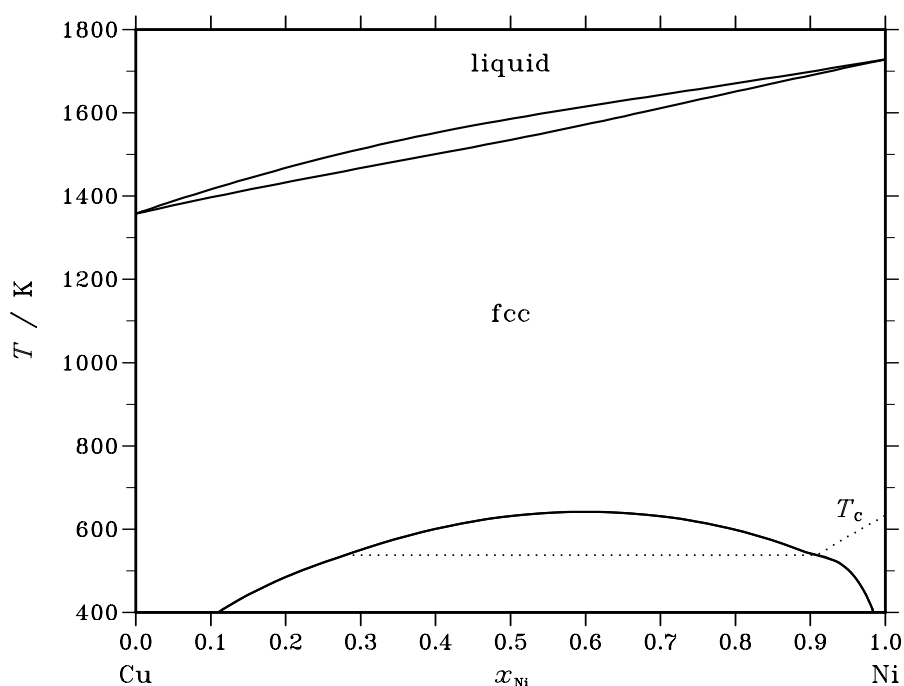


**Cu – Ni (Copper – Nickel)****Fig. 1.** Calculated phase diagram for the system Cu-Ni.

Copper and nickel are both important alloying elements for many alloys, such as Cu-base leaded nickel-tin bronzes or nickel-silver. The Cu-Ni system is fairly simple with only two condensed stable phases, liquid and fcc. Indirect experimental evidence indicates the presence of a miscibility gap in the fcc phase at a temperature somewhere between 450 and 923 K [91Cha]. Due to the slow kinetics at these temperatures no reliable direct experimental determination of the miscibility gap is available. A series of thermodynamic assessments of this system have been carried out, with each improving the thermodynamic description of the phases. The recommended assessment of [92Mey] reproduces the experimental data well, including liquidus, solidus, the enthalpy of mixing and the activities of both elements in the liquid and the fcc phase. The miscibility gap obtained from this description is in accord with the experimental observations.

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

| Phase  | Struktur-bericht | Prototype | Pearson symbol | Space group  | SGTE name | Model                |
|--------|------------------|-----------|----------------|--------------|-----------|----------------------|
| liquid |                  |           |                |              | LIQUID    | (Cu,Ni) <sub>1</sub> |
| fcc    | A1               | Cu        | cF4            | $Fm\bar{3}m$ | FCC_A1    | (Cu,Ni) <sub>1</sub> |

**Table II.** Invariant reactions.

| Reaction   | Type     | $T / \text{K}$ | Compositions / $x_{\text{Ni}}$ |       |       | $\Delta_r H / (\text{J/mol})$ |
|--|----------|----------------|--------------------------------|-------|-------|-------------------------------|
| $\text{fcc} \rightleftharpoons \text{fcc}' + \text{fcc}''$ | critical | 641.7          | 0.599                          | 0.599 | 0.599 | 0                             |

**Table IIIa.** Integral quantities for the liquid phase at 1753 K.

| $x_{\text{Ni}}$ | $\Delta G_{\text{m}}$<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           | −3464                            | 950                              | 2.518                                | 1274                                 | −0.185                                   | 0.000                       |
| 0.200           | −5022                            | 1749                             | 3.862                                | 2272                                 | −0.298                                   | 0.000                       |
| 0.300           | −5913                            | 2374                             | 4.727                                | 2991                                 | −0.352                                   | 0.000                       |
| 0.400           | −6381                            | 2802                             | 5.239                                | 3428                                 | −0.357                                   | 0.000                       |
| 0.500           | −6521                            | 3012                             | 5.438                                | 3581                                 | −0.325                                   | 0.000                       |
| 0.600           | −6361                            | 2981                             | 5.329                                | 3448                                 | −0.267                                   | 0.000                       |
| 0.700           | −5878                            | 2687                             | 4.885                                | 3026                                 | −0.194                                   | 0.000                       |
| 0.800           | −4981                            | 2106                             | 4.043                                | 2312                                 | −0.117                                   | 0.000                       |
| 0.900           | −3434                            | 1218                             | 2.654                                | 1304                                 | −0.049                                   | 0.000                       |
| 1.000           | 0                                | 0                                | 0.000                                | 0                                    | 0.000                                    | 0.000                       |

