

Phase relations and thermodynamics in the copper-lead-sulphur system

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SYNOPSIS

Phase relations within the condensed Cu-Cu₂S-PbS-Pb region of the Cu-Pb-S ternary were investigated. The boundaries of the ternary liquid-miscibility gap were redrawn, and the directions of the tie-lines were established by the quenching of samples equilibrated in evacuated and sealed silica capsules at 1473 K. The activities of lead in sulphur-saturated Cu-Pb alloys along the boundary of the miscibility gap were measured by the dew-point technique at 1473 K. From the tie-line distributions, measured lead activities, known activities of the Cu₂S-PbS join, and the ternary Gibbs-Duhem integration, consistent sets of activities for lead and copper and partial pressures of sulphur were obtained along the ternary miscibility gap at 1473 K.

SAMEVATTING

Die faseverhoudings binne die gekondenseerde Cu-Cu₂S-PbS-Pb-streek van die ternêre Cu-Pb-S-legering is ondersoek. Die grense van die ternêre vloeistofoplosbaarheids-gaping is oorgetrek en die rigting van die koppellyne is bepaal deur die blus van monsters wat by 1473 K in geëvakuëerde silikakapsules in ewewig gebring is. Die aktiwiteit van lood in swaelversadigde Cu-Pb-legerings langs die grens van die oplosbaarheids-gaping is volgens die dopunt-tegniek by 1473 K gemeet. Nie-strydige stelle aktiwiteite vir lood en koper en swaeldeeldrukke is aan die bekende aktiwiteite van die Cu₂S-PbS-samevoeging en die ternêre Gibbs-Duhem-integrasie by 1473 K langs die ternêre oplosbaarheids-gaping verkry.

Introduction

A knowledge of the high-temperature thermodynamic properties of the Cu-Pb-S system is essential for a proper understanding of the extraction and refining processes of both copper and lead. The binary Pb-PbS portion of that ternary was recently studied in detail by Eric and Timucin¹. They redrew the high-temperature portion of the PbS liquidus, and measured PbS activities in liquid solutions of this system at 1473 K. Their results were compatible with a subregular solution model that permitted development of analytical equations completely describing the thermodynamics and high-temperature phase relations. At 1473 K, the Pb-PbS system forms a continuous series of liquid solutions precluding the claimed existence of a liquid miscibility gap^{2,3}. The activities of both components deviate positively from ideality¹.

The binary sulphide system PbS-Cu₂S is a simple eutectic⁴. The activities of PbS in sulphide melts of this system were measured at 1473 K by Eric and Timucin⁵ by the dew-point technique. They found the system to show large negative deviations from ideality. Both the phase equilibria and the thermodynamics of the bounding Cu-Pb and Cu-Cu₂S binaries are well known⁶⁻¹³ and therefore are not repeated here.

Phase equilibria within the system Cu-Pb-S at matte-smelting temperatures (typically 1200 °C) have been the subject of numerous investigations¹⁴⁻²⁰. The system is characterized by a large ternary miscibility gap along which molten sulphide and metal phases are in equi-

