Dy – Ho (Dysprosium – Holmium)

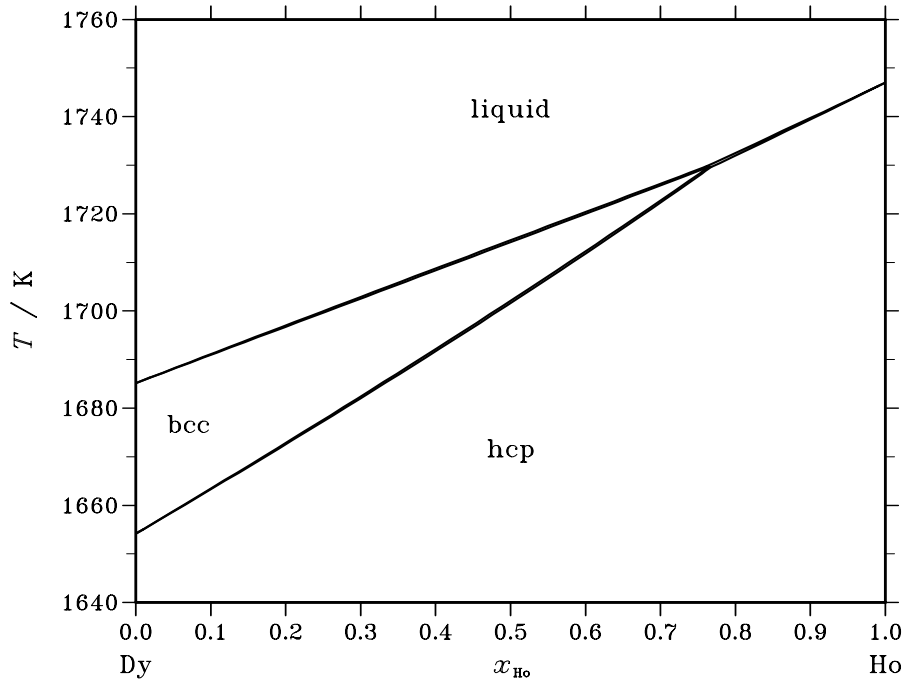

Fig. 1. Calculated phase diagram for the system Dy-Ho.

Iron with addition of different rare-earth (RE) elements have attracted attention due to their magnetostrictive properties for building actuators. The analysis of ternary Fe-RE1-RE2 systems is important in order to understand and to optimise synthesis conditions. The binary inter-rare-earth system Dy-Ho has been assessed by Norgren [00Nor] based on literature data. Experimental information on solid-liquid equilibria is reported by Spedding *et al.* [73Spe]. They applied metallographic, X-ray and thermal analysis to investigate the system. Complete mutual solubility is observed. The melting point varies with composition almost linearly which makes the two phase equilibrium zone very narrow. The stable structure at low temperature is hcp ($A3$). The bcc ($A2$) phase starts to form at 25 at.% Dy from the melt. The assessment is in good agreement with the experimental data.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Dy,Ho)_1$
bcc	$A2$	W	$cI2$	$Im\overline{3}m$	BCC_A2	$(Dy,Ho)_1$
hcp	$A3$	Mg	$hP2$	$P6_3/mmc$	HCP_A3	$(Dy,Ho)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Ho}			$\Delta_r H$ / (J/mol)
liquid + hcp $\rightleftharpoons$ bcc	peritectic	1729.6	0.759	0.768	0.764	-2184

Table IIIa. Integral quantities for the liquid phase at 1750 K.

x_{Ho}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G_{\mathrm{m}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{m}}^{\mathrm{E}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−4730	0	2.703	0	0.000	0.000
0.200	−7281	0	4.161	0	0.000	0.000
0.300	−8888	0	5.079	0	0.000	0.000
0.400	−9793	0	5.596	0	0.000	0.000
0.500	−10086	0	5.763	0	0.000	0.000
0.600	−9793	0	5.596	0	0.000	0.000
0.700	−8888	0	5.079	0	0.000	0.000
0.800	−7281	0	4.161	0	0.000	0.000
0.900	−4730	0	2.703	0	0.000	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: Dy(liquid), Ho(liquid)

Table IIIb. Partial quantities for Dy in the liquid phase at 1750 K.

