In – La (Indium – Lanthanum)

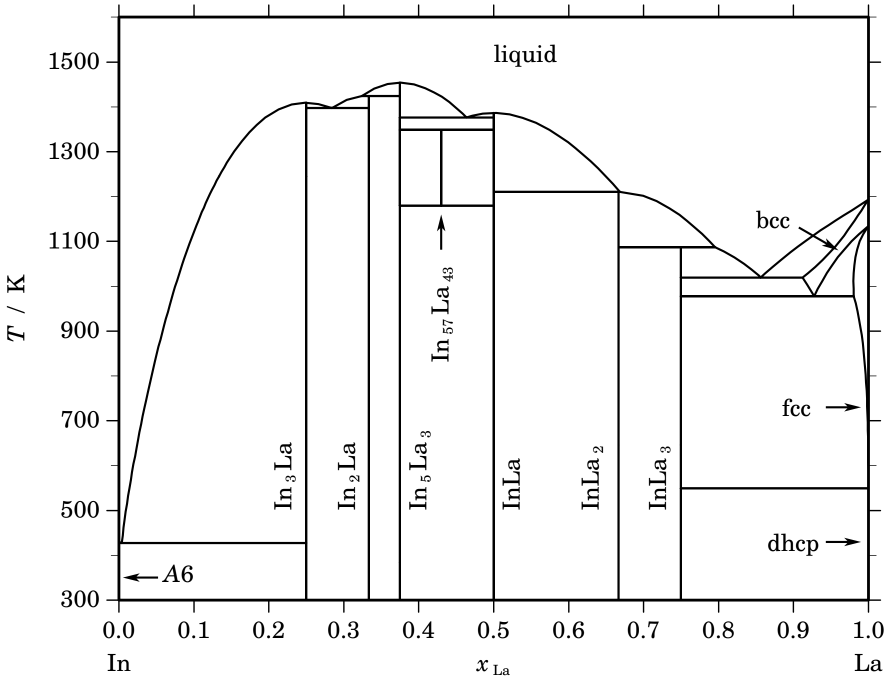

Fig. 1. Calculated phase diagram for the system In-La.

Most of the interest in the In-La system has probably been attracted by the superconducting compound $InLa_3$ which has one of the highest transition temperatures among the superconducting intermetallics of lanthanum. Variations in the reported transition temperatures between 8 and 10 K have been attributed to impurities and prompted for investigations on the solubility range and the phase diagram. The literature on the In-La system has been reviewed by [1992Pal] and a thermodynamic dataset has been optimised in [2002Wei] which is presented here. The phase diagram for the In-La system has been essentially worked out by [1974McM] and in addition the liquidus of In-rich melts with up to 10 at.% La has been investigated by [1971Deg]. Seven intermetallic compounds have been established and only for In_5La_3 a small range of solid solubility has been indicated but not quantified. Therefore, the assessment [2002Wei] describes all of them as stoichiometric. Enthalpies of formation have been measured by [1977Bor] across the whole composition range. For In_3La several other measurements of the enthalpy of formation have been reported and also EMF measurements of the Gibbs energy of formation [1971Deg].

