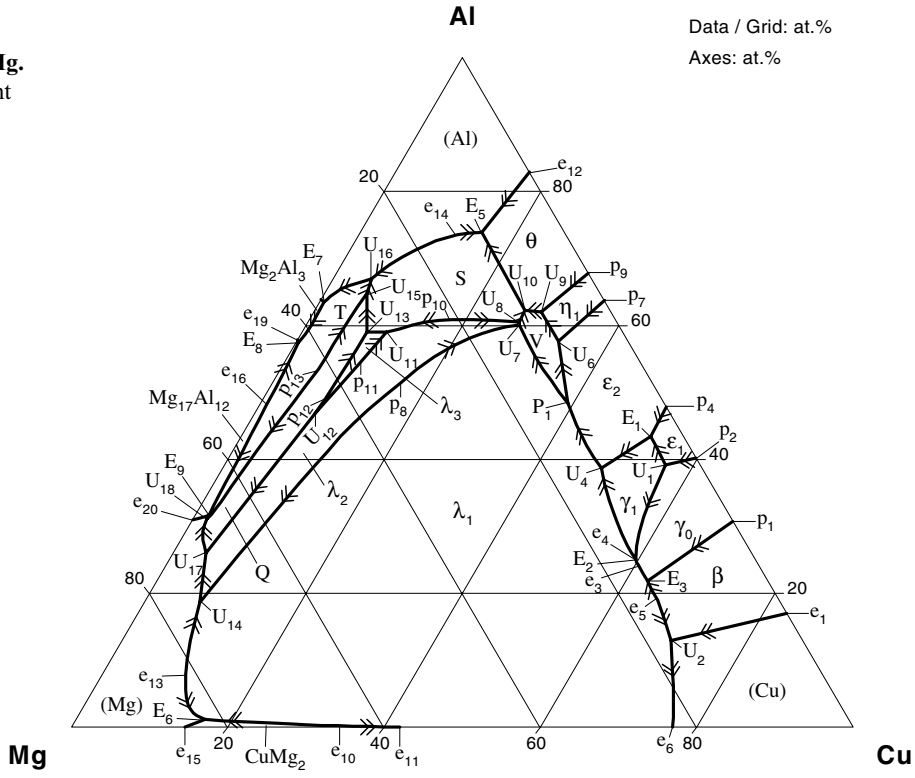

Fig. 2: Al-Cu-Mg. Liquidus univariant lines and primary phases

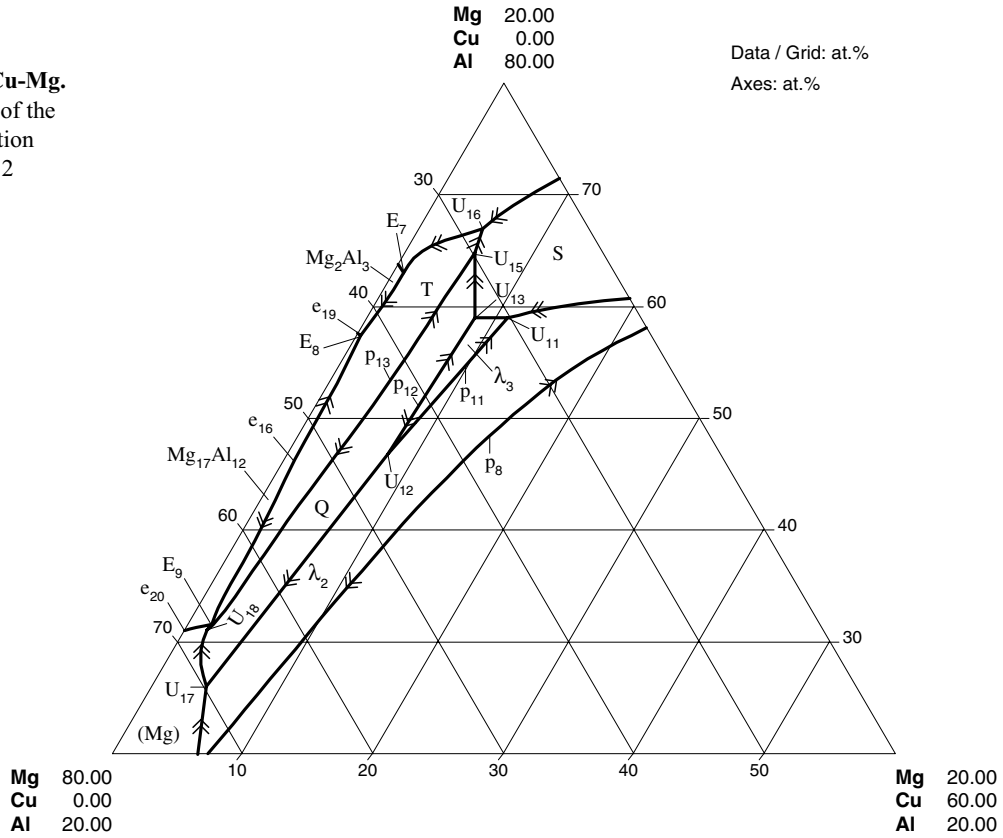

Fig. 2a: Al-Cu-Mg. Enlarged part of the liquidus projetion shown in Fig. 2

