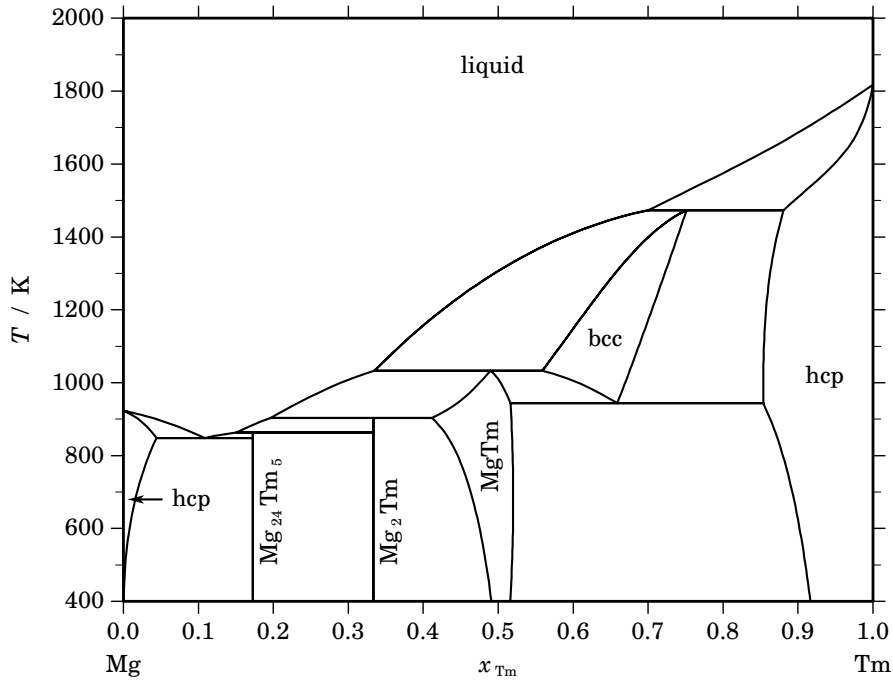


**Mg – Tm** (Magnesium – Thulium)**Fig. 1.** Calculated phase diagram for the system Mg-Tm.

The rare earth elements have attracted some attention as additives to light metal alloys in the aerospace and automotive industry due to the improvement of mechanical properties of Al- and Mg-alloys at high temperatures. A review on the literature of the Mg-Tm system has been given by [1988Nay]. Du *et al.* [2004Du] prepared a thermodynamic optimisation of the Mg-Tm system, which is mostly based on an experimental investigation of the phase equilibria at elevated temperatures throughout the composition range from 0 to 70 at.% Tm [1995Sac]. The Mg-rich part of the phase diagram and the solubility of thulium in crystalline magnesium has been measured by [1977Rok]. No experimental reports have been available for the solubility of Mg in solid Tm and for the thermodynamic mixing properties of the melt. The thermodynamic properties of the intermetallic compounds are also not investigated experimentally except for the standard enthalpy of formation of MgTm which has been determined by [1967Ogr].

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

| Phase                            | Strukturbericht | Prototype         | Pearson symbol | Space group               | SGTE name | Model                                    |
|----------------------------------|-----------------|-------------------|----------------|---------------------------|-----------|--|
| liquid                           |                 |                   |                |                           | LIQUID    | (Mg,Tm) <sub>1</sub>                     |
| hcp                              | A3              | Mg                | <i>hP2</i>     | <i>P6<sub>3</sub>/mmc</i> | HCP_A3    | (Mg,Tm) <sub>1</sub>                     |
| Mg <sub>24</sub> Tm <sub>5</sub> | A12             | αMn               | <i>cI58</i>    | <i>I43m</i>               | MG24TM5   | Mg <sub>24</sub> Tm <sub>5</sub>         |
| Mg <sub>2</sub> Tm               | C14             | MgZn <sub>2</sub> | <i>hP12</i>    | <i>P6<sub>3</sub>/mmc</i> | MG2TM     | Mg <sub>2</sub> Tm <sub>1</sub>          |
| MgTm                             | B2              | CsCl              | <i>cP2</i>     | <i>Pm3m</i>               | MGTm      | (Mg,□) <sub>1</sub> (Mg,Tm) <sub>1</sub> |
| bcc                              | A2              | W                 | <i>cI2</i>     | <i>Im3m</i>               | BCC_A2    | (Mg,Tm) <sub>1</sub>                     |