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(In,La)_1$
$A6$	$A6$	In	$tI2$	$I4/mmm$	TETRAGONAL_A6	In_1
In_3La	$L1_2$	$AuCu_3$	$cP4$	$Pm\overline{3}m$	IN3LA	In_3La_1
In_2La	···	$CeCu_2$	$oI12$	$Imma$	IN2LA	In_2La_1
In_5La_3	···	Pd_5Pu_3	$oC32$	$Cmcm$	IN5LA3	In_5La_3
$In_{57}La_{43}$	···	···	···	···	IN57LA43	$In_{57}La_{43}$
InLa	$B2$	CsCl	$cP2$	$Pm\overline{3}m$	INLA	In_1La_1
$InLa_2$	$B8_2$	$InNi_2$	$hP6$	$P6_3/mmc$	INLA2	In_1La_2
$InLa_3$	$L1_2$	$AuCu_3$	$cP4$	$Pm\overline{3}m$	INLA3	In_1La_3
bcc	$A2$	W	$cI2$	$Im\overline{3}m$	BCC_A2	$(In,La)_1$
fcc	$A1$	Cu	$cF4$	$Fm3\overline{3}m$	FCC_A1	$(In,La)_1$
dhcp	$A3'$	αLa	$hP4$	$P6_3/mmc$	DHCP	$(In,La)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{La}			$\Delta_{\mathrm{r}}H$ / (J/mol)
liquid $\rightleftharpoons$ In_5La_3	congruent	1453.8	0.375	0.375		−21411
liquid + In_5La_3 $\rightleftharpoons$ In_2La	peritectic	1424.3	0.324	0.375	0.333	−18701
liquid $\rightleftharpoons$ In_3La	congruent	1409.0	0.250	0.250		−26980
liquid $\rightleftharpoons$ In_3La + In_2La	eutectic	1397.4	0.284	0.250	0.333	−24731
liquid $\rightleftharpoons$ InLa	congruent	1386.6	0.500	0.500		−23309
liquid $\rightleftharpoons$ In_5La_3 + InLa	eutectic	1376.3	0.464	0.375	0.500	−22165
In_5La_3 + InLa $\rightleftharpoons$ $In_{57}La_{43}$	peritectoid	1348.9	0.375	0.500	0.430	0
InLa + liquid $\rightleftharpoons$ $InLa_2$	peritectic	1210.7	0.500	0.668	0.667	−12261
$In_{57}La_{43}$ $\rightleftharpoons$ In_5La_3 + InLa	eutectoid	1179.4	0.430	0.375	0.500	0
$InLa_2$ + liquid $\rightleftharpoons$ $InLa_3$	peritectic	1086.7	0.667	0.796	0.750	−5978
liquid $\rightleftharpoons$ $InLa_3$ + bcc	eutectic	1019.5	0.856	0.750	0.912	−6203
bcc $\rightleftharpoons$ $InLa_3$ + fcc	eutectoid	977.9	0.927	0.750	0.980	−2560
fcc $\rightleftharpoons$ $InLa_3$ + dhcp	eutectoid	549.4	1.000	0.750	1.000	−369
liquid $\rightleftharpoons$ $A6$ + In_3La	eutectic	427.4	0.004	0.000	0.250	−3377

Table IIIa. Integral quantities for the liquid phase at 1500 K.

x_{La}	ΔG_m [J/mol]	ΔH_m [J/mol]	ΔS_m [J/(mol·K)]	G_m^E [J/mol]	S_m^E [J/(mol·K)]	ΔC_P [J/(mol·K)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−15954	−18215	−1.508	−11899	−4.210	0.000
0.200	−26035	−30946	−3.274	−19794	−7.435	0.000
0.300	−31814	−38732	−4.612	−24195	−9.691	0.000
0.400	−34006	−42112	−5.404	−25612	−10.999	0.000
0.500	−33200	−41623	−5.615	−24555	−11.378	0.000
0.600	−29927	−37804	−5.251	−21533	−10.847	0.000
0.700	−24676	−31194	−4.345	−17057	−9.424	0.000
0.800	−17877	−22331	−2.969	−11636	−7.130	0.000
0.900	−9835	−11753	−1.279	−5780	−3.982	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: In(liquid), La(liquid)

Table IIIb. Partial quantities for In in the liquid phase at 1500 K.

x_{In}	ΔG_{In} [J/mol]	ΔH_{In} [J/mol]	ΔS_{In} [J/(mol·K)]	G_{In}^E [J/mol]	S_{In}^E [J/(mol·K)]	a_{In}	γ_{In}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−3401	−2832	0.380	−2087	−0.496	0.761	0.846
0.800	−10451	−10608	−0.105	−7668	−1.960	0.433	0.541
0.700	−20172	−22253	−1.388	−15723	−4.353	0.198	0.283
0.600	−31604	−36690	−3.390	−25233	−7.638	0.079	0.132
0.500	−43823	−52841	−6.012	−35178	−11.775	0.030	0.060
0.400	−55965	−69629	−9.109	−44537	−16.728	0.011	0.028
0.300	−67308	−85978	−12.447	−52292	−22.457	0.005	0.015
0.200	−77495	−100810	−15.544	−57422	−28.925	0.002	0.010
0.100	−87625	−113049	−16.950	−58908	−36.094	0.001	0.009
0.000	$-\infty$	−121618	∞	−55729	−43.926	0.000	0.011

