# **Co – Gd** (Cobalt – Gadolinium)

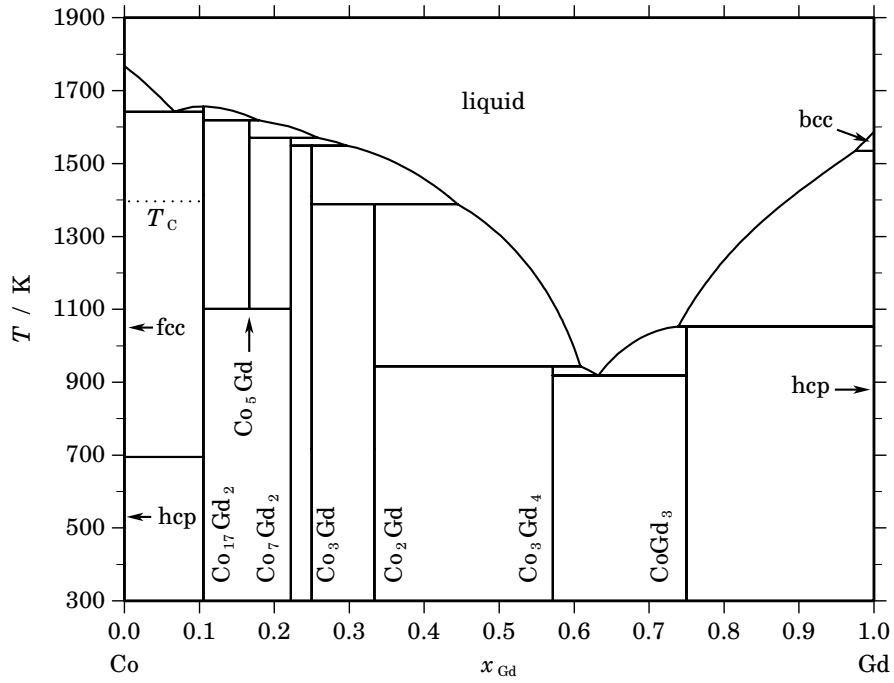


**Fig. 1.** Calculated phase diagram for the system Co-Gd.

Intermetallic compounds formed between rare earth and transition metals, especially 3d elements are of particular interest regarding their magnetic properties and their reversible absorption of hydrogen gas at room temperature and nearly atmospheric pressure. The phase diagram of the Co-Gd system was measured by [1961Nov, 1969Bus, 1992Ge]. [1992Oka] reviewed this system. The results of [1961Nov] are quite different from those of the studies of [1969Bus, 1992Ge] and are discarded. The last two investigations gave the same kind of relationships, i.e. two eutectic reactions, congruent melting of $Co_{17}Gd_2$ and incongruent melting of all other compounds. $Co_5Gd$ is unstable at low temperatures. Both $Co_5Gd$ and $Co_{17}Gd_2$ were reported to have a certain homogeneity region at high temperatures. $Co_{17}Gd_2$ and $Co_7Gd_2$ are dimorphic, but their transformation temperatures are unknown. The heat of mixing in the liquid phase at 1823 K was measured by [1989Nik] for the entire composition range. The enthalpies of formation of the compounds were measured by various authors [1976Deo, 1986Sch, 1987Col1] with the most complete set being that by [1987Col1, 1987Col2]. The heat capacities of $Co_5Gd$ and $Co_2Gd$ were measured by [1974Kel, 1989Leg] in the temperature ranges 5-300 K and 300-473 K, respectively. [1987Bar] measured the heat capacity at the composition 63.2 at.% Gd in the temperature range 800-980 K. Magnetic measurements of the compounds are reported by [1966Lem1, 1966Lem2, 1972Bur]. The thermodynamic assessment of the Co-Gd system is from [1995Liu]. The fcc, hcp, bcc, and the liquid phases were described by a substitutional solution model using the Redlich-Kister equation. A magnetic contribution is added for the fcc, hcp and bcc phases, and no solubility range is assumed for these phases. The seven intermetallic compounds $Co_{17}Gd_2$, $Co_5Gd$, $Co_7Gd_2$, $Co_3Gd$, $Co_2Gd$, $Co_3Gd_4$, and $CoGd_3$ are all treated as stoichiometric compounds because of limited information. Good agreement is obtained between the calculation and the experimental results.