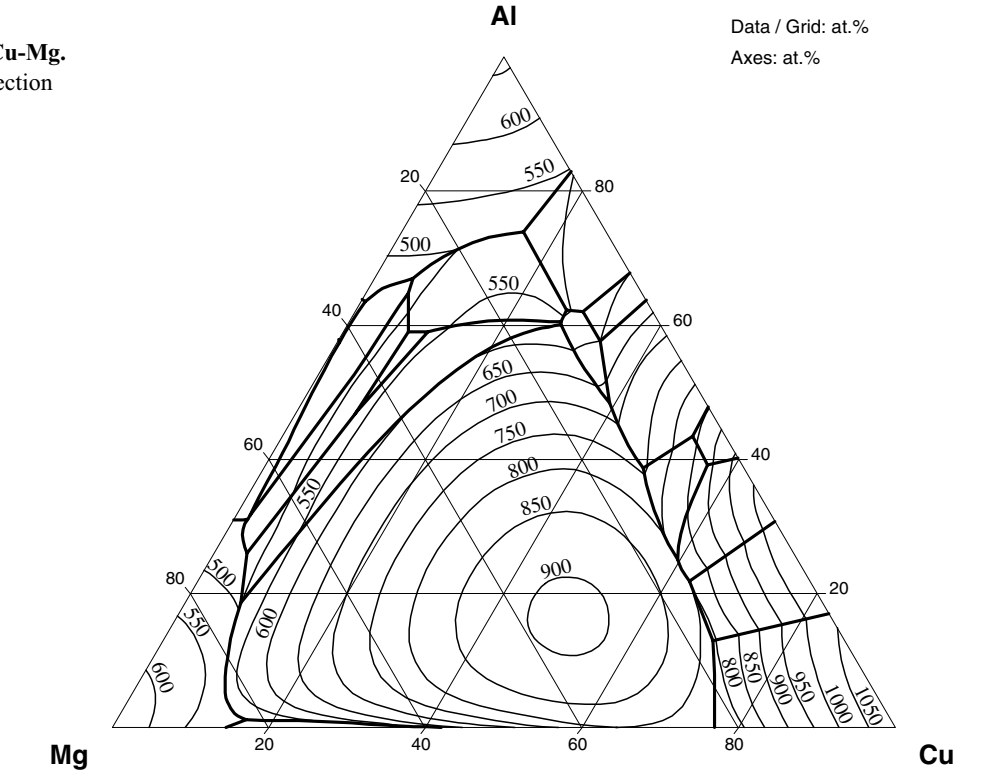

Fig. 2b: Al-Cu-Mg. Liquidus projection with liquidus isotherms

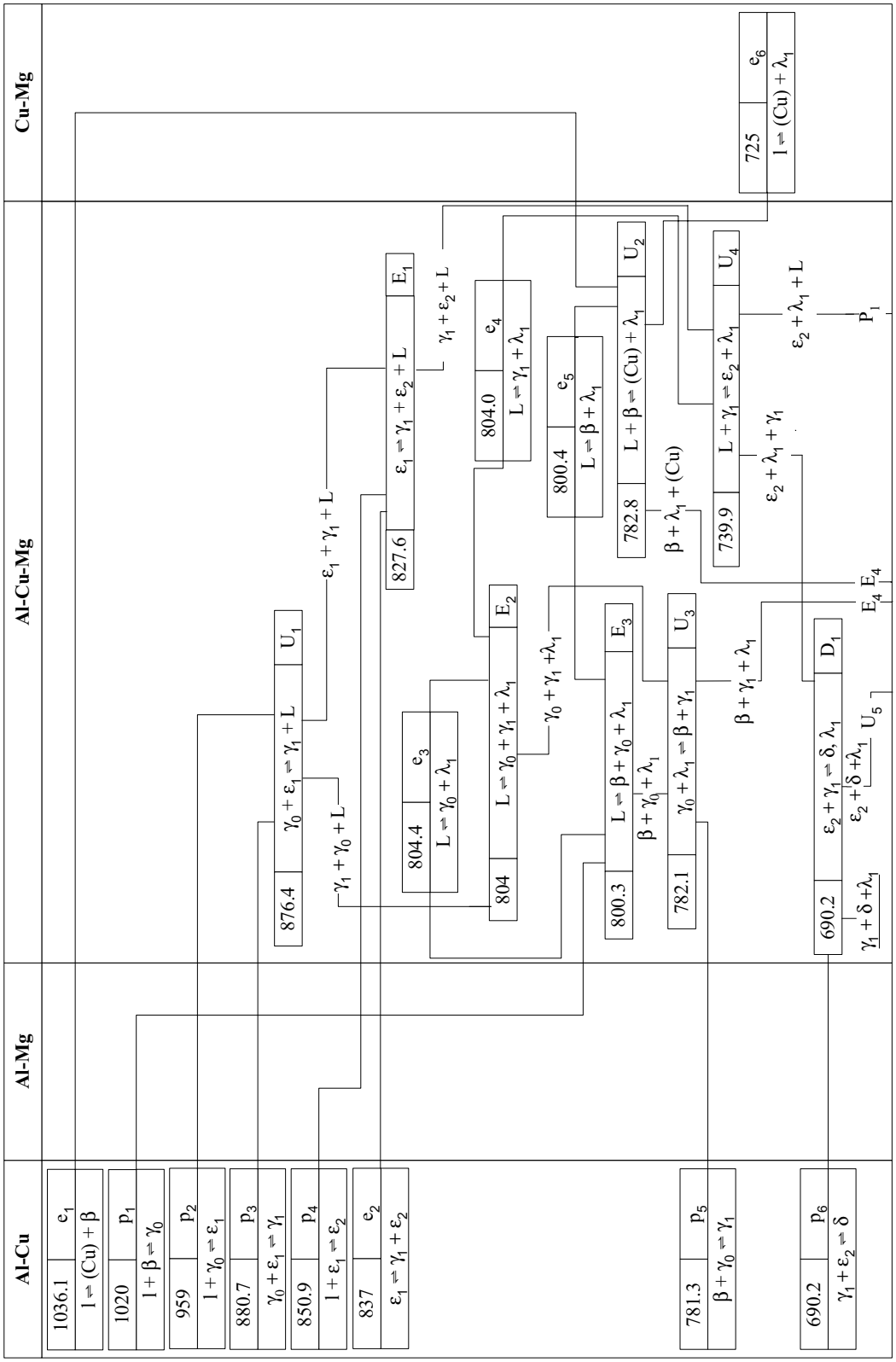

Fig. 3a: Al-Cu-Mg. Reaction scheme, part 1.