Reference states: Cu(liquid), Ni(liquid)

**Table IIIb.** Partial quantities for Cu in the liquid phase at 1753 K.

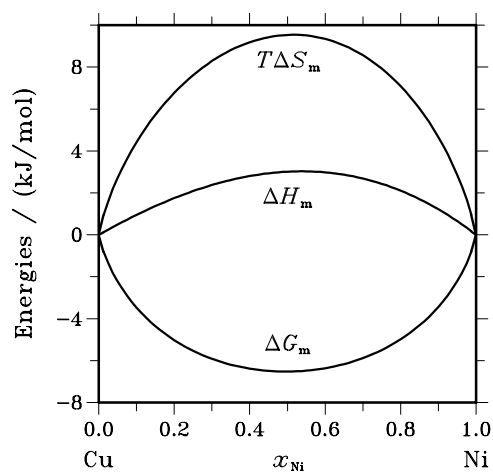
| $x_{\text{Cu}}$ | $\Delta G_{\text{Cu}}$<br>[J/mol] | $\Delta H_{\text{Cu}}$<br>[J/mol] | $\Delta S_{\text{Cu}}$<br>[J/(mol·K)] | $G_{\text{Cu}}^{\text{E}}$<br>[J/mol] | $S_{\text{Cu}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Cu}}$ | $\gamma_{\text{Cu}}$ |
|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |
| 0.900           | −1398                             | 72                                | 0.839                                 | 138                                   | −0.037                                    | 0.909           | 1.010                |
| 0.800           | −2698                             | 318                               | 1.720                                 | 555                                   | −0.135                                    | 0.831           | 1.039                |
| 0.700           | −3943                             | 783                               | 2.696                                 | 1255                                  | −0.270                                    | 0.763           | 1.090                |
| 0.600           | −5200                             | 1511                              | 3.828                                 | 2245                                  | −0.419                                    | 0.700           | 1.167                |
| 0.500           | −6574                             | 2547                              | 5.203                                 | 3529                                  | −0.560                                    | 0.637           | 1.274                |
| 0.400           | −8243                             | 3935                              | 6.947                                 | 5112                                  | −0.671                                    | 0.568           | 1.420                |
| 0.300           | −10549                            | 5721                              | 9.282                                 | 6999                                  | −0.729                                    | 0.485           | 1.616                |
| 0.200           | −14263                            | 7949                              | 12.671                                | 9195                                  | −0.711                                    | 0.376           | 1.879                |
| 0.100           | −21855                            | 10664                             | 18.551                                | 11706                                 | −0.594                                    | 0.223           | 2.233                |
| 0.000           | −∞                                | 13910                             | ∞                                     | 14536                                 | −0.357                                    | 0.000           | 2.711                |

Reference state: Cu(liquid)

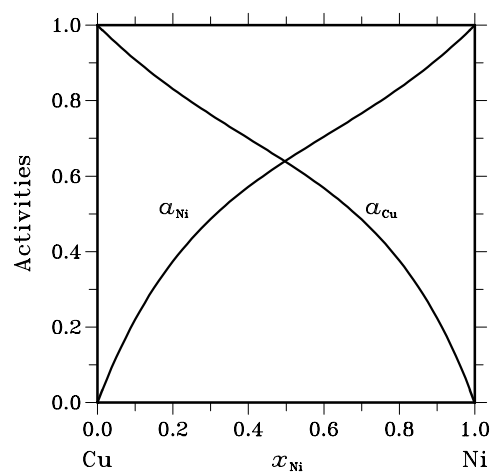
**Table IIIc.** Partial quantities for Ni in the liquid phase at 1753 K.