librium; this gap originates from the Cu-Cu₂S binary, extends all the way into the ternary, and is closed at compositions near the Pb-PbS binary. In most of these studies, the distributions of tie-lines within the immiscibility gap were determined¹⁴⁻¹⁸. In addition, Azuma, Goto, and Takabe¹⁵ measured the activity of lead in sulphur-saturated Cu-Pb liquids at 1473 K in a limited composition range up to $X_{Pb} = 0,62$. Later, Choudary, Lee, and Chang²⁰, making use of the tie-line distributions provided¹⁴⁻¹⁶ and boundary binary thermodynamics, calculated the activities of Cu, Pb, and S by a method developed by Choudary and Chang²¹ along the miscibility gap at 1473 K. However, they had to modify the tie-line distributions¹⁴⁻¹⁶ at the lead-rich portion of the ternary miscibility gap to obtain consistent data with the model²¹ used. Goto *et al.*¹⁸ calculated the activities of copper, lead, and sulphur along the miscibility gap at 1473 K by a similar method, this time using their own tie-line distributions. However, the agreement between their values and those of Choudary, Lee, and Chang²⁰ was rather poor. Most recently, Goto and Ogawa¹⁹ recalculated the relevant activities, making use of the tie-line distributions determined in their laboratory^{17,18}, by a modified model employing the ternary three-suffix Margules equations. Goto and Ogawa concluded that the method developed by Choudary and Chang²¹ was not applicable to the whole miscibility-gap region, although it was thermodynamically consistent. Even so, the values calculated for lead activities from Margules' equations were partly contradictory to thermodynamics¹⁹. This was attributed by the authors¹⁹ to the lack of information on the limiting activity coefficients of Cu and Pb in sulphur at high temperatures, and also to the unsymmetrical nature of the ternary system. The equations con-

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sidered in both model attempts^{19,21} are considered useful for cases of relatively small unsymmetry. Furthermore, the equations depend fairly heavily on tie-line distributions and binary thermodynamic data. The limiting activity coefficients in sulphur-saturated Cu–Pb melts are not available and are estimated. Small deviations in tie-line distributions, especially at both the copper-rich and the lead-rich sides result in considerable differences in activities, however good the agreement between the directions and distribution of tie-lines.

The present study was initiated (i) to re-establish the directions and distributions of tie-lines between co-existing liquid sulphide and liquid metal phases in the Cu–Pb–S ternary throughout the composition range by conventional, careful quenching experiments, and (ii) to measure the Pb activities of sulphur-saturated Cu–Pb alloys at 1473 K by use of the dew-point method. From the measured Pb activities and from the known activities⁵ in PbS–Cu₂S melts at 1473 K, the isoactivities of copper and lead and the partial pressures of sulphur along the miscibility gap would easily be calculated through direct ternary Gibbs–Duhem integration, which is thermodynamically consistent. This procedure would circumvent the indirect model-based calculations of activities along the miscibility gap.

The dew-point technique makes use of the volatility of a component in solution, and thus circumvents the problems encountered in open-system measurements on systems with a volatile component. The details, limitations, and merits of the dew-point technique have been discussed by Eric and Timucin⁵, Timucin⁶, Bilgin and Eric²², and Komarek²³. The available data for the vapour species of the Cu–Pb–S system easily show that the dew-point technique gives practically unambiguous results of lead activities for the system studied.

Experimental Procedure

The primary starting materials were electrolytic copper (99,99 per cent minimum purity), triply distilled sulphur, and lead obtained by hydrogen reduction of Merck analytical-grade PbO powder. Cu₂S and PbS were synthesized from their elements. PbS was prepared by the reacting of a stoichiometric mixture of lead and sulphur in an evacuated ($\approx 10^{-7}$ atm) and sealed silica tube. The tube was heated first at 500°C for 48 hours, and the Pb and S became molten and reacted rapidly to form PbS. In a second-stage heating, PbS was melted and homogenized at 1150°C for 4 hours. Cu₂S was prepared by the same procedure, except that the initial heating was at 700°C and the final melting at 1200°C. At the end of the melting stage, the silica tubes were plunged into water to quench the molten sulphides to room temperature. X-ray-diffraction analyses on the products verified their complete formation. Chemical analyses showed that the compounds had the correct stoichiometric compositions within the limits of analytical error.

