MAGNETIC PROPERTIES OF COPPER-NICKEL ALLOYS

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Abstract

The magnetic susceptibility of alloys of copper and nickel in proportions ranging from 0.1 to 70 percent nickel have been studied. X-ray photographs of the alloys show that they are a homogeneous mixture of the copper and nickel crystals. Although copper is only weakly diamagnetic it requires 0.8 or 0.9 percent nickel to neutralize this diamagnetic effect and 56 percent nickel is required before the alloy shows ferromagnetic properties at ordinary temperatures. For amounts of nickel from one percent up to 30 percent the alloy, while paramagnetic in most respects, does not obey any known law of paramagnetism with regard to temperature. As the temperature is increased the susceptibility first increases and then decreases, the maximum occurring in the neighborhood of the Curie point for nickel. In the case of alloys containing more than 30 percent nickel the susceptibility decreases with increase of temperature for temperatures above 20°C.

THE magnetic properties of alloys of diamagnetic and ferromagnetic substances have been studied very little. Of the diamagnetic metals that will alloy to some extent with Fe, Ni or Co, copper alloys with nickel the most perfectly. These metals form, as Gürther[1] and others have shown, an unbroken series of homogeneously mixed crystals. Since both copper and nickel form face centered cubic crystals, x-ray photographs show only a progressive shifting of the lines as larger amounts of nickel are included.

Gans and Fonseka[2] and Sacklowski[3] investigated copper-nickel alloys in order that a survey of the structure in relation to the concentration could be extended and if possible to obtain insight into the connection of the magnetic property with the crystal structure. Now, below 50 percent nickel the alloys are weakly paramagnetic whereas above 60 percent they are strongly ferromagnetic. The results obtained by the above authors indicate that the magnetic phenomenon has no influence on the lattice spacing, at least in the case of copper-nickel alloys.

It was thought desirable to repeat and continue this investigation studying especially the variation of magnetic susceptibility in the neighborhood of the transition points from diamagnetism to paramagnetism and from paramagnetism to ferromagnetism and also the dependence of the susceptibility on temperature.

The alloys were prepared by melting pure copper and nickel in an induction furnace in a receptacle free from iron. The induction furnace serves not only to melt the metals but at the same time stirs them quite thoroughly.

[1] W. Gürther and F. Tammann, Zeits. f. Anorg. Chem. **52**, 25 (1907).

[2] R. Gans and R. Fonseka, Ann. d. Physik **61**, 742 (1920).

[3] A. Sacklowski, Ann. d. Physik **77**, 241 (1925).

Samples taken from different parts of the melt gave approximately the same value of the magnetic susceptibility.

X-ray photographs of filings of alloys containing amounts of nickel varying from 0 to 100 percent in steps of 20 percent were taken. In this the author wishes to acknowledge the assistance of Dr. W. B. Sisson of the Chemistry Department. The results are shown in Fig. 1 and confirm the results of those experimenters who have found that copper and nickel form a homogeneous mixture in all proportions. It can be seen that the shifts in the principal lines are approximately proportional to the amount of nickel and careful measurements showed this to be almost exactly a straight line relation.

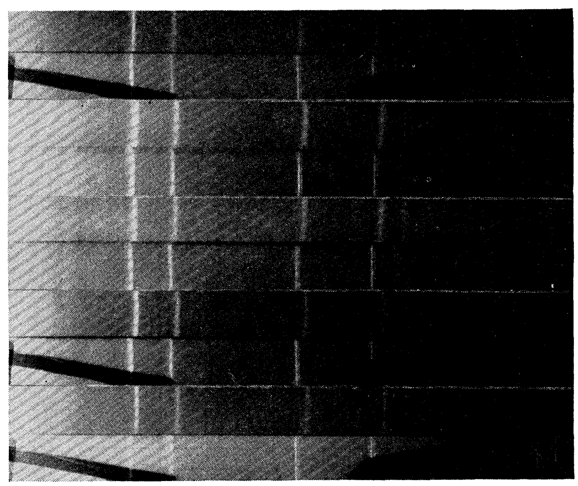


Fig. 1. Photographs showing that the displacement of Roentgen lines is proportional to the nickel content.

The susceptibility measurements were made by means of a Curie balance electrically operated as described by Guthrie and Bourland.[4] The variation of the magnetic susceptibility at room temperature with percentage of nickel is shown in Table I.

TABLE I. *Magnetic susceptibility of copper-nickel alloys at room temperature.*

Percent Ni	$\chi\times10^6$	Percent Ni	$\chi\times10^6$ $H=1300$	$\chi\times10^6$ $H=5700$
0.	−.14	40	2.90	2.90
0.1	−.08	50	10.83	10.83
0.5	−.02	54	18.3	18.3
1.0	+.02	55	20.5	20.5
2.0	.07	56	28.0	27.0
5.0	.14	58	58.0	51.6
10.0	.40	60	81.5	73.2
20.0	.82	65	2140.	710.
30.0	1.01	70	13300.0	—

[4] A. N. Guthrie and L. T. Bourland. Phys. Rev. **37,** 303 (1931).