**Table II.** Invariant reactions.

| Reaction  | Type       | $T / \text{K}$ | Compositions / $x_{\text{Tm}}$ |       |       | $\Delta_r H / (\text{J/mol})$ |
|---|------------|----------------|--------------------------------|-------|-------|-------------------------------|
| liquid + hcp $\rightleftharpoons$ bcc   | peritectic | 1473.2         | 0.700                          | 0.881 | 0.751 | –6985                         |
| liquid + bcc $\rightleftharpoons$ MgTm  | peritectic | 1033.2         | 0.335                          | 0.559 | 0.490 | –11785                        |
| bcc $\rightleftharpoons$ MgTm + hcp   | eutectoid  | 943.4          | 0.659                          | 0.516 | 0.854 | –6754                         |
| liquid + MgTm $\rightleftharpoons$ Mg <sub>2</sub> Tm                             | peritectic | 903.0          | 0.197                          | 0.412 | 0.333 | –6580                         |
| liquid + Mg <sub>2</sub> Tm $\rightleftharpoons$ Mg <sub>24</sub> Tm <sub>5</sub> | peritectic | 863.1          | 0.151                          | 0.333 | 0.172 | –9990                         |
| liquid $\rightleftharpoons$ hcp + Mg <sub>24</sub> Tm <sub>5</sub>                | eutectic   | 848.0          | 0.109                          | 0.044 | 0.172 | –9407                         |

**Table IIIa.** Integral quantities for the liquid phase at 1900 K.

| $x_{\text{Tm}}$ | $\Delta G_{\text{m}}$<br>[J/mol] | $\Delta H_{\text{m}}$<br>[J/mol] | $\Delta S_{\text{m}}$<br>[J/(mol·K)] | $G_{\text{m}}^{\text{E}}$<br>[J/mol] | $S_{\text{m}}^{\text{E}}$<br>[J/(mol·K)] | $\Delta C_P$<br>[J/(mol·K)] |
|-----------------|----------------------------------|----------------------------------|--------------------------------------|--------------------------------------|--|-----------------------------|
| 0.000           | 0                                | 0                                | 0.000                                | 0                                    | 0.000                                    | 0.000                       |
| 0.100           | –6186                            | –1649                            | 2.388                                | –1051                                | –0.315                                   | 0.000                       |
| 0.200           | –9677                            | –2607                            | 3.721                                | –1772                                | –0.439                                   | 0.000                       |
| 0.300           | –11850                           | –2994                            | 4.661                                | –2200                                | –0.418                                   | 0.000                       |
| 0.400           | –13002                           | –2934                            | 5.299                                | –2370                                | –0.297                                   | 0.000                       |
| 0.500           | –13269                           | –2547                            | 5.643                                | –2319                                | –0.120                                   | 0.000                       |
| 0.600           | –12714                           | –1957                            | 5.661                                | –2082                                | 0.066                                    | 0.000                       |
| 0.700           | –11346                           | –1286                            | 5.295                                | –1696                                | 0.216                                    | 0.000                       |
| 0.800           | –9101                            | –654                             | 4.446                                | –1196                                | 0.285                                    | 0.000                       |
| 0.900           | –5754                            | –185                             | 2.931                                | –619                                 | 0.228                                    | 0.000                       |
| 1.000           | 0                                | 0                                | 0.000                                | 0                                    | 0.000                                    | 0.000                       |

Reference states: Mg(liquid), Tm(liquid)