The classical equilibration–quenching technique was used to establish the equilibrium relations between the immiscible melts of the Cu–Pb–S system. The distribution of tie-lines in the ternary miscibility gap was ascertained from determinations of the compositions of the sulphur-saturated Cu–Pb melts and sulphur-deficient sulphide melts that were in equilibrium with each other

at 1473 K. The samples selected for this study were prepared by the mixing of PbS, Pb, Cu, and Cu₂S in such a manner that their gross composition would lie along the mid-range of the miscibility gap. These samples, each weighing about 18 to 20 g, were placed in silica tubes of 20 mm internal diameter, which were evacuated to $\approx 10^{-7}$ atm. The tubes were gettered with copper gauze at 500°C for 6 hours, and then sealed again to a final length of about 30 mm. The silica capsules containing the samples were suspended by a platinum wire and basket into the dew-point furnace and heated at 1473 K for 5 hours to effect the melting of the charge, its separation into two liquids, and the attainment of equilibrium between these liquids. Details of the dew-point furnace are given elsewhere^{5,6} and are not repeated here. Time to reach equilibrium was established by chemical analysis of the stratified liquids at intervals of 1 hour for a total of 5 hours. These analyses revealed that 3 hours would be sufficient duration for equilibration; the actual runs, however, took 5 hours each for the sake of convenience. The two liquids formed during equilibration were virtually immiscible in each other; the sulphide melt floated on top of the metallic melt because of its lower density. This stratification was preserved when the samples were quenched to room temperature by the careful dropping of the capsules into water. The quenched samples were removed from the capsules, the immiscible phases were separated readily from each other, and representative portions of these were analysed chemically by standard techniques for Cu, Pb, and S. The accuracy of the analyses were reported to be about $\pm 0,5$ per cent by weight.

The activities of Pb at 1473 K along the sulphur-saturated Cu–Pb alloys of the ternary miscibility gap of the Cu–Pb–S system were determined by measurement of the dew-point temperatures of samples selected from the sulphur-saturated ends of the previously determined tie-lines. After equilibration–quenching tests, a large portion of the sulphur-saturated Cu–Pb alloys were reserved (about 7 to 10 g) for dew-point experiments. In that way, the activities of Pb on each tie-line determined would be measured. Chips of these samples were placed in transparent silica tubes of 10 mm internal diameter, which were evacuated, gettered, and sealed in the manner explained earlier for the equilibration–quenching samples. The only difference was that the final length of these tubes was 15 cm, which was dictated by the temperature profile of the dew-point furnace^{5,6}. Further, in order to facilitate the detection of condensates, the top of each dew-point capsule was shaped, prior to evacuation, into a nipple 10 mm long and 5 mm in diameter.

For a dew-point determination, the sample tube was introduced slowly into the dew-point furnace from the bottom, and was raised inside its proper location with the aid of an alumina pedestal. The tube was centred by the alumina plug covering the top of the furnace tube. At the start of each run, both ends of the sample tube were kept at 1473 K for 6 hours to effect the melting of the charge and to establish the equilibrium between the vapour and the liquid phases. Later, through the use of temperature-control devices, the tip of the probe was cooled slowly until small condensing droplets of Pb were observed through a telescope directed at the tip. The con-

densate was re-evaporated and recondensed several times while the interval of superheating and cooling was decreased continuously. The dew-point temperature of a sample was considered to be the average of the final condensation and evaporation temperatures. Upon completion of a dew-point run, the silica tube was quenched in air and the sample was removed for phase identification and chemical analyses.

Results and Discussion

The directions of tie-lines within the ternary miscibility gap of the Cu–Pb–S system bounded by the compositions Cu, Cu₂S, PbS, and Pb were established at 1473 K. The boundaries of the liquid immiscibility region were drawn based on the compositions of the end-points of the tie-lines representing the equilibrium between sulphur and sulphide-saturated liquids. The relevant data are given in Table I and Fig. 1. The Cu–Cu₂S binary-phase equilibria ($X_S = 0,023$) and thermodynamic data ($a_{Cu} = 0,981 \pm 0,002$, $P_{S_2} = 9,37 (\pm 1,5) \times 10^{-7}$ atm) are taken from Kellogg⁹.