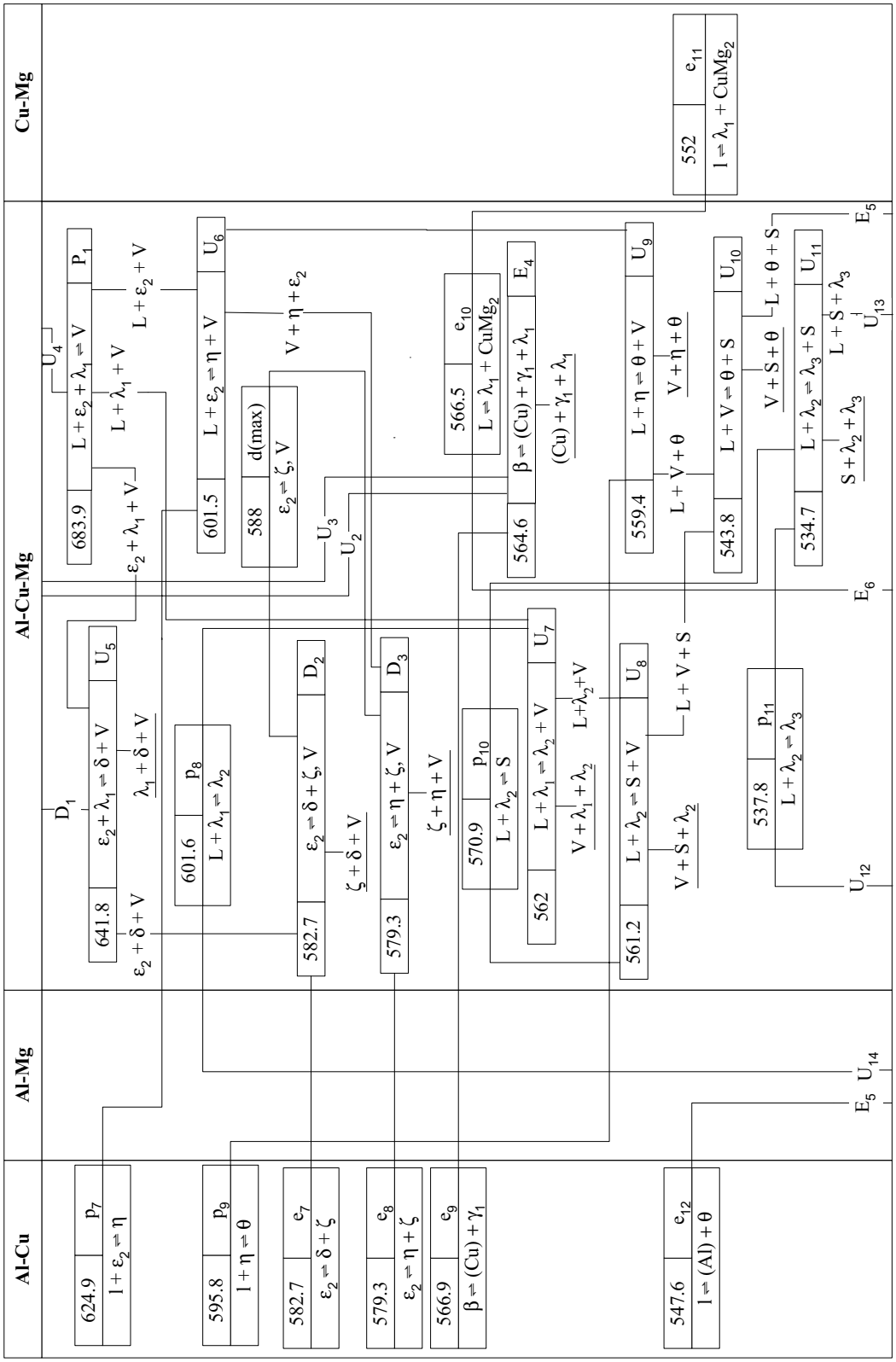

Fig. 3b: Al-Cu-Mg. Reaction scheme, part 2

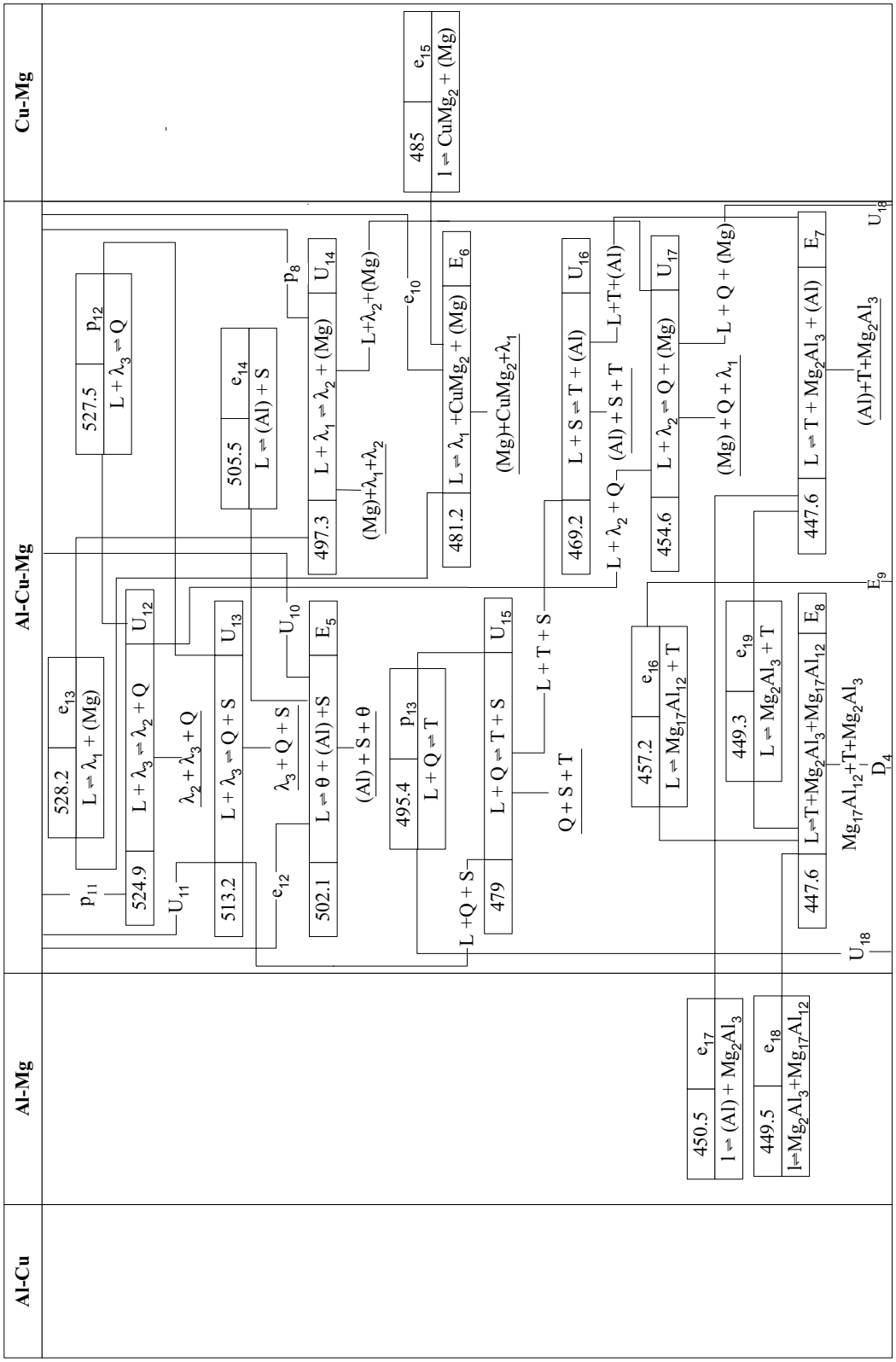

Fig. 3c: Al-Cu-Mg. Reaction scheme, part 3

