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# CHEMISTRY

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Fig. 1

Figure 1: Fig. 1

**Abstract****Full Text***CHEMISTRY*

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**ON THE PHASE DIAGRAM OF Ni–C**

1. In studying the concentration dependence of the viscosity and electrical conductivity of liquid nickel alloys with carbon, we found a discrepancy between the character of the composition–property curves and the phase diagram. Although, in the general case, the properties of liquid alloys are not determined by the phase diagram <sup>(1)</sup>, nevertheless in systems in which no radical change in the bonding forces occurs upon melting, including the Ni–C system, one may expect a certain correlation between the form of the composition–property curves and the phase diagram. In this connection it seemed expedient to investigate more thoroughly the nickel-rich alloys, especially since the diagram mentioned was constructed from work carried out more than 30 years ago <sup>(2,3)</sup>, and the principal method used in constructing the solidus lines was graphical interpolation of the results of thermal analysis and determination of the solubility of carbon in liquid nickel <sup>(4)</sup>.

**Fig. 1.** Polytherms of the electrical resistivity of nickel alloys with carbon. C content: 1–0; 2–1.16; 3–1.30; 4–1.75; 5–2.2 wt.%

2. Electrolytic nickel and spectrally pure graphite were used for preparing the alloys. The alloys were prepared in an arc electric furnace with a water-cooled mold in an atmosphere of purified helium. A master alloy containing 7% carbon was prepared in a vacuum induction furnace by prolonged holding of nickel in a graphite crucible. After melting in the arc furnace, all alloys were remelted in a vacuum induction furnace at a pressure of about  $10^{-3}$ – $10^{-4}$  mm Hg. Particular attention was paid to controlling the carbon content. After holding in vacuum, the oxygen content in all alloys (0.25–2.20% C) was approximately the same and amounted to 0.003–0.004%.
3. The liquidus and solidus lines were constructed from the jump in electrical resistivity during melting from cooling curves, and also with the aid of metallographic analysis. The electrical resistivity in the solid and liquid

Fig. 2. Phase diagram: 1 –thermal analysis; 2 –electrical resistance; 3 – according to (7)

Figure 2: Fig. 2. Phase diagram: 1 –thermal analysis; 2 –electrical resistance; 3 –according to (7)

states was measured by a contactless method according to the previously described procedure (5). Thermal analysis was carried out by the usual method, recording cooling and heating curves on a Kurnakov pyrometer. The sensor was a platinum-platinum-rhodium thermocouple, which, by means of a special device, could be lowered into the melt without disturbing the tightness of the furnace. All experiments were carried out in an atmosphere of purified helium, while an approximately constant cooling rate was maintained.

4. From the curves of the temperature dependence of the specific electrical resistivity for the solid and liquid states, the moment of appearance of the first drops of liquid and the moment of disappearance of...

of the last crystals. From Fig. 1, where a portion of the most characteristic curves is shown, it is seen that each curve of the specific electrical resistance consists of three sections, the middle section corresponding to the two-phase state; therefore the inflection points may be regarded as the solidus and liquidus temperatures. The advantage of this method is its lack of inertia and its high sensitivity. The jump in electrical resistance upon melting of pure nickel proved to be equal to 1.3, whereas, according to Mott's rule ( $\rho_{\text{liq}}/\rho_{\text{sol}}$ ), it should be equal to 2.34. This result confirms the conclusion of A. R. Regel (6) concerning the inapplicability of Mott's rule to metals of the triad. The results of determining the liquidus and solidus lines in the Ni–C system from the jump in electrical resistance are presented in Fig. 2, 1. As an illustration of the possibilities of the method of contactless determination of electrical resistance in a rotating magnetic field, we note that the method permits the Curie-point temperature to be recorded with an accuracy of the order of 5–10°, which for alloys of the nickel-carbon system proved to be 320–340° and independent of the carbon concentration.

**Fig. 2. Phase diagram:** 1 –thermal analysis; 2 –electrical resistance; 3 – according to (7)

5. All the melts investigated proved to be very prone to supercooling; therefore the liquidus lines are shifted on the temperature scale. However, the eutectic point, determined with the aid of cooling curves, coincided with the results of measurements of the jump in electrical resistance ( $\sim 1.3\%$  C) (Fig. 2, 2). Metallographic analysis showed the presence of a graphite eutectic with a very small amount of carbides.

Thus, thermal analysis, as well as measurement of the jump in electrical conductivity, provides grounds for refining the position of the liquidus lines on the

diagram. The discrepancy with older works<sup>(2-4)</sup>, according to whose results the Ni–C phase diagram was constructed<sup>(7)</sup>, Fig. 2, 3), can be explained in light of the study<sup>(8)</sup>, where it was shown that nickel-carbon alloys, at sufficiently high cooling rates, may crystallize also according to a metastable diagram with separation of the carbide Ni<sub>3</sub>C, the eutectic point of the metastable diagram being shifted toward high carbon concentrations.

It should be noted that in melts of the Ni–C type, apparently, a “quasi-ordered” arrangement of atoms is possible. It is natural to expect in carbon-rich alloys a greater tendency toward crystallization according to the stable diagram than in nickel-rich alloys, since in the former case the appearance of carbon microgroupings is already observed in the melt.

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*Note: Figure translations are in progress. See original paper for figures.*

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