TABLE I
EXPERIMENTAL DATA FOR THE TIE-LINES OF THE Cu–Pb–S SYSTEM AT 1473 K

Compositions after equilibration, mole fractions

Along sulphide-saturation boundary			Along sulphur-saturation boundary			Dew-point temperatures and Pb activities	
X_{Cu}	X_{Pb}	X_S	X_{Cu}	X_{Pb}	X_S	K	a_{Pb}
0,640	0,020	0,340	0,892	0,087	0,022	1377 ± 2	0,353
0,631	0,029	0,340	0,788	0,190	0,022	1407 ± 2	0,496
0,626	0,047	0,327	0,609	0,354	0,037	1431 ± 2	0,645
0,614	0,048	0,338	0,397	0,584	0,019	1449 ± 2	0,781
0,588	0,066	0,346	0,152	0,845	0,003	1459 ± 2	0,866
0,522	0,112	0,366	0,055	0,939	0,006	1463 ± 2	0,903
0,402	0,200	0,398	0,051	0,943	0,006	1467 ± 1	0,941
0,233	0,371	0,396	0,012	0,985	0,003	1470 ± 1	0,970
0,137	0,438	0,425	0,018	0,924	0,058	–	–
0,670*	–	0,330*	0,977*	–	0,023*	–	–

* From Kellogg⁹

In Fig. 1 the full circles represent the end-points of the tie-lines determined by chemical analyses, and the light lines joining the full circles are the conjugation (tie) lines. The heavy lines represent the boundaries of the miscibility gap derived from the tie-line data. Near the Pb–PbS side, owing to experimental difficulties, an inferred boundary is drawn as shown by heavy dashed lines. The heavy straight line joining the compositions Cu₂S and PbS represents stoichiometric Cu₂S–PbS liquid solutions and is hypothetical.

The shape of the redrawn miscibility-gap boundaries are similar to and in good agreement with the previous ones^{15–18,20}. At the Cu₂S-rich side, the earlier boundary almost coincides with the boundary from this investigation. However, small deviations start after about $X_{PbS} = 0,5$ (along the Cu₂S–PbS join), and the previous inferred curve predicts higher sulphur contents. Further, the boundary of Azuma *et al.*¹⁵ and of Choudary *et al.*²⁰ approaches closer to the Pb–PbS binary. As far as this

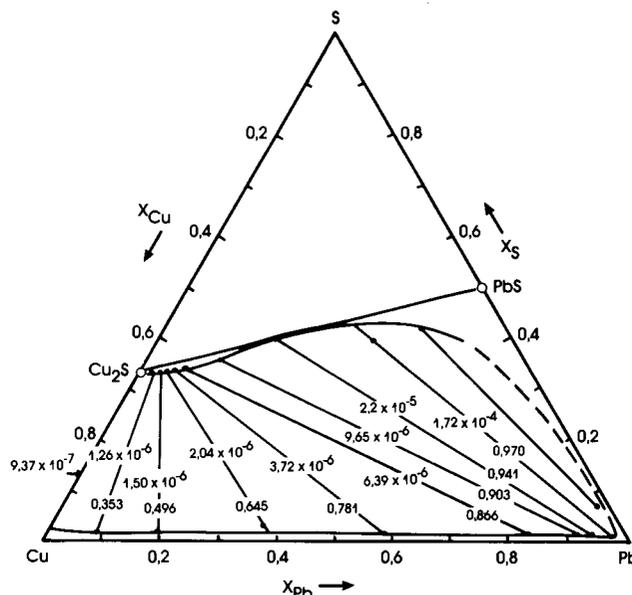


Fig. 1—Experimentally determined tie-lines and Pb activities in Cu–Pb–S melts at 1473 K, with superimposed sulphur partial pressures calculated through Gibbs–Duhem integrations on each tie-line

part of the boundary is concerned, the results of this work are in much better agreement with those of Goto *et al.*¹⁸. The lower boundary representing the sulphur saturation determined in the present study is almost parallel to those given previously^{15–18,20} but predicts slightly lower sulphur contents.