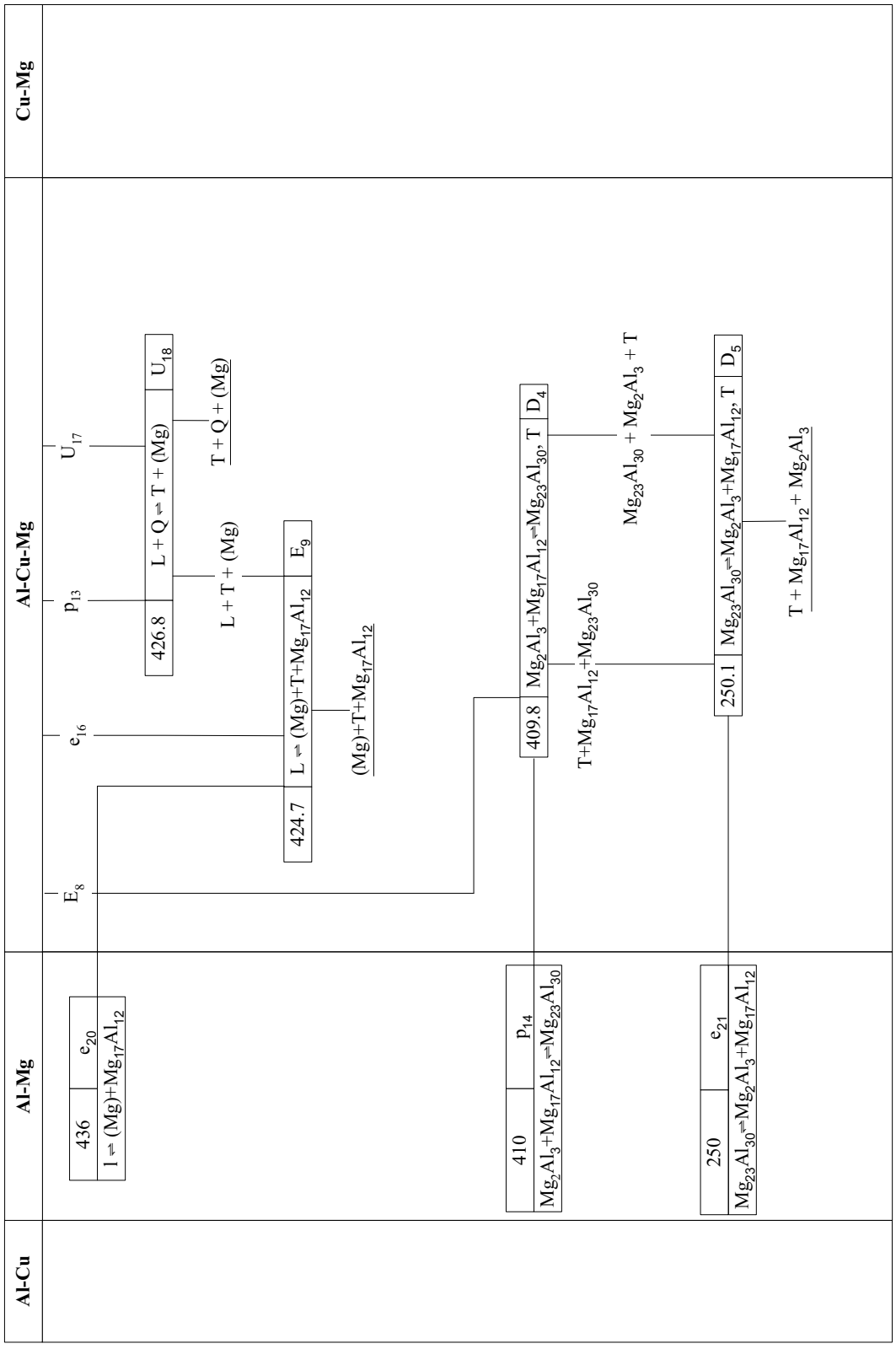

Fig. 3d: Al-Cu-Mg. Reaction scheme, part 4

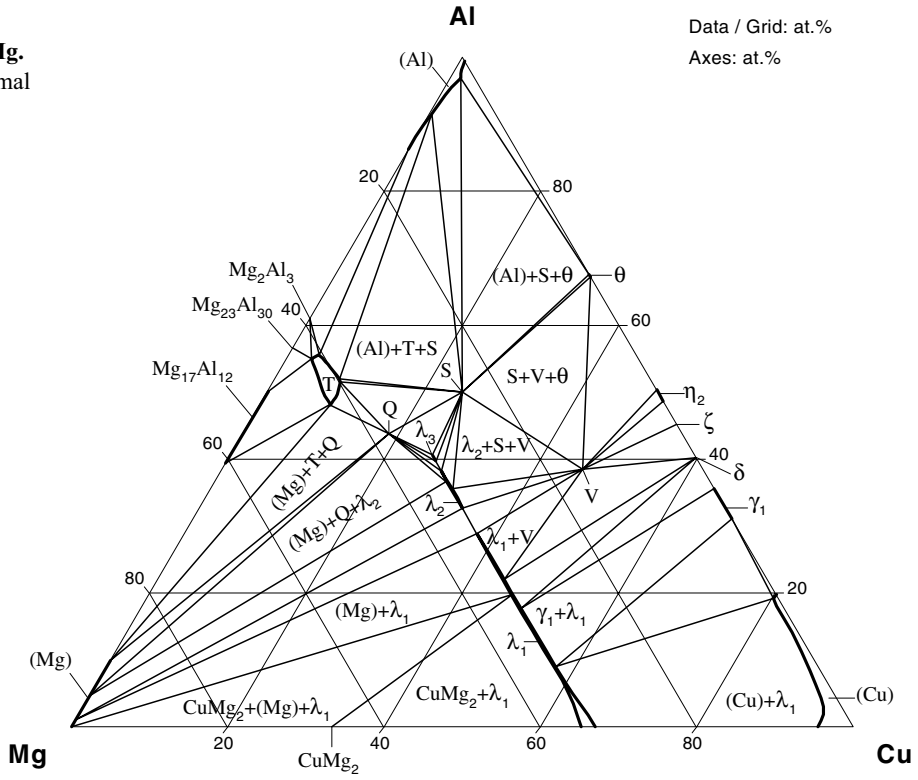

Fig. 4: Al-Cu-Mg. Calculated isothermal section at 400°C