| $x_{\text{Ni}}$ | $\Delta G_{\text{Ni}}$<br>[J/mol] | $\Delta H_{\text{Ni}}$<br>[J/mol] | $\Delta S_{\text{Ni}}$<br>[J/(mol·K)] | $G_{\text{Ni}}^{\text{E}}$<br>[J/mol] | $S_{\text{Ni}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Ni}}$ | $\gamma_{\text{Ni}}$ |
|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| 0.000           | −∞                                | 10187                             | ∞                                     | 14115                                 | −2.241                                    | 0.000           | 2.634                |
| 0.100           | −22059                            | 8855                              | 17.635                                | 11502                                 | −1.510                                    | 0.220           | 2.201                |
| 0.200           | −14317                            | 7473                              | 12.430                                | 9141                                  | −0.952                                    | 0.374           | 1.872                |
| 0.300           | −10508                            | 6086                              | 9.466                                 | 7040                                  | −0.544                                    | 0.486           | 1.621                |
| 0.400           | −8153                             | 4740                              | 7.354                                 | 5203                                  | −0.264                                    | 0.572           | 1.429                |
| 0.500           | −6469                             | 3478                              | 5.674                                 | 3634                                  | −0.089                                    | 0.642           | 1.283                |
| 0.600           | −5106                             | 2345                              | 4.250                                 | 2339                                  | 0.003                                     | 0.704           | 1.174                |
| 0.700           | −3875                             | 1386                              | 3.001                                 | 1323                                  | 0.036                                     | 0.767           | 1.095                |
| 0.800           | −2661                             | 646                               | 1.886                                 | 592                                   | 0.031                                     | 0.833           | 1.041                |
| 0.900           | −1387                             | 169                               | 0.888                                 | 149                                   | 0.012                                     | 0.909           | 1.010                |
| 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |

Reference state: Ni(liquid)



**Fig. 2.** Integral quantities of the liquid phase at  $T=1753$  K.



**Fig. 3.** Activities in the liquid phase at  $T=1753$  K.

**Table IVa.** Integral quantities for the stable phases at 1273 K.

| Phase | $x_{\text{Ni}}$ | $\Delta G_{\text{m}}$<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)] |
|-------|-----------------|----------------------------------|----------------------------------|--------------------------------------|--------------------------------------|--|-----------------------------|
| fcc   | 0.000           | 0                                | 0                                | 0.000                                | 0                                    | 0.000                                    | 0.000                       |
|       | 0.100           | -2379                            | 580                              | 2.325                                | 1061                                 | -0.378                                   | -0.009                      |
|       | 0.200           | -3385                            | 1097                             | 3.521                                | 1912                                 | -0.640                                   | -0.018                      |
|       | 0.300           | -3924                            | 1527                             | 4.282                                | 2542                                 | -0.797                                   | -0.027                      |
|       | 0.400           | -4181                            | 1845                             | 4.734                                | 2942                                 | -0.862                                   | -0.036                      |
|       | 0.500           | -4233                            | 2026                             | 4.917                                | 3104                                 | -0.847                                   | -0.045                      |
|       | 0.600           | -4106                            | 2047                             | 4.833                                | 3017                                 | -0.763                                   | -0.054                      |
|       | 0.700           | -3792                            | 1881                             | 4.457                                | 2674                                 | -0.622                                   | -0.062                      |
|       | 0.800           | -3234                            | 1504                             | 3.722                                | 2063                                 | -0.439                                   | -0.065                      |
|       | 0.900           | -2266                            | 887                              | 2.477                                | 1175                                 | -0.226                                   | -0.050                      |
|       | 1.000           | 0                                | 0                                | 0.000                                | 0                                    | 0.000                                    | 0.000                       |

Reference states: Cu(fcc), Ni(fcc)