Tie-lines, illustrated in Fig. 1, cover almost the whole composition range, in contrast to some of the previous results. A group of authors had studied the Cu-rich side^{14–16} and another group the Pb-rich side^{17–18}. However, there is generally good agreement between all the previous studies^{14–18} and this work on the distribution and direction of tie-lines. The sulphide-saturation ends concentrate on the Cu₂S-rich side of the upper boundary, whereas the sulphur-saturation ends concentrate on the Pb-rich side of the lower boundary. Thermodynamically, this behaviour simply implies opposite deviations from ideality for the Cu₂S–PbS and Cu–Pb solution, as confirmed previously^{5,6}. Along the mid range and high Pb side of the miscibility gap, the directions of previous tie-lines^{15–18} represent equilibrium between a very highly Pb-rich sulphur-saturated liquid and a relatively low PbS-containing sulphide-saturated liquid. The present work indicates that such high Pb-containing sulphur-saturated liquid phases are in equilibrium with higher PbS-containing sulphide-saturated liquids. At the Cu-rich side, there is much better agreement.

The directions of the tie-lines are closely related to the soundness of the chemical analyses. In order to minimize errors, each tie-line was determined by the equilibration of more than one sample of the same initial composition. Chemical analyses of the stratified liquids of each of these provided an average composition value for the end-points of each tie-line.

The activities of Pb at 1473 K along the sulphur-saturation boundary of the ternary miscibility gap were determined, as mentioned earlier, by measurement of the dew-point temperatures of samples selected from the

sulphur-saturated ends of the previously determined tie-lines. The dew-point temperatures and activities are also given in Table I. The Pb activities were evaluated from the relationship

$$a_{Pb} = P_{Pb}/p_{Pb}^{\circ}, \dots\dots\dots (1)$$

where p_{Pb} is the vapour pressure of pure Pb at the dew-point temperature and p_{Pb}° represents the same for pure liquid Pb at the equilibration temperature of 1473 K. Thus, the standard state for Pb activities is pure liquid Pb at 1473 K. These quantities were calculated from the following vapour-pressure equation:

$$\log p_{Pb}(\text{atm}) = -9558/T + 4,7475 \\ (1100 \text{ K} \leq T \leq 1500 \text{ K}). \dots\dots\dots (2)$$

Equation (2) is derived from the vaporization data compiled by Kellogg²³. All the equations available in the literature²³⁻²⁵ on lead vapour pressures give almost identical activities for Pb when they are used in vapour-phase measurements. Fig. 1 contains, on each tie-line, the Pb activities together with sulphur partial pressures that were calculated by the methods outlined below.

Ternary Gibbs-Duhem integrations were performed to evaluate the activities of copper (with pure liquid Cu at 1473 K as the standard state) and partial pressures of sulphur from measured Pb activities along the miscibility gap. Since the system involves two liquid phases in equilibrium with each other, the activities of each component will remain constant along each tie-line and it is therefore possible to write two ternary Gibbs-Duhem equations for the two liquid phases.

For the sulphide-saturated liquid phase:

$$X_{Cu} d \log a_{Cu} + X_{Pb} d \log a_{Pb} + X_S d \log a_S = 0 \dots\dots (3)$$

For the sulphur-saturated liquid phase:

$$X'_{Cu} d \log a_{Cu} + X'_{Pb} d \log a_{Pb} + X'_S d \log a_S = 0, \dots (4)$$

where X_i are the mole fractions along the sulphide-saturation boundary and X'_i are the mole fractions along the sulphur saturation boundary of the system. When equation (3) is multiplied by X'_S and equation (4) by X_S , and the terms with $d \log a_S$ are eliminated, the following equation is obtained for the activity of copper:

$$d \log a_{Cu} = \psi d \log a_{Pb}, \dots\dots\dots (5)$$

where the composition parameter ψ is given by

$$\psi = - \frac{X'_S X_{Pb} - X_S X'_{Pb}}{X'_S X_{Cu} - X_S X'_{Cu}} \dots\dots\dots (6)$$