Reference state: In(liquid)

Table IIIc. Partial quantities for La in the liquid phase at 1500 K.

x_{La}	ΔG_{La} [J/mol]	ΔH_{La} [J/mol]	ΔS_{La} [J/(mol·K)]	G_{La}^E [J/mol]	S_{La}^E [J/(mol·K)]	a_{La}	γ_{La}
0.000	$-\infty$	−211362	∞	−140711	−47.101	0.000	0.000
0.100	−128926	−156665	−18.492	−100209	−37.637	0.000	0.000
0.200	−88372	−112297	−15.950	−68300	−29.332	0.001	0.004
0.300	−58979	−77183	−12.136	−43964	−22.146	0.009	0.029
0.400	−37609	−50244	−8.423	−26181	−16.042	0.049	0.123
0.500	−22577	−30405	−5.218	−13932	−10.981	0.164	0.327
0.600	−12568	−16587	−2.679	−6197	−6.927	0.365	0.608
0.700	−6405	−7715	−0.873	−1956	−3.839	0.598	0.855
0.800	−2973	−2711	0.174	−190	−1.681	0.788	0.985
0.900	−1191	−498	0.462	123	−0.414	0.909	1.010
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: La(liquid)

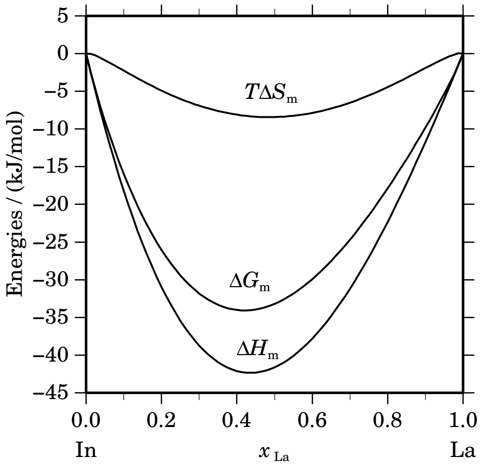

Fig. 2. Integral quantities of the liquid phase at T=1500 K.

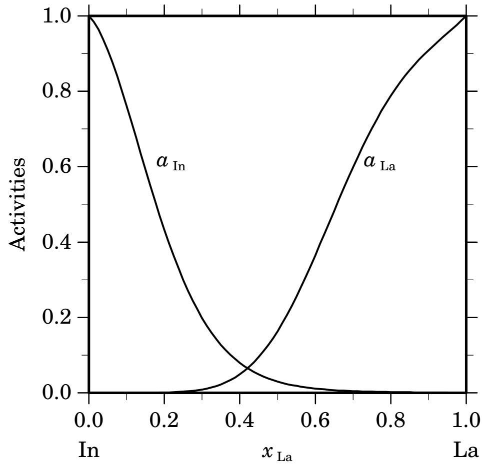

Fig. 3. Activities in the liquid phase at T=1500 K.

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

Compound	x_{La}	$\Delta_f G^\circ$ / (J/mol)	$\Delta_f H^\circ$ / (J/mol)	$\Delta_f S^\circ$ / (J/(mol·K))	$\Delta_f C_P^\circ$ / (J/(mol·K))
In_3La_1	0.250	−52657	−57092	−14.876	0.000
In_2La_1	0.333	−53128	−56759	−12.181	0.000
In_5La_3	0.375	−53323	−56714	−11.374	0.000
$In_{57}La_{43}$	0.430	−53434	−57105	−12.314	−0.002
In_1La_1	0.500	−53577	−57607	−13.518	0.000
In_1La_2	0.667	−35950	−37692	−5.843	0.000
In_1La_3	0.750	−27021	−28087	−3.574	0.000

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