**Table I.** Phases, structures and models.

| Phase | Struktur-bericht | Prototype | Pearson symbol | Space group | SGTE name | Model |
|---|---|---|---|---|---|---|
| liquid | | | | | LIQUID | $(Co,Gd)_1$ |
| fcc | $A1$ | Cu | $cF4$ | $Fm\overline{3}m$ | FCC_A1 | $(Co,Gd)_1$ |
| hcp | $A3$ | Mg | $hP2$ | $P6_3/mmc$ | HCP_A3 | $(Co,Gd)_1$ |
| $Co_{17}Gd_2$ | $\cdots$ | $Th_2Zn_{17}$ | $hR19$ | $R\overline{3}m$ | CO17GD2 | $Co_{17}Gd_2$ |
| $Co_5Gd$ | $D2_d$ | $CaCu_5$ | $hP6$ | $P6/mmm$ | CO5GD | $Co_5Gd_1$ |
| $Co_7Gd_2$ | $\cdots$ | $Co_7Er_2$ | $hR18$ | $R\overline{3}m$ | CO7GD2 | $Co_7Gd_2$ |
| $Co_3Gd$ | $\cdots$ | $Be_3Nb$ | $hR12$ | $R\overline{3}m$ | CO3GD | $Co_3Gd_1$ |
| $Co_2Gd$ | $C15$ | $Cu_2Mg$ | $cF24$ | $Fd\overline{3}m$ | CO2GD | $Co_2Gd_1$ |
| $Co_3Gd_4$ | $\cdots$ | $Co_3Ho_4$ | $hP22$ | $P6_3/m$ | CO3GD4 | $Co_3Gd_4$ |
| $CoGd_3$ | $D0_{11}$ | $Fe_3C$ | $oP16$ | $Pnma$ | COGD3 | $Co_1Gd_3$ |
| bcc | $A2$ | W | $cI2$ | $Im\overline{3}m$ | BCC_A2 | $(Co,Gd)_1$ |

**Table II.** Invariant reactions.

| Reaction | Type | $T$ / K | Compositions / $x_{Gd}$ | | | $\Delta_r H$ / (J/mol) |
|---|---|---|---|---|---|---|
| liquid $\rightleftharpoons$ $Co_{17}Gd_2$ | congruent | 1657.0 | 0.105 | 0.105 | | −21931 |
| liquid $\rightleftharpoons$ fcc + $Co_{17}Gd_2$ | eutectic | 1641.6 | 0.067 | 0.000 | 0.105 | −19536 |
| $Co_{17}Gd_2$ + liquid $\rightleftharpoons$ $Co_5Gd$ | peritectic | 1618.6 | 0.105 | 0.179 | 0.167 | −17447 |
| $Co_5Gd$ + liquid $\rightleftharpoons$ $Co_7Gd_2$ | peritectic | 1570.2 | 0.167 | 0.258 | 0.222 | −14393 |
| $Co_7Gd_2$ + liquid $\rightleftharpoons$ $Co_3Gd$ | peritectic | 1549.5 | 0.222 | 0.297 | 0.250 | −8145 |
| liquid + bcc $\rightleftharpoons$ hcp | peritectic | 1534.9 | 0.975 | 1.000 | 1.000 | −3677 |
| $Co_3Gd$ + liquid $\rightleftharpoons$ $Co_2Gd$ | peritectic | 1388.2 | 0.250 | 0.445 | 0.333 | −5201 |
| $Co_5Gd$ $\rightleftharpoons$ $Co_{17}Gd_2$ + $Co_7Gd_2$ | eutectoid | 1100.8 | 0.167 | 0.105 | 0.222 | −790 |
| liquid + hcp $\rightleftharpoons$ $CoGd_3$ | peritectic | 1053.0 | 0.739 | 1.000 | 0.750 | −6517 |
| $Co_2Gd$ + liquid $\rightleftharpoons$ $Co_3Gd_4$ | peritectic | 943.1 | 0.333 | 0.608 | 0.571 | −4822 |
| liquid $\rightleftharpoons$ $Co_3Gd_4$ + $CoGd_3$ | eutectic | 917.9 | 0.632 | 0.571 | 0.750 | −5018 |
| fcc + $Co_{17}Gd_2$ $\rightleftharpoons$ hcp | peritectoid | 695.0 | 0.000 | 0.105 | 0.000 | −428 |