Although the magnitude of the susceptibility of pure nickel is 10^8 times that of pure copper, it requires approximately 0.8 percent nickel in order to overcome the diamagnetic effect of the copper. This is true notwithstanding the fact that both nickel and copper have the same crystalline structure and, according to x-ray analysis, form a homogeneous mixture. It is not until the percentage of nickel exceeds 55 percent that the ferromagnetic property of the nickel begins to become noticeable if measurements are made at room temperature. Thus throughout the whole range from 0.8 percent nickel to 55 percent nickel the alloys remain paramagnetic. Beyond 55 percent nickel the ferromagnetic effect increases very rapidly. It has been shown[5] that the amount of nickel necessary to produce ferromagnetism depends upon the

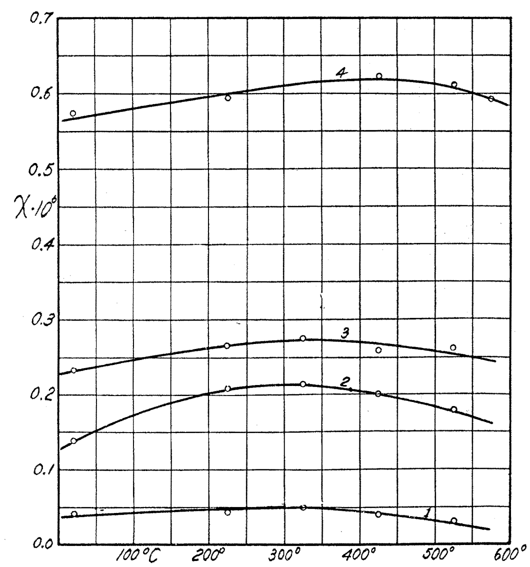


Fig. 2. Curve 1, 1 percent nickel. Curve 2, 2 percent nickel. Curve 3, 5 percent nickel. Curve 4, 10 percent nickel.

temperature at which measurements are made, decreasing as the temperature decreases.

The variation of the susceptibility with temperature was measured for alloys containing from 0.5 percent nickel to 50 percent nickel. The results are shown in Figs. 2 and 3. For 0.5 percent nickel the alloy is diamagnetic and the susceptibility remains constant with temperature change within the limits of experimental error. For amounts of nickel from 1 percent to 30 percent the alloys, while paramagnetic in most respects, do not obey the usual law of paramagnetism with regard to temperature. As the temperature is increased the susceptibility first increases and then decreases, the maximum occurring in the neighborhood of the Curie point for nickel. In the case of

[5] Int. National Critical Tables, Vol. 6, p. 405.

alloys containing 40 percent nickel, or more, the susceptibility decreases with increase of temperature for temperatures above 20°C.

Measurements repeated on the same sample after it had been heated to 500° or 600°C gave results for the susceptibility which were invariably higher than the original values. For third and fourth repetitions the change became less so that the value tended toward a maximum. Precautions were taken to prevent oxidation and it made no difference whether the cooling took place

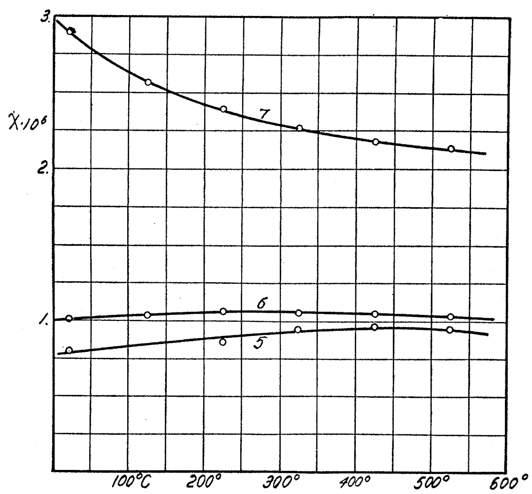
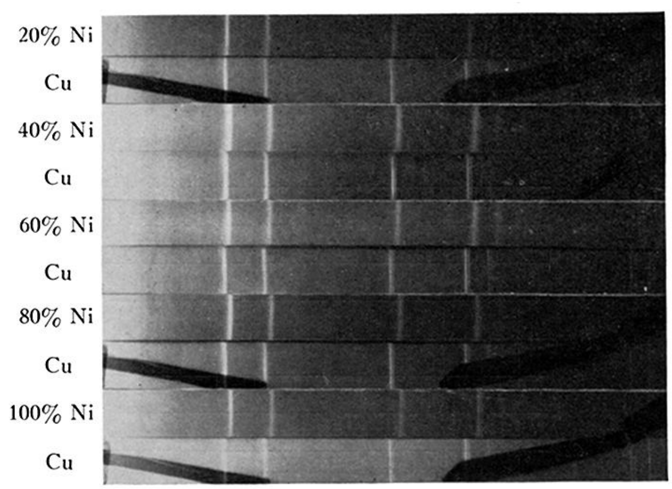


Fig. 3. Curve 5, 20 percent nickel. Curve 6, 30 percent nickel. Curve 7, 40 percent nickel.

in the presence of a magnetic field or not. The results shown in Figs. 2 and 3 are, in every case, first measurement results.

So far as the phenomenon of increasing paramagnetic susceptibility is concerned, we are unable to offer any explanation. It has been suggested that a few atoms or molecules of nickel do not lose their magnetic identity in the alloy and that these atoms with their spinning electrons become more mobile as the temperature is increased. One objection to this is that the susceptibility is independent of the field over a wide range.



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