On the 'Permalloy Problem'

SINCE the discovery of permalloy in 1923[1] the problem of explaining the very high permeability observed with 78 per cent nickel and the special heat treatment ('permalloy heat treatment') leading to these high values, has raised a good deal of discussion[2] and many *ad hoc* hypotheses have been put forward[3,4,5].

F. Lichtenberger[6], basing his explanation on Becker's theory, assumes that permalloy owes its unique properties to the neighbourhood of three singular points in the nickel iron system: 71 per cent, where the crystal anisotropy vanishes, 82 per cent where the absolute value of the magnetostriction passes through a minimum, and 85·5 per cent where the anisotropy of the latter vanishes.

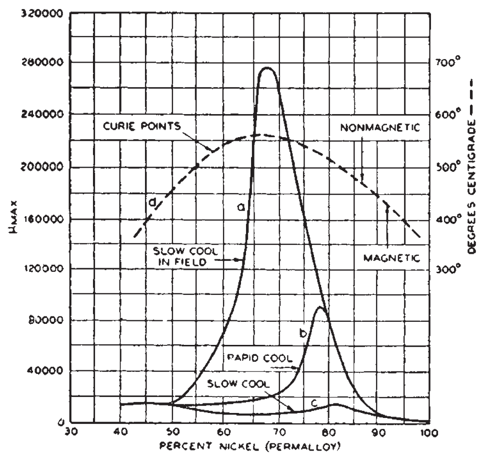

FIG. 1. Maximum permeabilities of iron-nickel alloys cooled in different ways after annealing at 1,000° C. Curie points of the same alloys are shown by the broken line.

It seems to me that recent experiments of Dillinger and Bozorth[7] on the influence of a magnetic field applied during cooling, combined with the work of Yenssen and Ziegler[8] and Ruder[9] on the influence of grain size and crystal orientation on the permeability of iron and silicon iron, together with a renewed estimation I have made of the exact situation of the first mentioned singular point, definitely make it clear that Lichtenberger's explanation is essentially the right one.

Fig. 1 of Dillinger and Bozorth's paper (page 280), where the result of three different heat treatments is given, is reproduced here (Fig. 1) in order to facilitate the explanation. Slowly cooling in zero field brings the disturbing influence of magnetostriction on the permeability into full action due to the different positions of the magnetisation being 'frozen in'. This results in a low permeability, especially where the Curie point lies well above 500° (the flowing limit). The first thing to be noted now is that in this case the maximum permeability is found exactly at 82 per cent, where the mean magnetostriction has its minimum value (not zero !).

By the permalloy heat treatment (rapid cooling from 600°) the 'freezing' process is eliminated, and the permeabilities are accordingly much higher. The maximum shifts to lower nickel concentrations, while the crystal anisotropy, the other disturbing factor, is lower there.

Heat treating in a magnetic field results in a further radical elimination of the disturbing magnetostriction effects (only in one direction this time). This has two consequences: first, the permeability is again increased enormously in the region where the Curie temperature is high enough. At the same time, however, the remaining influence of the crystal anisotropy clearly establishes itself by the circumstance that a pronounced maximum appears this time *just at the concentration where the crystal anisotropy vanishes* (66 per cent according to a renewed estimation I have made[10]).

Dillinger and Bozorth explain the same maximum by a corresponding maximum in the Curie point; the above explanation, however, seems to me to be the more probable one.

A direct influence of crystal anisotropy on the permeability has been established in pure samples of iron and silicon iron of varying grain size[8, 9]. The fact mentioned by Dillinger and Bozorth that heat treating pure iron in a magnetic field has little or no influence on its permeability finds its explanation in the same way, the crystal anisotropy of iron being rather strong.

J. L. SNOEK.

Natuurkundig Laboratorium,
N. V. Philips' Gloeilampenfabrieken,
Eindhoven.
Jan. 20.

[1] H. D. Arnold and G. W. Elmen, *J. Franklin Inst.*, **195**, 621 (1923).
[2] L. M. McKeehan and P. P. Cioffi, *Phys. Rev.*, **28**, 146 (1926). M. Kersten, *Z. Phys.*, **71**, 553, 572 (1932).
[3] G. W. Elmen, *J. Franklin Inst.*, **207**, 583 (1929).
[4] O. Dahl, *Z. Metallkunde*, **24**, 107 (1932).
[5] A. Kussmann, B. Scharnow and W. Steinhaus, *Festschrift der Heraeus Vacuumschmelze*, 310 (1923–1933).
[6] F. Lichtenberger, *Ann. Physik*, **15**, 45 (1935).
[7] J. F. Dillinger and R. M. Bozorth, *Physics*, **6**, 279 (1935).
[8] T. D. Yenssen and N. A. Ziegler, *Trans. Amer. Soc. Met.*, **23**, 556 (1935).
[9] W. E. Ruder, *Trans. Amer. Soc. Met.*, **22**, 1120 (1934).
[10] W. G. Burgers and J. L. Snoek, *Z. Metallkunde*, **27**, 158 (1935).

Electrical Conductivity of Thin Films of Rubidium on Glass Surfaces

THE electrical conductivity of films of the order of a few atomic diameters in thickness has been investigated for rubidium on pyrex glass surfaces. The work, carried out under rigid conditions of purity and high vacua, has yielded results differing so markedly from those of previous investigators that a preliminary note of the results seems worth while.

A defined beam of rubidium atoms is condensed on a flat pyrex glass surface at temperatures of 90° K. or lower. Contacts to the film are made by thin layers of colloidal graphite baked on to the surface. Owing to a discrepancy in the published data of the vapour pressure of rubidium, the film thicknesses quoted below may all be too small by a factor of 2, but this doubt should shortly be removed by an independent calibration of the apparatus by the hot tungsten filament method.

The influence of the surface condition on the resistivities has been thoroughly investigated, and it has been found possible to reproduce a standard surface infallibly by vigorous heat treatment. The accompanying table gives a brief summary of the

Film thickness (No. of atomic layers)	Resistivity (ohm cm.)		
	90° K.	77° K.	64° K.
1	2×10^{2}	8×10^{1}	2×10^{-3}
5	8×10^{-3}	3×10^{-4}	3×10^{-5}
10	8×10^{-4}	3×10^{-5}	1×10^{-5}

Resistivity of the bulk metal, $1 \cdot 13 \times 10^{-5}$ ohm cm. at 273° K.; $2 \cdot 6 \times 10^{-6}$ at 90° K. (Hackspill[1]).