**Table IIIa.** Integral quantities for the liquid phase at 1823 K.

| $x_{Gd}$ | $\Delta G_m$ [J/mol] | $\Delta H_m$ [J/mol] | $\Delta S_m$ [J/(mol·K)] | $G_m^E$ [J/mol] | $S_m^E$ [J/(mol·K)] | $\Delta C_P$ [J/(mol·K)] |
|---|---|---|---|---|---|---|
| 0.000 | 0 | 0 | 0.000 | 0 | 0.000 | 0.000 |
| 0.100 | −6889 | −7349 | −0.253 | −1961 | −2.956 | 3.085 |
| 0.200 | −10761 | −12756 | −1.094 | −3176 | −5.255 | 5.484 |
| 0.300 | −13021 | −16335 | −1.818 | −3762 | −6.897 | 7.197 |
| 0.400 | −14036 | −18203 | −2.286 | −3834 | −7.882 | 8.226 |
| 0.500 | −14016 | −18477 | −2.447 | −3510 | −8.210 | 8.568 |
| 0.600 | −13105 | −17273 | −2.286 | −2904 | −7.882 | 8.226 |
| 0.700 | −11393 | −14707 | −1.818 | −2134 | −6.897 | 7.197 |
| 0.800 | −8901 | −10895 | −1.094 | −1316 | −5.255 | 5.484 |
| 0.900 | −5493 | −5954 | −0.253 | −566 | −2.956 | 3.085 |
| 1.000 | 0 | 0 | 0.000 | 0 | 0.000 | 0.000 |

Reference states: Co(liquid), Gd(liquid)

**Table IIIb.** Partial quantities for Co in the liquid phase at 1823 K.

| $x_{Co}$ | $\Delta G_{Co}$ [J/mol] | $\Delta H_{Co}$ [J/mol] | $\Delta S_{Co}$ [J/(mol·K)] | $G^{E}_{Co}$ [J/mol] | $S^{E}_{Co}$ [J/(mol·K)] | $a_{Co}$ | $\gamma_{Co}$ |
|---|---|---|---|---|---|---|---|
| 1.000 | 0 | 0 | 0.000 | 0 | 0.000 | 1.000 | 1.000 |
| 0.900 | −1989 | −991 | 0.548 | −392 | −0.328 | 0.877 | 0.974 |
| 0.800 | −4796 | −3809 | 0.542 | −1414 | −1.314 | 0.729 | 0.911 |
| 0.700 | −8239 | −8221 | 0.010 | −2833 | −2.956 | 0.581 | 0.830 |
| 0.600 | −12159 | −13996 | −1.007 | −4417 | −5.255 | 0.448 | 0.747 |
| 0.500 | −16438 | −20899 | −2.447 | −5932 | −8.210 | 0.338 | 0.676 |
| 0.400 | −21035 | −28700 | −4.204 | −7147 | −11.823 | 0.250 | 0.624 |
| 0.300 | −26078 | −37165 | −6.082 | −7829 | −16.092 | 0.179 | 0.597 |
| 0.200 | −32140 | −46061 | −7.637 | −7745 | −21.018 | 0.120 | 0.600 |
| 0.100 | −41564 | −55157 | −7.456 | −6663 | −26.601 | 0.064 | 0.644 |
| 0.000 | −∞ | −64219 | ∞ | −4350 | −32.841 | 0.000 | 0.751 |

Reference state: Co(liquid)

**Table IIIc.** Partial quantities for Gd in the liquid phase at 1823 K.

| $x_{Gd}$ | $\Delta G_{Gd}$ [J/mol] | $\Delta H_{Gd}$ [J/mol] | $\Delta S_{Gd}$ [J/(mol·K)] | $G^{E}_{Gd}$ [J/mol] | $S^{E}_{Gd}$ [J/(mol·K)] | $a_{Gd}$ | $\gamma_{Gd}$ |
|---|---|---|---|---|---|---|---|
| 0.000 | −∞ | −83597 | ∞ | −23728 | −32.841 | 0.000 | 0.209 |
| 0.100 | −50982 | −64575 | −7.456 | −16080 | −26.601 | 0.035 | 0.346 |
| 0.200 | −34620 | −48542 | −7.637 | −10225 | −21.018 | 0.102 | 0.509 |
| 0.300 | −24179 | −35266 | −6.082 | −5930 | −16.092 | 0.203 | 0.676 |
| 0.400 | −16850 | −24514 | −4.204 | −2961 | −11.823 | 0.329 | 0.823 |
| 0.500 | −11594 | −16055 | −2.447 | −1087 | −8.210 | 0.465 | 0.931 |
| 0.600 | −7819 | −9655 | −1.007 | −76 | −5.255 | 0.597 | 0.995 |
| 0.700 | −5100 | −5082 | 0.010 | 306 | −2.956 | 0.714 | 1.020 |
| 0.800 | −3091 | −2104 | 0.542 | 291 | −1.314 | 0.816 | 1.019 |
| 0.900 | −1485 | −487 | 0.548 | 112 | −0.328 | 0.907 | 1.007 |
| 1.000 | 0 | 0 | 0.000 | 0 | 0.000 | 1.000 | 1.000 |

Reference state: Gd(liquid)