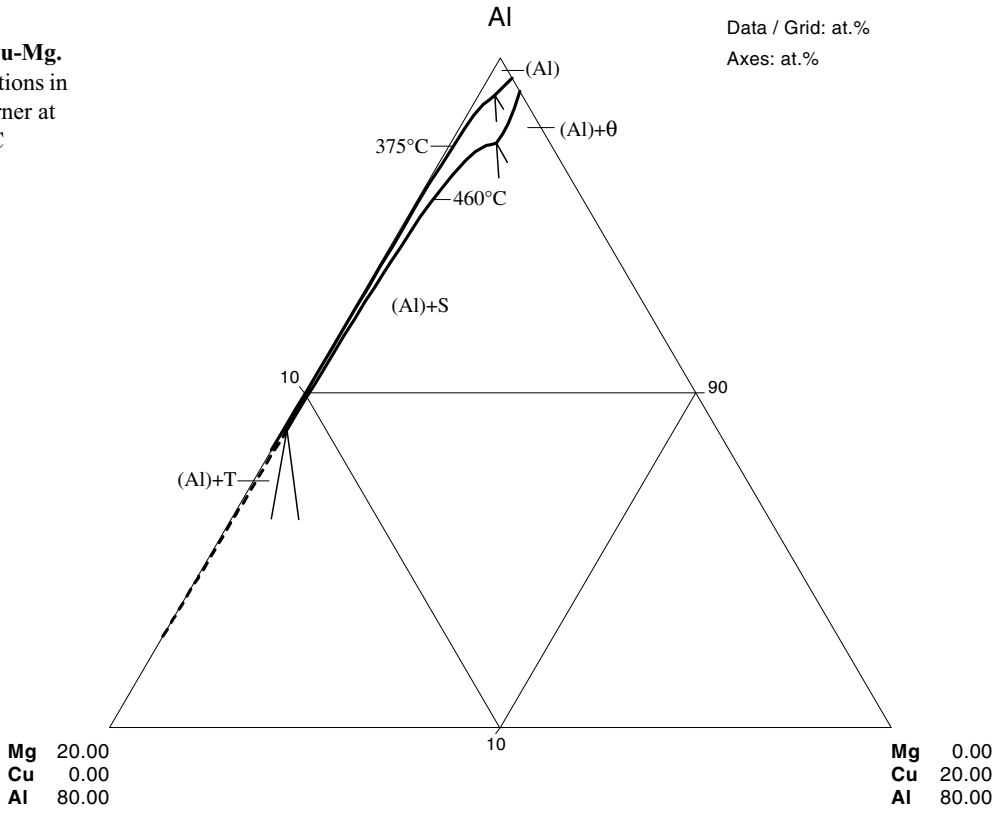

Fig. 5: Al-Cu-Mg. Isothermal sections in the Al-rich corner at 460 and 375°C

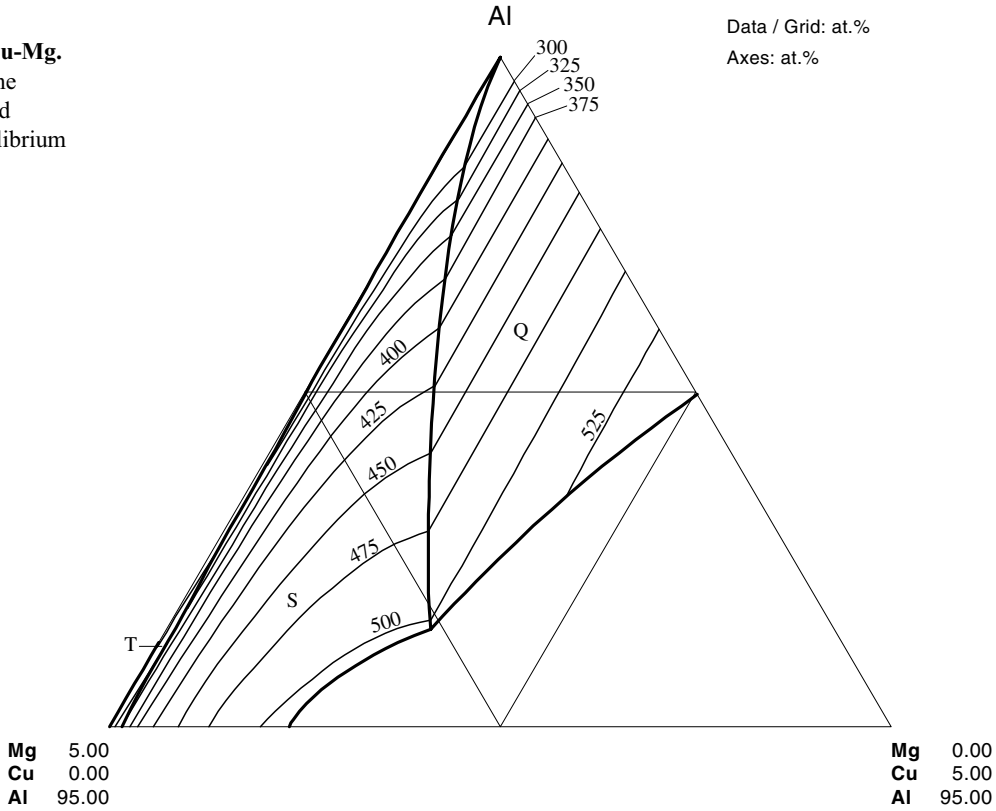