x_{Dy}	ΔG_{Dy} [J/mol]	ΔH_{Dy} [J/mol]	ΔS_{Dy} [J/(mol·K)]	$G_{\mathrm{Dy}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Dy}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Dy}	γ_{Dy}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−1533	0	0.876	0	0.000	0.900	1.000
0.800	−3247	0	1.855	0	0.000	0.800	1.000
0.700	−5190	0	2.966	0	0.000	0.700	1.000
0.600	−7433	0	4.247	0	0.000	0.600	1.000
0.500	−10086	0	5.763	0	0.000	0.500	1.000
0.400	−13332	0	7.619	0	0.000	0.400	1.000
0.300	−17518	0	10.010	0	0.000	0.300	1.000
0.200	−23418	0	13.382	0	0.000	0.200	1.000
0.100	−33504	0	19.145	0	0.000	0.100	1.000
0.000	$-\infty$	0	∞	0	0.000	0.000	1.000

Reference state: Dy(liquid)

Table IIIc. Partial quantities for Ho in the liquid phase at 1750 K.

x_{Ho}	ΔG_{Ho} [J/mol]	ΔH_{Ho} [J/mol]	ΔS_{Ho} [J/(mol·K)]	$G_{\mathrm{Ho}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Ho}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Ho}	γ_{Ho}
0.000	$-\infty$	0	∞	0	0.000	0.000	1.000
0.100	−33504	0	19.145	0	0.000	0.100	1.000
0.200	−23418	0	13.382	0	0.000	0.200	1.000
0.300	−17518	0	10.010	0	0.000	0.300	1.000
0.400	−13332	0	7.619	0	0.000	0.400	1.000
0.500	−10086	0	5.763	0	0.000	0.500	1.000
0.600	−7433	0	4.247	0	0.000	0.600	1.000
0.700	−5190	0	2.966	0	0.000	0.700	1.000
0.800	−3247	0	1.855	0	0.000	0.800	1.000
0.900	−1533	0	0.876	0	0.000	0.900	1.000
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Ho(liquid)

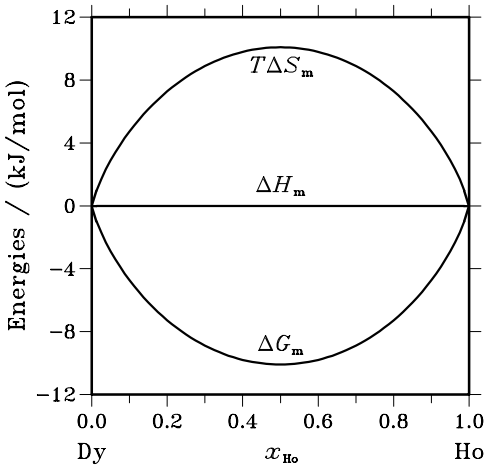

Fig. 2. Integral quantities of the liquid phase at T=1750 K.

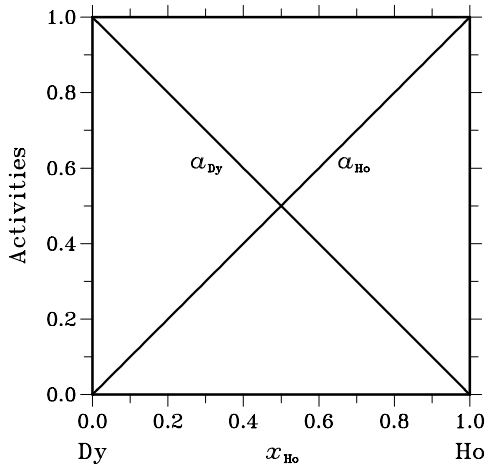

Fig. 3. Activities in the liquid phase at T=1750 K.

Table IVa. Integral quantities for the stable phases at 1600 K.

Phase	x_{Ho}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G_{\mathrm{m}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{m}}^{\mathrm{E}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
hcp	0.000	0	0	0.000	0	0.000	0.000
	0.100	−4325	0	2.703	0	0.000	0.000
	0.200	−6657	0	4.161	0	0.000	0.000
	0.300	−8126	0	5.079	0	0.000	0.000
	0.400	−8953	0	5.596	0	0.000	0.000
	0.500	−9221	0	5.763	0	0.000	0.000
	0.600	−8953	0	5.596	0	0.000	0.000
	0.700	−8126	0	5.079	0	0.000	0.000
	0.800	−6657	0	4.161	0	0.000	0.000
	0.900	−4325	0	2.703	0	0.000	0.000
	1.000	0	0	0.000	0	0.000	0.000

Reference states: Dy(hcp), Ho(hcp)

Table IVb. Partial quantities for Dy in the stable phases at 1600 K.

