Sb – Zn (Antimony – Zinc)

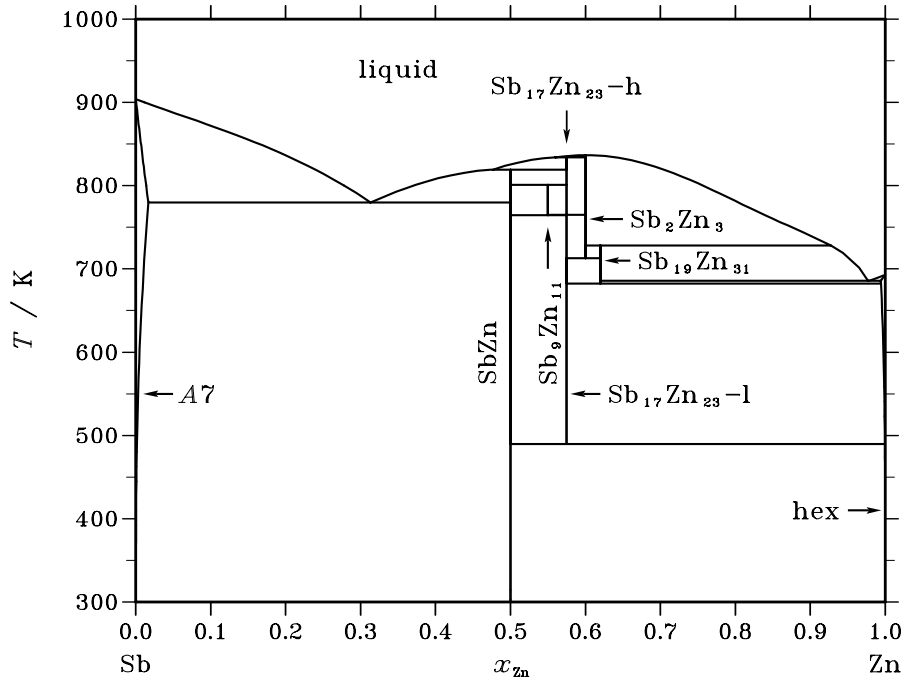

Fig. 1. Calculated phase diagram for the system Sb-Zn.

While the lead-tin system is a basic building block for a range of commonly used solders there has been a growing requirement for the development of alternative materials which are more environmentally sound and provide fewer potential health problems. Tin based solders containing elements such as Ag, Bi, Cu, In, Sb and Zn are candidate replacements and therefore a detailed understanding of the thermodynamics and phase equilibria in the Sb-Zn system is desirable in order to model the properties of such solders.
The phase diagram for the Sb-Zn system is characterised by complete mixing in the liquid phase, negligible solubility of Sb in hcp Zn and low solubility of Zn in rhombohedral Sb, and the formation of a number of intermetallic phases exhibiting small ranges of homogeneity between 50 and 62 at.% Zn. The experimental data for the system have been reviewed by Zabdyr [92Zab, 93Zab]. In addition to studies of the phase diagram there have been various studies of the activities of both components and the enthalpies of mixing. The critically assessed data for the system were derived by Liu *et al.* [00Liu].

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Sb,Zn)_1$
$A7$	$A7$	αAs	$hR2$	$R\bar{3}m$	RHOMBOHEDRAL_A7	$(Sb,Zn)_1$
SbZn	B_e	CdSb	$oP16$	$Pbca$	SBZN	Sb_1Zn_1
Sb_9Zn_{11}	···	···	···	···	SB9ZN11	Sb_3Zn_4
$Sb_{17}Zn_{23}$-l	···	···	···	···	SB17ZN23L	$Sb_{17}Zn_{23}$
$Sb_{17}Zn_{23}$-h	···	···	···	···	SB17ZN23H	$Sb_{17}Zn_{23}$
Sb_2Zn_3	···	···	oI*	···	SB2ZN3	Sb_2Zn_3
$Sb_{19}Zn_{31}$	···	···	$oP30$	$Pmmn$	SB19ZN31	$Sb_{19}Zn_{31}$
hex	$A3$	Mg	$hP2$	$P6_3/mmc$	HCP_ZN	Zn_1