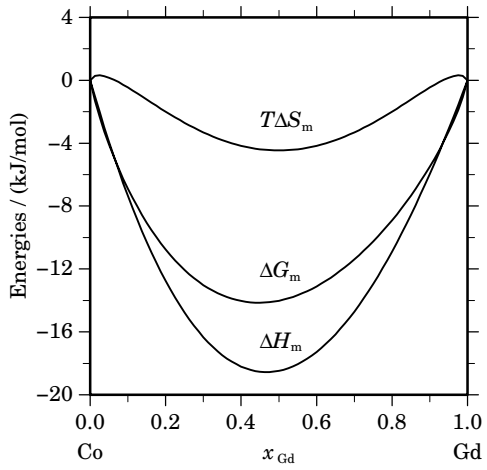


**Fig. 2.** Integral quantities of the liquid phase at $T$=1823 K.

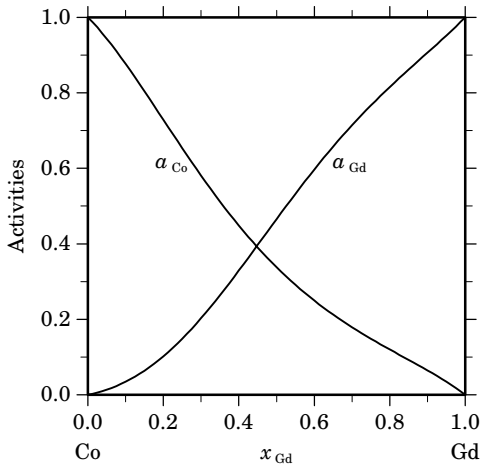


**Fig. 3.** Activities in the liquid phase at $T$=1823 K.

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

| Compound | $x_{\mathrm{Gd}}$ | $\Delta_{\mathrm{f}}G^{\circ}$ / (J/mol) | $\Delta_{\mathrm{f}}H^{\circ}$ / (J/mol) | $\Delta_{\mathrm{f}}S^{\circ}$ / (J/(mol·K)) | $\Delta_{\mathrm{f}}C_P^{\circ}$ / (J/(mol·K)) |
|---|---|---|---|---|---|
| $Co_{17}Gd_2$ | 0.105 | −7717 | −7229 | 1.637 | −0.130 |
| $Co_5Gd_1$ | 0.167 | −11347 | −11449 | −0.345 | 1.594 |
| $Co_7Gd_2$ | 0.222 | −15390 | −15925 | −1.793 | −0.113 |
| $Co_3Gd_1$ | 0.250 | −16463 | −17141 | −2.274 | −0.109 |
| $Co_2Gd_1$ | 0.333 | −15798 | −16270 | −1.584 | −0.097 |
| $Co_3Gd_4$ | 0.571 | −12787 | −13930 | −3.833 | 1.546 |
| $Co_1Gd_3$ | 0.750 | −8984 | −9906 | −3.094 | 1.572 |

## References


[1961Nov] V.F. Novy, R.C. Vickery, E.V. Kleber: Trans. Metall. Soc. AIME **221** (1961) 588–590.
[1966Lem1] R. Lemaire: Cobalt **32** (1966) 132–140.
[1966Lem2] R. Lemaire: Cobalt **33** (1966) 201–211.
[1969Bus] K.H.J. Buschow, A.S. van der Goot: J. Less-Common Met. **17** (1969) 249–255.
[1972Bur] E. Burzo: Phys. Rev. B **6B** (1972) 2882–2887.
[1974Kel] D.A. Keller, S.G. Sankar, R.S. Craig, W.E. Wallace: Am. Inst. Phys. Conf. Proc. **18** (1974) 1207–1211.
[1976Deo] S.S. Deodhar, P.J. Ficalora: High Temp. Sci. **8** (1976) 185–193.
[1986Sch] J. Schott, F. Sommer: J. Less-Common Met. **119** (1986) 307–317.
[1987Bar] M. Barrico, C. Antonions and L. Battezzati: Scr. Metall. **21** (1987) 849–852.
[1987Col1] C. Colinet, A. Pasturel, K.H.J. Buschow: Metall. Trans. A **18A** (1987) 903–907.
[1987Col2] C. Colinet, A. Pasturel: Calphad **11** (1987) 323–324.
[1989Nik] I.V. Nikolaenko, M.A. Turchanin: Rasplavy **5** (1989) 77–79.
[1989Leg] S.B.K. Leghari: J. Nat. Sci. Math. **29** (1989) 69–85.
[1992Ge] W.Q. Ge, C.H. Wu, Y.C. Chuang: Z. Metallkd. **83** (1992) 300–303.
[1992Oka] H. Okamoto: J. Phase Equilibria **13** (1992) 673–674.
[1995Liu] Z.-K. Liu, W. Zhang, B. Sundman: J. Alloys Comp. **226** (1995) 33–45.