Phase	x_{Dy}	ΔG_{Dy} [J/mol]	ΔH_{Dy} [J/mol]	ΔS_{Dy} [J/(mol·K)]	$G_{\mathrm{Dy}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Dy}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Dy}	γ_{Dy}
hcp	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−1402	0	0.876	0	0.000	0.900	1.000
	0.800	−2969	0	1.855	0	0.000	0.800	1.000
	0.700	−4745	0	2.966	0	0.000	0.700	1.000
	0.600	−6796	0	4.247	0	0.000	0.600	1.000
	0.500	−9221	0	5.763	0	0.000	0.500	1.000
	0.400	−12190	0	7.619	0	0.000	0.400	1.000
	0.300	−16017	0	10.011	0	0.000	0.300	1.000
	0.200	−21411	0	13.382	0	0.000	0.200	1.000
	0.100	−30632	0	19.145	0	0.000	0.100	1.000
	0.000	$-\infty$	0	∞	0	0.000	0.000	1.000

Reference state: Dy(hcp)

Table IVc. Partial quantities for Ho in the stable phases at 1600 K.

Phase	x_{Ho}	ΔG_{Ho} [J/mol]	ΔH_{Ho} [J/mol]	ΔS_{Ho} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Ho}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Ho}}$ [J/(mol·K)]	a_{Ho}	γ_{Ho}
hcp	0.000	$-\infty$	0	∞	0	0.000	0.000	1.000
	0.100	−30632	0	19.145	0	0.000	0.100	1.000
	0.200	−21411	0	13.382	0	0.000	0.200	1.000
	0.300	−16017	0	10.010	0	0.000	0.300	1.000
	0.400	−12190	0	7.619	0	0.000	0.400	1.000
	0.500	−9221	0	5.763	0	0.000	0.500	1.000
	0.600	−6796	0	4.247	0	0.000	0.600	1.000
	0.700	−4745	0	2.966	0	0.000	0.700	1.000
	0.800	−2969	0	1.855	0	0.000	0.800	1.000
	0.900	−1402	0	0.876	0	0.000	0.900	1.000
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Ho(hcp)

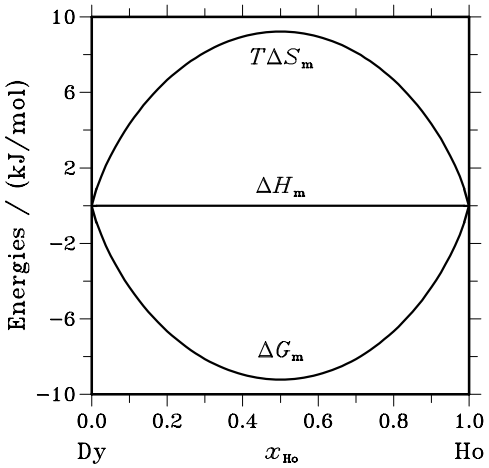

Fig. 4. Integral quantities of the stable phases at T=1600 K.

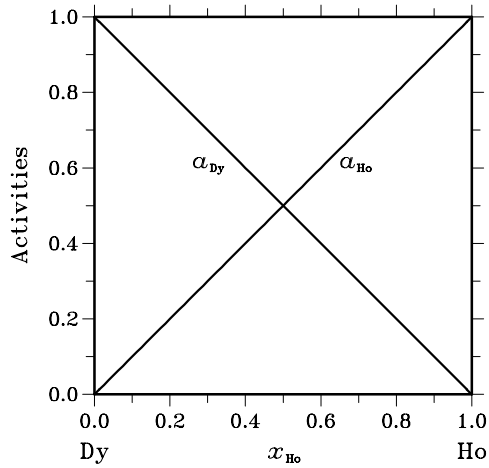

Fig. 5. Activities in the stable phases at T=1600 K.

References

[73Spe] F.H. Spedding, B. Sanden, B.J. Beaudry: J. Less-Common Met. **31** (1973) 1–13.
[00Nor] S. Norgren: J. Phase Equilibria **21** (2000) 148–156.