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Zn}			$\Delta_{\mathrm{r}}H$ / (J/mol)
liquid $\rightleftharpoons$ Sb_2Zn_3	congruent	836.6	0.600	0.600		−14848
liquid + Sb_2Zn_3 $\rightleftharpoons$ $Sb_{17}Zn_{23}$-h	peritectic	833.8	0.560	0.600	0.575	−11732
liquid + $Sb_{17}Zn_{23}$-h $\rightleftharpoons$ SbZn	peritectic	819.3	0.477	0.575	0.500	−18245
SbZn + $Sb_{17}Zn_{23}$-h $\rightleftharpoons$ Sb_9Zn_{11}	peritectoid	801.0	0.500	0.575	0.550	−3
liquid $\rightleftharpoons$ $A7$ + SbZn	eutectic	779.6	0.313	0.017	0.500	−21484
$Sb_{17}Zn_{23}$-h $\rightleftharpoons$ $Sb_{17}Zn_{23}$-l	polymorphic	764.9	0.575	0.575		−383
Sb_9Zn_{11} $\rightleftharpoons$ SbZn + $Sb_{17}Zn_{23}$-l	eutectoid	764.6	0.550	0.500	0.575	−252
Sb_2Zn_3 + liquid $\rightleftharpoons$ $Sb_{19}Zn_{31}$	peritectic	727.9	0.600	0.928	0.620	−987
Sb_2Zn_3 $\rightleftharpoons$ $Sb_{17}Zn_{23}$-l + $Sb_{19}Zn_{31}$	eutectoid	712.6	0.600	0.575	0.620	−1319
liquid $\rightleftharpoons$ $Sb_{19}Zn_{31}$ + hex	eutectic	685.5	0.977	0.620	0.994	−8169
$Sb_{19}Zn_{31}$ $\rightleftharpoons$ $Sb_{17}Zn_{23}$-l + hex	eutectoid	682.5	0.620	0.575	0.994	−1845
$Sb_{17}Zn_{23}$-l $\rightleftharpoons$ SbZn + hex	eutectoid	489.7	0.575	0.500	1.000	−2078

Table IIIa. Integral quantities for the liquid phase at 913 K.

x_{Zn}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{m}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{m}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−3402	896	4.708	−934	2.005	0.000
0.200	−5591	64	6.194	−1792	2.033	0.000
0.300	−7099	−1344	6.303	−2462	1.224	0.000
0.400	−7975	−2508	5.988	−2866	0.392	0.000
0.500	−8226	−2935	5.795	−2965	0.032	0.000
0.600	−7863	−2467	5.910	−2754	0.314	0.000
0.700	−6903	−1272	6.167	−2265	1.088	0.000
0.800	−5367	146	6.038	−1568	1.878	0.000
0.900	−3234	958	4.591	−766	1.888	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: Sb(liquid), Zn(liquid)

Table IIIb. Partial quantities for Sb in the liquid phase at 913 K.

x_{Sb}	ΔG_{Sb} [J/mol]	ΔH_{Sb} [J/mol]	ΔS_{Sb} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Sb}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Sb}}$ [J/(mol·K)]	a_{Sb}	γ_{Sb}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−816	1084	2.081	−16	1.205	0.898	0.998
0.800	−1927	2634	4.995	−233	3.140	0.776	0.970
0.700	−3529	2842	6.978	−822	4.013	0.628	0.897
0.600	−5723	891	7.244	−1845	2.997	0.471	0.784
0.500	−8518	−3042	5.998	−3256	0.235	0.326	0.651
0.400	−11857	−7791	4.453	−4901	−3.165	0.210	0.524
0.300	−15656	−11195	4.885	−6516	−5.125	0.127	0.424
0.200	−19947	−10105	10.780	−7729	−2.601	0.072	0.361
0.100	−25540	−375	27.562	−8061	8.418	0.035	0.346
0.000	$-\infty$	23128	∞	−6920	32.911	0.000	0.402