Fig. 6: Al-Cu-Mg. Isotherms of the (Al)-solvus and phases in equilibrium with (Al)

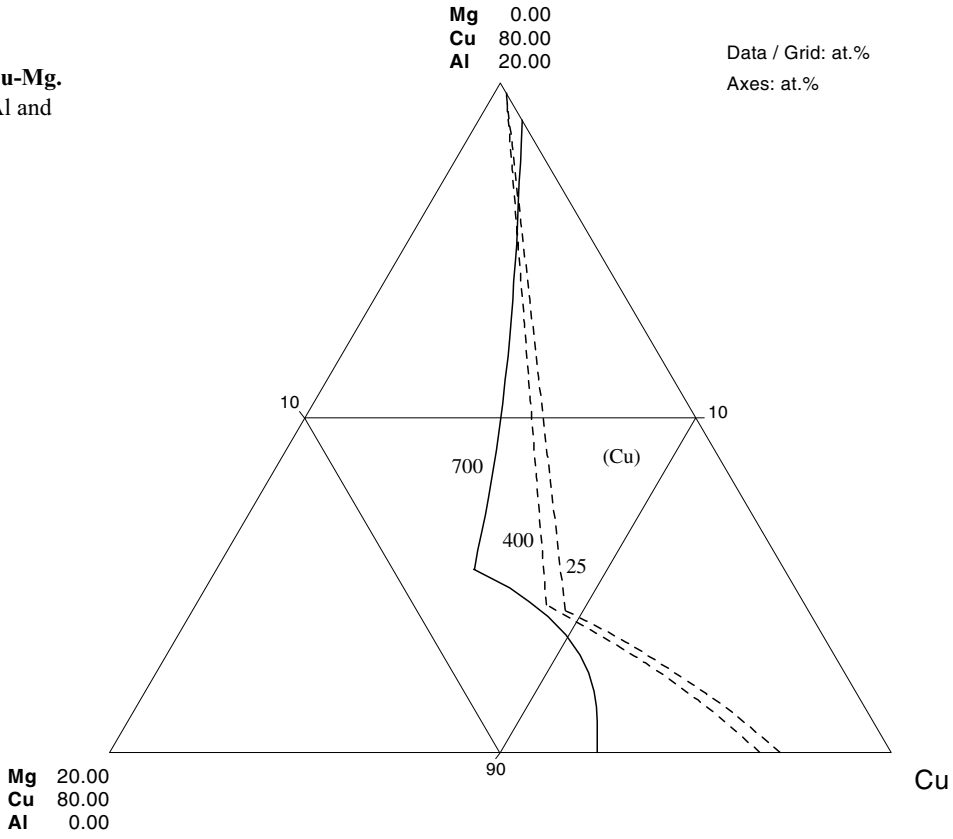

Fig. 7: Al-Cu-Mg. Solubility of Al and Mg in (Cu) [1957Rog]