**Table IVb.** Partial quantities for Cu in the stable phases at 1273 K.

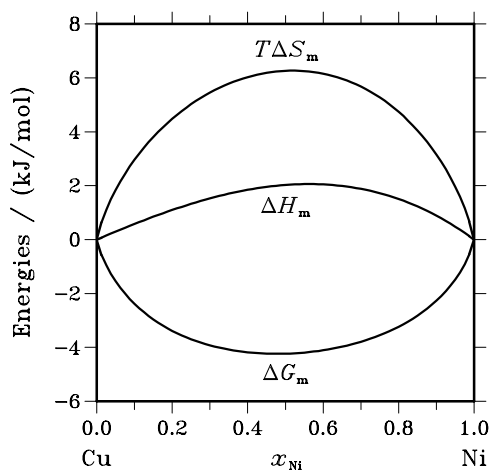
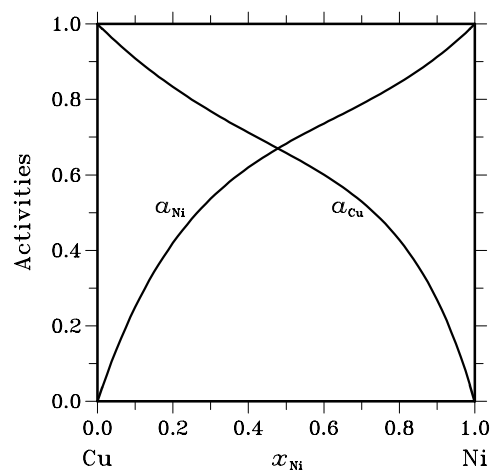
| Phase | $x_{\text{Cu}}$ | $\Delta G_{\text{Cu}}$<br>[J/mol] | $\Delta H_{\text{Cu}}$<br>[J/mol] | $\Delta S_{\text{Cu}}$<br>[J/(mol·K)] | $G_{\text{Cu}}^{\text{E}}$<br>[J/mol] | $S_{\text{Cu}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Cu}}$ | $\gamma_{\text{Cu}}$ |
|-------|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| fcc   | 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |
|       | 0.900           | -1011                             | 27                                | 0.816                                 | 104                                   | -0.060                                    | 0.909           | 1.010                |
|       | 0.800           | -1934                             | 142                               | 1.631                                 | 428                                   | -0.225                                    | 0.833           | 1.041                |
|       | 0.700           | -2784                             | 394                               | 2.496                                 | 991                                   | -0.470                                    | 0.769           | 1.098                |
|       | 0.600           | -3595                             | 830                               | 3.476                                 | 1812                                  | -0.771                                    | 0.712           | 1.187                |
|       | 0.500           | -4428                             | 1502                              | 4.658                                 | 2908                                  | -1.105                                    | 0.658           | 1.316                |
|       | 0.400           | -5400                             | 2457                              | 6.171                                 | 4299                                  | -1.447                                    | 0.600           | 1.501                |
|       | 0.300           | -6740                             | 3748                              | 8.239                                 | 6003                                  | -1.771                                    | 0.529           | 1.763                |
|       | 0.200           | -8992                             | 5441                              | 11.337                                | 8043                                  | -2.044                                    | 0.428           | 2.138                |
|       | 0.100           | -13929                            | 7611                              | 16.920                                | 10443                                 | -2.225                                    | 0.268           | 2.682                |
|       | 0.000           | $-\infty$                         | 10324                             | $\infty$                              | 13223                                 | -2.278                                    | 0.000           | 3.488                |

Reference state: Cu(fcc)

**Table IVc.** Partial quantities for Ni in the stable phases at 1273 K.

| Phase | $x_{\text{Ni}}$ | $\Delta G_{\text{Ni}}$<br>[J/mol] | $\Delta H_{\text{Ni}}$<br>[J/mol] | $\Delta S_{\text{Ni}}$<br>[J/(mol·K)] | $G_{\text{Ni}}^{\text{E}}$<br>[J/mol] | $S_{\text{Ni}}^{\text{E}}$<br>[J/(mol·K)] | $a_{\text{Ni}}$ | $\gamma_{\text{Ni}}$ |
|-------|-----------------|-----------------------------------|-----------------------------------|---------------------------------------|---------------------------------------|---|-----------------|----------------------|
| fcc   | 0.000           | $-\infty$                         | 6035                              | $\infty$                              | 11638                                 | −4.401                                    | 0.000           | 3.003                |
|       | 0.100           | −14694                            | 5555                              | 15.906                                | 9678                                  | −3.238                                    | 0.250           | 2.495                |
|       | 0.200           | −9189                             | 4918                              | 11.082                                | 7846                                  | −2.300                                    | 0.420           | 2.099                |
|       | 0.300           | −6584                             | 4172                              | 8.449                                 | 6159                                  | −1.561                                    | 0.537           | 1.790                |
|       | 0.400           | −5060                             | 3367                              | 6.620                                 | 4638                                  | −0.999                                    | 0.620           | 1.550                |
|       | 0.500           | −4037                             | 2551                              | 5.175                                 | 3300                                  | −0.588                                    | 0.683           | 1.366                |
|       | 0.600           | −3244                             | 1773                              | 3.941                                 | 2163                                  | −0.306                                    | 0.736           | 1.227                |
|       | 0.700           | −2529                             | 1081                              | 2.836                                 | 1247                                  | −0.130                                    | 0.787           | 1.125                |
|       | 0.800           | −1794                             | 520                               | 1.818                                 | 568                                   | −0.037                                    | 0.844           | 1.055                |
|       | 0.900           | −970                              | 140                               | 0.872                                 | 145                                   | −0.004                                    | 0.912           | 1.014                |
|       | 1.000           | 0                                 | 0                                 | 0.000                                 | 0                                     | 0.000                                     | 1.000           | 1.000                |

Reference state: Ni(fcc)

**Fig. 4.** Integral quantities of the stable phases at  $T=1273$  K.**Fig. 5.** Activities in the stable phases at  $T=1273$  K.

## References

- [91Cha] D.J. Chakrabarti, D.E. Laughlin, S.W. Chen, Y.A. Chang: Phase Diagrams of Binary Nickel Alloys, Ed. P. Nash, ASM International, Materials Park, OH, (1991) 85–95.  
 [92Mey] S. an Mey: Calphad **16** (1992) 255–260.