**Table IIIb.** Partial quantities for Mg in the liquid phase at 1900 K.

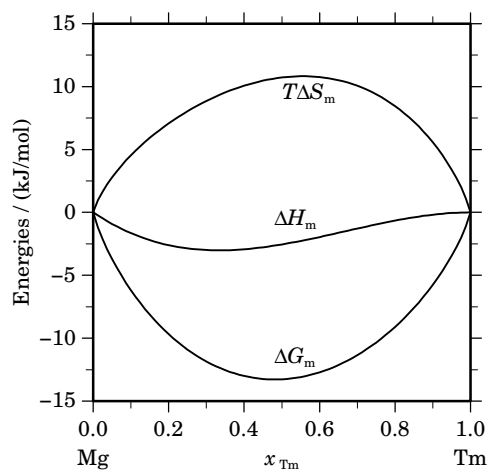
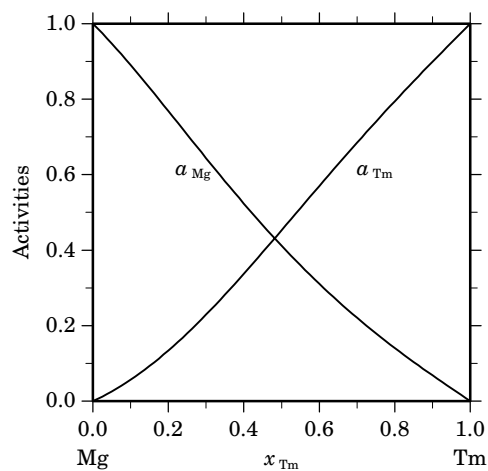
| $x_{\text{Mg}}$ | $\Delta G_{\text{Mg}}$<br>[J/mol] | $\Delta H_{\text{Mg}}$<br>[J/mol] | $\Delta S_{\text{Mg}}$<br>[J/(mol·K)] | $G_{\text{Mg}}^{\text{E}}$<br>[J/mol] | $S_{\text{Mg}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Mg}}$ | $\gamma_{\text{Mg}}$ |
|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |
| 0.900           | –1835                             | –366                              | 0.773                                 | –171                                  | –0.103                                    | 0.890           | 0.989                |
| 0.800           | –4160                             | –1303                             | 1.504                                 | –635                                  | –0.351                                    | 0.768           | 0.961                |
| 0.700           | –6955                             | –2565                             | 2.311                                 | –1321                                 | –0.655                                    | 0.644           | 0.920                |
| 0.600           | –10226                            | –3909                             | 3.325                                 | –2156                                 | –0.923                                    | 0.523           | 0.872                |
| 0.500           | –14018                            | –5090                             | 4.699                                 | –3068                                 | –1.064                                    | 0.412           | 0.823                |
| 0.400           | –18462                            | –5865                             | 6.630                                 | –3987                                 | –0.989                                    | 0.311           | 0.777                |
| 0.300           | –23858                            | –5990                             | 9.405                                 | –4839                                 | –0.606                                    | 0.221           | 0.736                |
| 0.200           | –30977                            | –5220                             | 13.557                                | –5552                                 | 0.175                                     | 0.141           | 0.704                |
| 0.100           | –42430                            | –3311                             | 20.589                                | –6055                                 | 1.444                                     | 0.068           | 0.682                |
| 0.000           | – $\infty$                        | –19                               | $\infty$                              | –6276                                 | 3.293                                     | 0.000           | 0.672                |

Reference state: Mg(liquid)

**Table IIIc.** Partial quantities for Tm in the liquid phase at 1900 K.

| $x_{\text{Tm}}$ | $\Delta G_{\text{Tm}}$<br>[J/mol] | $\Delta H_{\text{Tm}}$<br>[J/mol] | $\Delta S_{\text{Tm}}$<br>[J/(mol·K)] | $G_{\text{Tm}}^{\text{E}}$<br>[J/mol] | $S_{\text{Tm}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Tm}}$ | $\gamma_{\text{Tm}}$ |
|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| 0.000           | $-\infty$                         | -20361                            | $\infty$                              | -12274                                | -4.256                                    | 0.000           | 0.460                |
| 0.100           | -45345                            | -13197                            | 16.920                                | -8970                                 | -2.225                                    | 0.057           | 0.567                |
| 0.200           | -31745                            | -7823                             | 12.590                                | -6320                                 | -0.791                                    | 0.134           | 0.670                |
| 0.300           | -23271                            | -3996                             | 10.144                                | -4251                                 | 0.134                                     | 0.229           | 0.764                |
| 0.400           | -17166                            | -1471                             | 8.260                                 | -2691                                 | 0.642                                     | 0.337           | 0.843                |
| 0.500           | -12519                            | -5                                | 6.586                                 | -1569                                 | 0.823                                     | 0.453           | 0.905                |
| 0.600           | -8882                             | 648                               | 5.016                                 | -812                                  | 0.768                                     | 0.570           | 0.950                |
| 0.700           | -5984                             | 731                               | 3.534                                 | -349                                  | 0.568                                     | 0.685           | 0.978                |
| 0.800           | -3632                             | 487                               | 2.168                                 | -107                                  | 0.313                                     | 0.795           | 0.993                |
| 0.900           | -1679                             | 163                               | 0.969                                 | -15                                   | 0.093                                     | 0.899           | 0.999                |
| 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |

Reference state: Tm(liquid)

**Fig. 2.** Integral quantities of the liquid phase at  $T=1900$  K.**Fig. 3.** Activities in the liquid phase at  $T=1900$  K.**Table IV.** Standard reaction quantities at 298.15 K for the compounds per mole of atoms.

| Compound                         | $x_{\text{Tm}}$ | $\Delta_f G^\circ$ / (J/mol) | $\Delta_f H^\circ$ / (J/mol) | $\Delta_f S^\circ$ / (J/(mol·K)) | $\Delta_f C_P^\circ$ / (J/(mol·K)) |
|----------------------------------|-----------------|------------------------------|------------------------------|----------------------------------|------------------------------------|
| Mg <sub>24</sub> Tm <sub>5</sub> | 0.172           | -4529                        | -5013                        | -1.623                           | 0.000                              |
| Mg <sub>2</sub> Tm <sub>1</sub>  | 0.333           | -8197                        | -9442                        | -4.176                           | 0.000                              |
| MgTm                             | 0.500           | -8744                        | -9774                        | -3.454                           | 0.343                              |

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