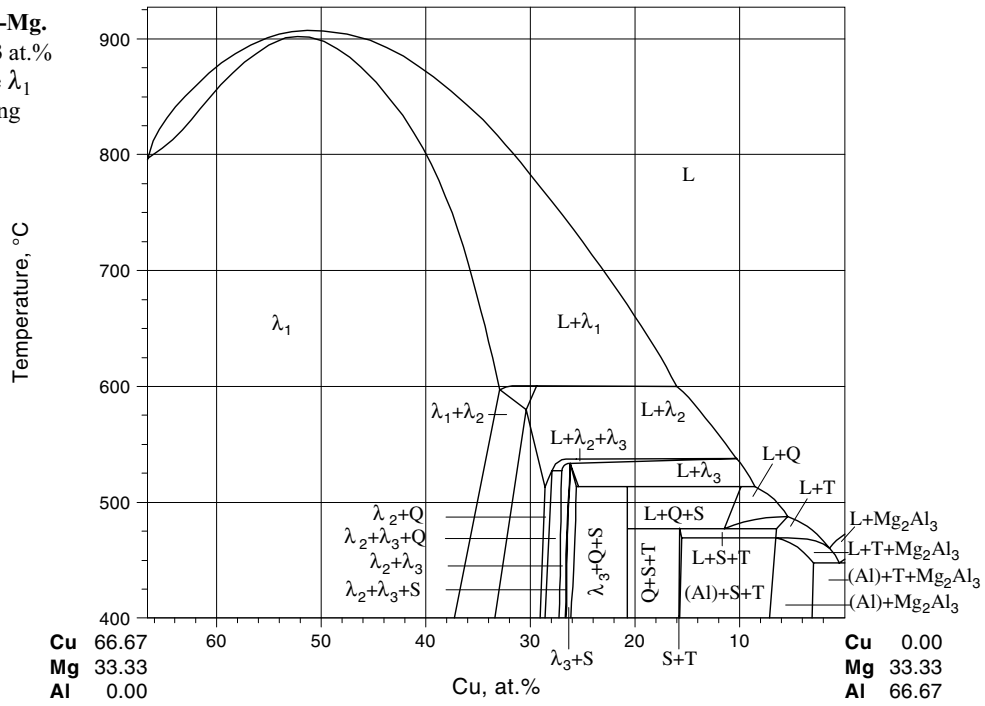

Fig. 8: Al-Cu-Mg. Isopleth at 33.33 at.% Mg showing the λ_1 congruent melting

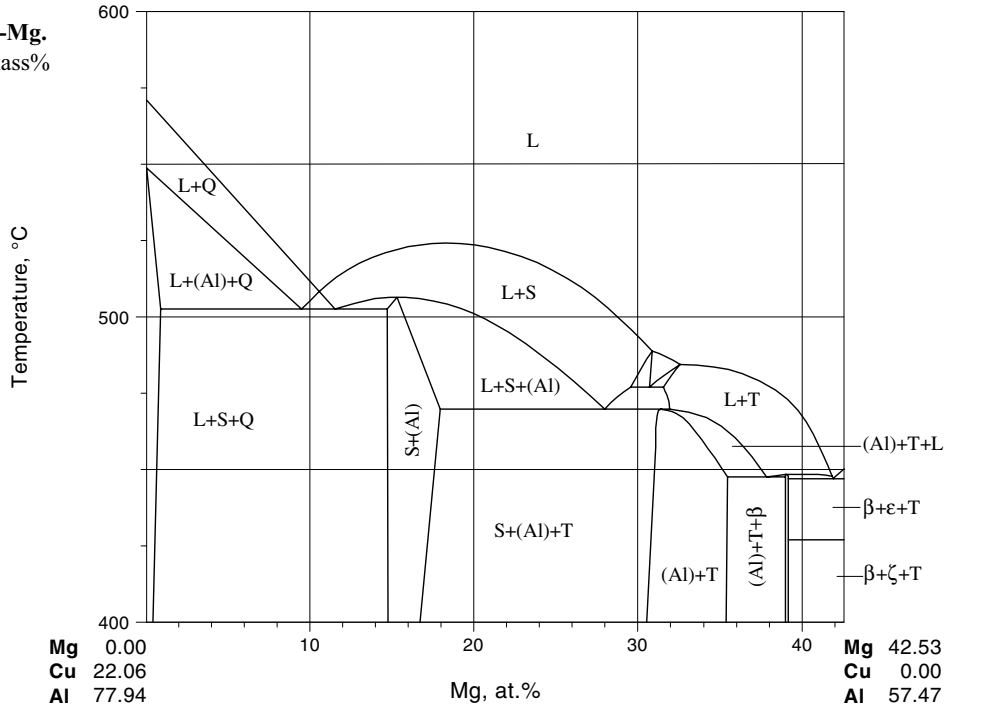

Fig. 9a: Al-Cu-Mg. Isopleth at 60 mass% Al

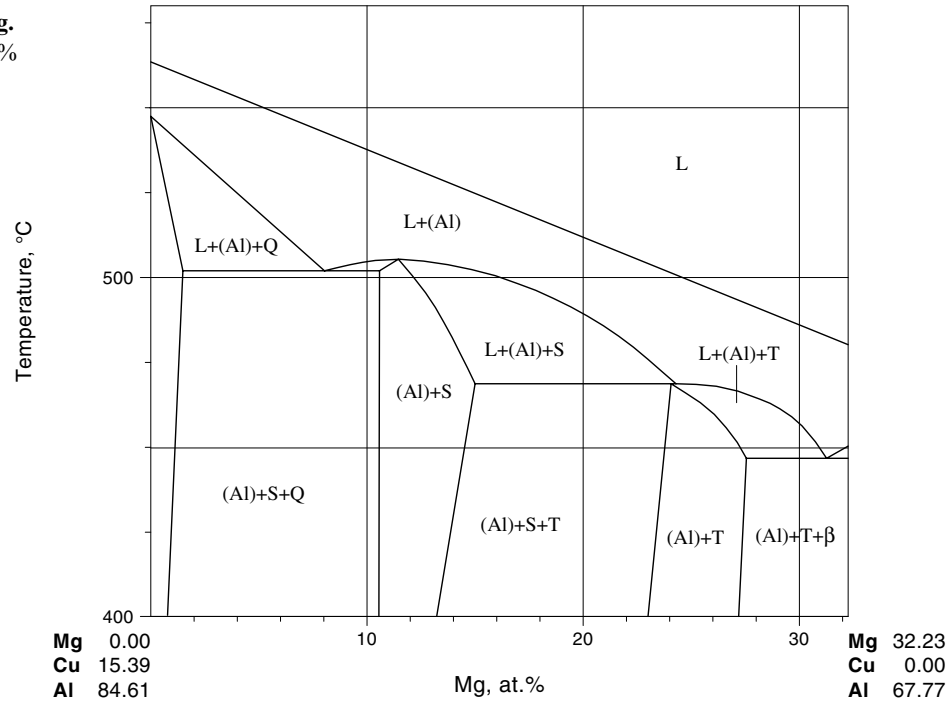

Fig. 9b: Al-Cu-Mg. Isopleth at 70 mass% Al