Reference state: Sb(liquid)

Table IIIc. Partial quantities for Zn in the liquid phase at 913 K.

x_{Zn}	ΔG_{Zn} [J/mol]	ΔH_{Zn} [J/mol]	ΔS_{Zn} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Zn}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Zn}}$ [J/(mol·K)]	a_{Zn}	γ_{Zn}
0.000	$-\infty$	22272	∞	−9254	34.531	0.000	0.295
0.100	−26674	−791	28.350	−9195	9.205	0.030	0.298
0.200	−20246	−10214	10.988	−8028	−2.394	0.069	0.347
0.300	−15427	−11112	4.727	−6287	−5.284	0.131	0.437
0.400	−11353	−7606	4.104	−4397	−3.515	0.224	0.560
0.500	−7935	−2828	5.593	−2673	−0.170	0.352	0.703
0.600	−5200	1083	6.881	−1322	2.634	0.504	0.840
0.700	−3151	2980	6.716	−444	3.750	0.660	0.943
0.800	−1722	2709	4.853	−28	2.998	0.797	0.996
0.900	−755	1106	2.039	44	1.163	0.905	1.006
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Zn(liquid)

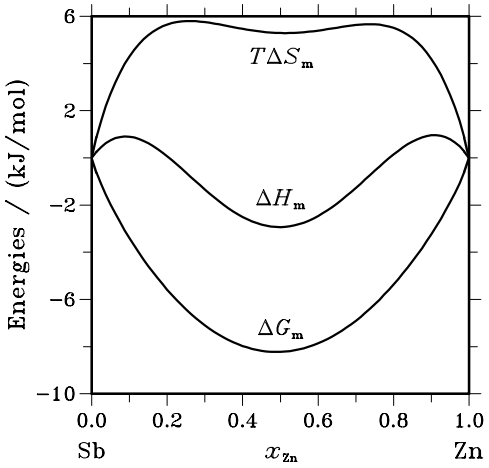

Fig. 2. Integral quantities of the liquid phase at T=913 K.

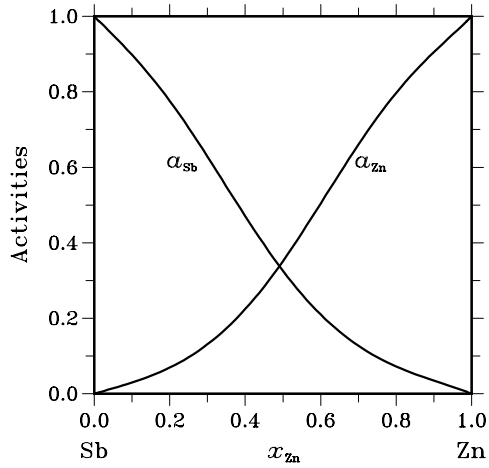

Fig. 3. Activities in the liquid phase at T=913 K.

Table IV. Standard reaction quantities at 298.15 K for the compounds per mole of atoms.

Compound	x_{Zn}	$\Delta_{\mathrm{f}}G^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}H^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}S^{\circ}$ / (J/(mol·K))	$\Delta_{\mathrm{f}}C^{\circ}_{P}$ / (J/(mol·K))
Sb_1Zn_1	0.500	−10052	−11543	−5.000	0.000
Sb_9Zn_{11}	0.550	−8350	−8749	−1.337	0.000
$Sb_{17}Zn_{23}$-l	0.575	−7730	−7730	0.000	0.000
$Sb_{17}Zn_{23}$-h	0.575	−7497	−7348	0.500	0.000
Sb_2Zn_3	0.600	−5924	−4918	3.376	0.000
$Sb_{19}Zn_{31}$	0.620	−5861	−5043	2.744	0.000

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[93Zab] L.A. Zabdyr: Calphad **17** (1993) 269–280.
[00Liu] X.J. Liu, C.P. Wang, I. Ohnuma, R. Kainuma, K. Ishida: J. Phase Equilibria **21** (2000) 432–442.