The integral of equation (5) can be written as

$$\log a_{Cu} = \log a_{Cu}^* + \int_{a_{Pb}^*}^{a_{Pb}} \psi d \log a_{Pb} \dots\dots\dots (7)$$

This integral can be performed to evaluate $\log a_{Cu}$ when $\log a_{Cu}^*$ at the starting point of integration is known, and when the data on a_{Pb} are sufficiently complete as a function of parameter ψ . The tie-line on which $a_{Pb} = 0,941$ served as the starting line. This is because the sulphide-saturation end of this particular line coincided with the Cu_2S -PbS stoichiometric solutions for which activity data are available at 1473 K from Eric and Timucin⁵. At that point, the sulphide activities are $a_{PbS} = 0,105$ and $a_{Cu_2S} = 0,373$ from their data. By use of

the measured a_{Pb} from this work, a_{PbS} from Eric and Timucin⁵ on this tie-line, and the standard free energy of formation of liquid PbS¹ at 1473 K ($\Delta G^{\circ} = -38755 \text{ J/mole}$), the partial pressure of sulphur on this tie-line was found to be $2,22 \times 10^{-5} \text{ atm}$. From the standard free energy of formation of liquid Cu_2S^9 at 1473 K ($\Delta G^{\circ} = -85163 \text{ J/mole}$), the available a_{Cu_2S} value⁵, and P_{S_2} as calculated above, a_{Cu} on this particular tie-line was calculated as $a_{Cu}^* = 0,275$. With this value as the starting point, the integral of equation (7) was evaluated graphically as the area under the curve for ψ against $\log a_{Pb}$.

For the calculation of the sulphur partial pressures, the standard state for sulphur was changed from hypothetical pure liquid sulphur (at 1473 K) to S_2 gas at 1 atm pressure by use of the reaction



The logarithm of equilibrium constant for reaction (8) can be written as

$$\log K = \log a_S - \frac{1}{2} \log P_{S_2} \dots\dots\dots (9)$$

Differentiation of equation (9) yields the following result:

$$d \log a_S = \frac{1}{2} d \log P_{S_2} \dots\dots\dots (10)$$

When $d \log a_S$ is replaced by $d \log p_{S_2}$ in equations (3) and (4) and the terms with the activity of copper are eliminated, the final equation for sulphur partial pressure is

$$\log p_{S_2} = \log p_{S_2}^* + \int_{a_{Pb}^*}^{a_{Pb}} \theta d \log a_{Pb}, \dots\dots\dots (11)$$

where

$$\theta = \frac{X'_{Cu} X_{Pb} - X_{Cu} X'_{Pb}}{\frac{1}{2}(X'_{Cu} X_S - X_{Cu} X'_S)} \dots\dots\dots (12)$$

Again, with the known value of $p_{S_2}^* = 2,22 \times 10^{-5} \text{ atm}$ at the starting point, the integral of equation (11) was evaluated graphically as the area under the curve for θ against $\log a_{Pb}$.

All the thermodynamic results along the ternary miscibility gap of the Cu-Pb-S system, obtained by the procedure explained above, were used in the construction of Figs. 2 to 4. Figs. 2 and 3 show the iso-activities of Pb and Cu in ternary representation respectively. The sulphur isobars are shown in Fig. 1 on each experimentally determined tie-line, together with the experimentally determined Pb activities. Fig. 4, on the other hand, depicts the activity composition relations of sulphur-saturated liquid Cu-Pb alloys in a binary form, although the system is not a true binary.