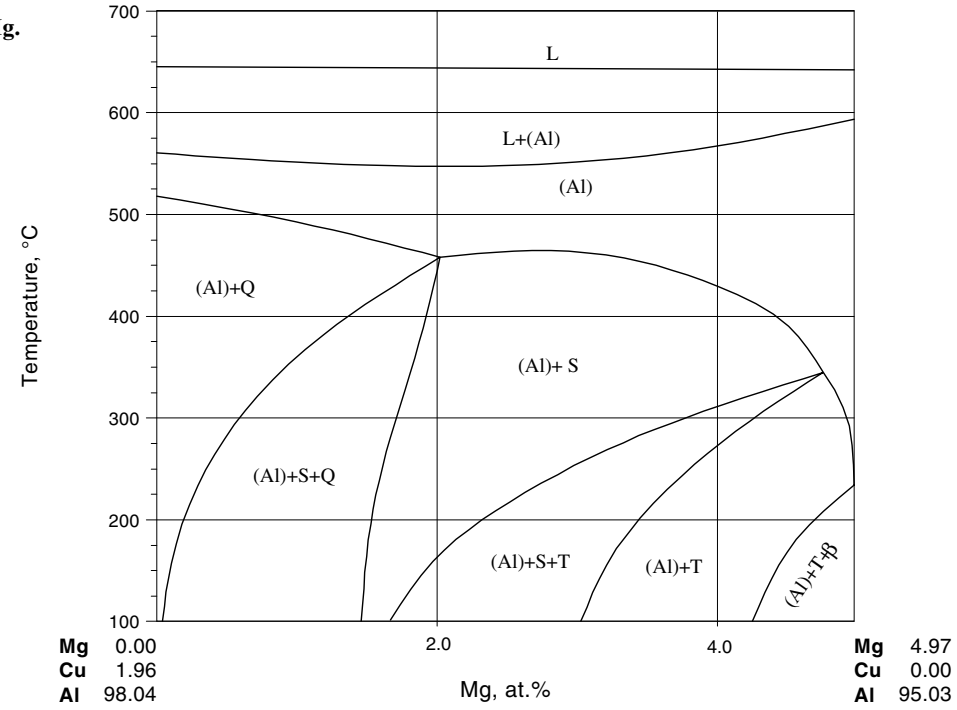

Fig. 9c: Al-Cu-Mg. Isopleth at 95.5 mass% Al

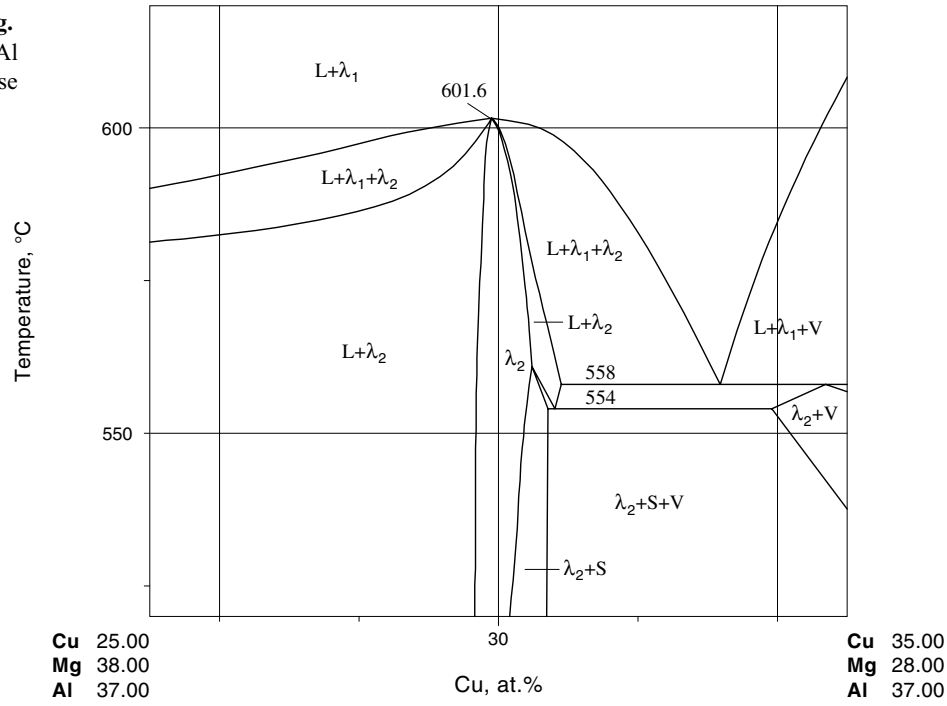

Fig. 10a: Al-Cu-Mg. Isopleth at 37 at.% Al showing the λ_2 phase formation

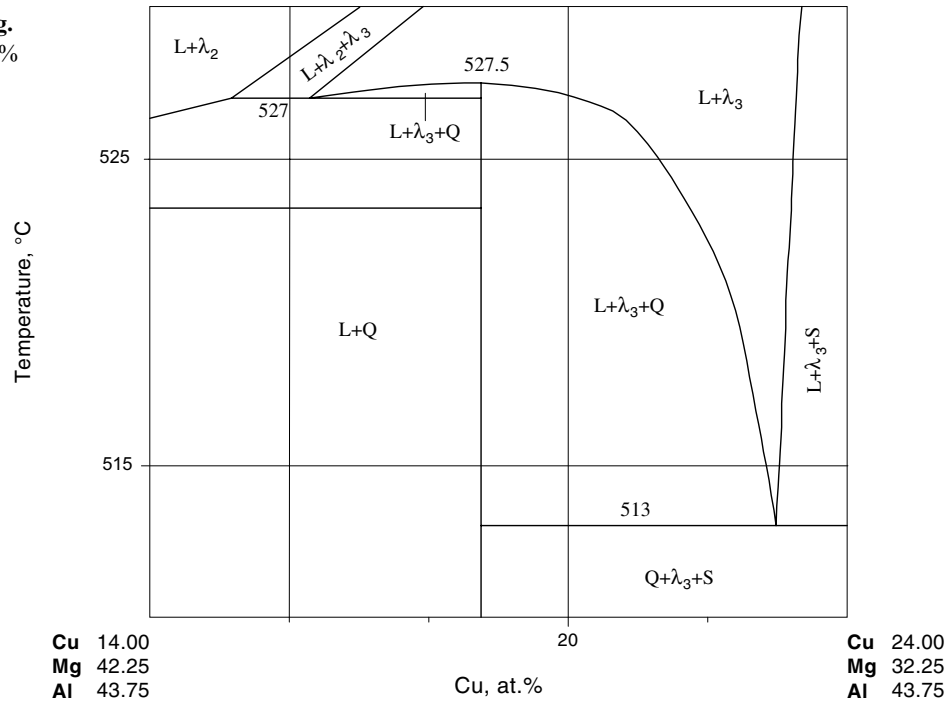

Fig. 10b: Al-Cu-Mg. Isopleth at 43.75 at.% Al showing the Q phase formation