When the lead activities determined in the present work are compared with the findings of Azuma *et al.*¹⁵ (broken lines in Fig. 4), it is seen that the agreement is very good up to about $X_{Pb} = 0,25$, but thereafter their activities become progressively higher. This also reflects the directions of the tie-lines determined in their study, dictating equilibrium between highly Pb-rich sulphur-saturated Cu-Pb melts and relatively low PbS-containing sulphide-saturated liquids. The lead activities calculated by Choudary *et al.*²⁰ are also higher after about $X_{Pb} = 0,20$. This is not unexpected, since their method of activity calculation was mostly based on the tie-line distribu-

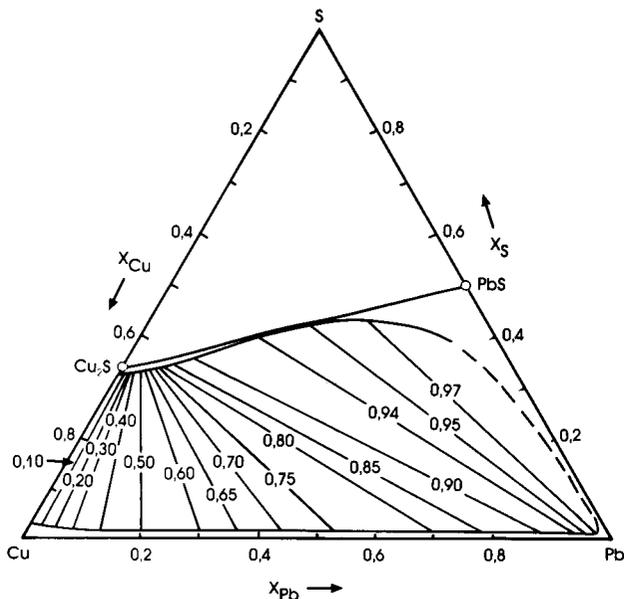


Fig. 2—Iso-activities of lead in Cu-Pb-S melts at 1473 K

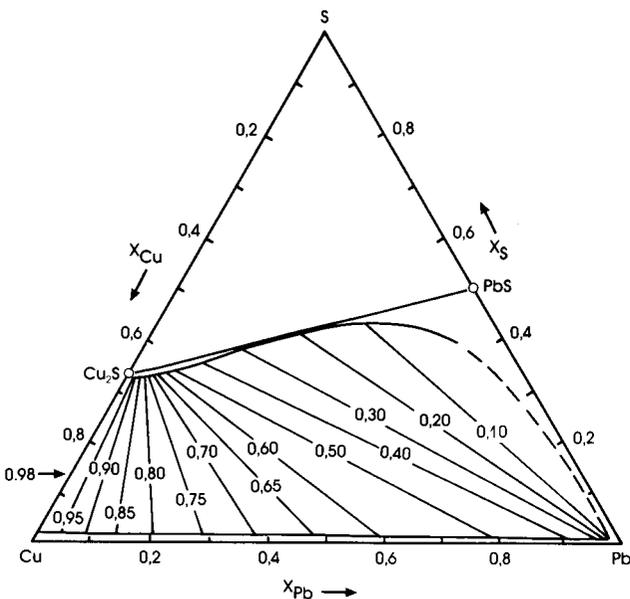


Fig. 3—Iso-activities of copper in Cu-Pb-S melts at 1473 K

tion described by Azuma *et al.*¹⁵ From $X_{Cu} = 0,3$ to $X_{Cu} \approx 1,0$, the copper activities of Choudary *et al.*²⁰ are in reasonable agreement with the present values but, for $X_{Cu} \leq 0,3$, their activities are lower. On the other hand, along the mid and lead-rich side of the miscibility gap, the Pb and Cu activities of the present work are in better agreement with those reported by Goto *et al.*¹⁸ and by Goto and Ogawa¹⁹.

It should be mentioned that the copper activities and sulphur partial pressures calculated by the help of the ψ and θ functions of equations (7) and (11) are very sensitive to the shapes of these functions. Plots were drawn for ψ and θ with respect to the logarithm of the activity of lead after successive iterations so that, for example, the known activities of copper on the Cu-Cu₂S join could be obtained within 0,003 units. This procedure

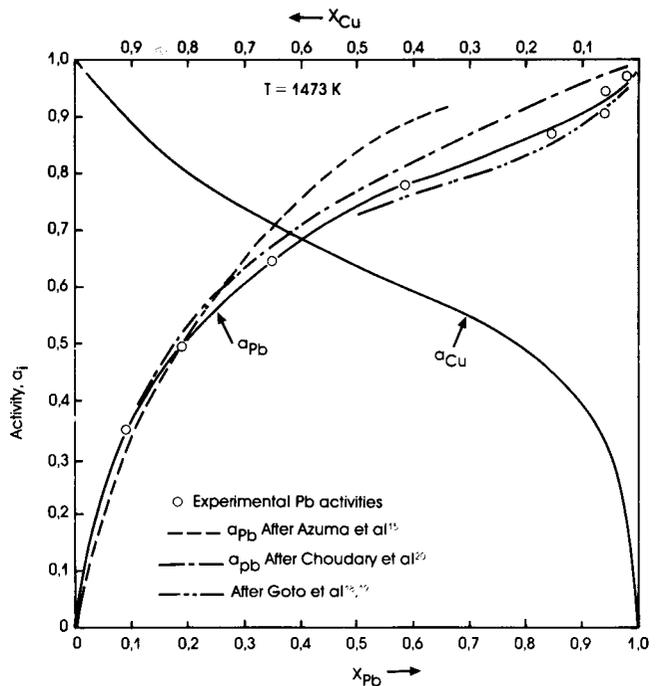


Fig. 4—Lead and copper activities in sulphur-saturated copper-lead alloys at 1473 K

yielded a set of activities and partial pressures consistent with the available data⁹.

The uncertainty in dew-point activity measurements has been analysed in detail elsewhere^{5,6}. By the same procedure, it is estimated that the errors in the activities are less than 0,7 per cent.

Conclusions

In the Cu-Pb-S system, the directions and distributions of the tie-lines between the co-existing liquid phases were determined experimentally within the whole composition range of the miscibility gap at 1473 K. Based on the end-points of the tie lines, the boundaries of the immiscibility region were redrawn. The activities of lead along the sulphur-saturation boundary were measured experimentally by use of the dew-point technique. The measured Pb activities permitted the derivation of copper activities and sulphur partial pressures along the miscibility gap by direct integration of the ternary Gibbs-Duhem equation. This procedure circumvented the problems associated with indirect model-based activity calculations and yielded thermodynamically consistent values that could reproduce the known binary data on the Cu-Cu₂S join of the miscibility gap.

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Castings and forgings

Castings & Forgings '88/Patt-Cast '88 proved an overwhelming success with exhibitors and visitors alike. The exhibition attracted over 75 exhibitors and 1700 visitors from the different countries.

The next 'Castings and Forgings' event will be in 1989, dates and venue to be announced shortly.

For further information on the exhibition on 'Castings & Forgings '89', please contact

Brian Wilkinson
Exhibition Sales Manager
Castings & Forgings '89
Queensway House

2 Queensway
Redhill, Surrey RH1 1QS
England.

Telephone: 0737 768611.

For further information on the associated conferences, please contact

Gillian Luis-Ravelo
PR and Publicity Manager
Castings & Forgings

at the above address and telephone number.

Practice in electrometallurgical plants

The Metallurgical Society of CIM (The Canadian Institute of Mining and Metallurgy) has announced that an International Symposium on Electrometallurgical Plant Practice will be held in Montreal, Quebec, Canada, from 21st to 24th October, 1990. The proceedings of the meeting will appear in book form at the time of the meeting.

The Symposium will be preceded by an Electrometallurgy Short Course featuring four internationally recognized lecturers; post-symposium technical tours to copper and zinc electrometallurgical plants are scheduled.

High-quality technical papers in all areas of *aqueous*

electrometallurgical plant practice are invited; 200-300 word abstracts are required before 1st November, 1989.

Abstracts and other correspondence should be sent to

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