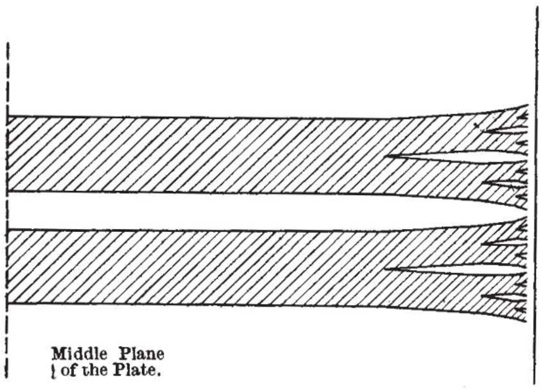
The Intermediate State of Supraconductors

IN a previous paper[1], I have shown that a body in the so-called 'intermediate' state consists of alternating layers of the supraconducting and normal phases. It can be shown, however, that the plane-parallel form of these layers discussed in this paper does not correspond to a minimum of the free energy*. A detailed investigation leads to the result that the thickness of the layers does not remain constant throughout the body, but is greatest in the inner part, and becomes very small near the surface of the body. The accompanying figure shows a section of a plate in a transverse magnetic field. The normal layers (shaded in the figure) branch in both directions towards the surface of the plate. A similar branching along the lines of force occurs in the intermediate state of a body of any other shape.



Calculation shows that the thickness of the layers in the middle of the body is of the order of magnitude $(l_0 l^2)^{1/3}$, l being the total length of the line of force inside the body and l_0 the depth of penetration of the magnetic field in a supraconductor (probably of the order 10^{-5} cm.).

The branching of the layers towards the surface continues until the thickness of the layers becomes of the order of magnitude of l_0, when it is no longer really possible to speak of the normal and supraconducting states as distinct phases. Hence, a region of the width l_0 near the surface of the body is not in the intermediate state, that is, does not consist of layers; but is in some different state which may be called the 'mixed' state.

The conception of the alternating layers leads to the conclusion that the intermediate state must be supraconducting in the direction of the magnetic field, but has resistance in perpendicular directions. It might seem that the body should be supraconducting also in the direction which is parallel to the layers but perpendicular to the direction of the field; however, it can easily be shown that, if the current is flowing in this direction, the layers turn so as to be perpendicular to the current.

For the resistance of the intermediate state perpendicular to the magnetic field, we should have $R = R_0 \dfrac{B}{H_c}$ (B, magnetic induction; H_c, critical field; R_0, resistance of the normal state). However, experiment shows[2] that the resistance of a wire in a transverse field tends to this value only if the current is comparatively large, the resistance for very small currents being much smaller. This indicates that an appreciable part of the current flows not in the middle of the wire through the intermediate state, but in the mixed state near the surface. More detailed experiments could in this way supply information about the properties of the mixed state, about which at present very little can be said theoretically.

The detailed calculations will appear elsewhere.

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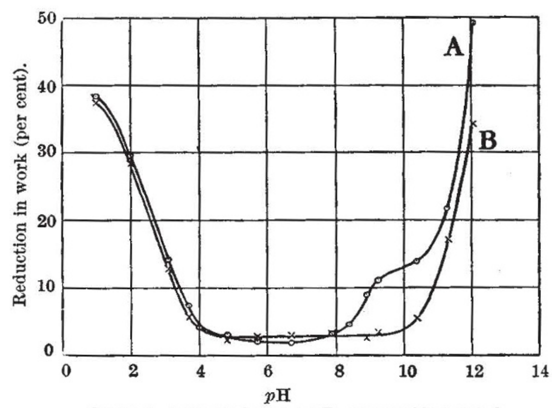
* I am indebted to Prof. R. Peierls for directing my attention to this point.

[1] Landau, L., *Sov. Phys.*, **11**, 130 (1937).
[2] de Haas, Voogd, Jonker, *Physica*, **1**, 281 (1934).

Action of Cyanamide on Wool

WHEN wool fibres are exposed to the action of light and air, the cystine linkages undergo decomposition with loss of sulphur and development of sulphydryl and aldehyde groups. In consequence, the increased alkali-combining power of the exposed tips, as compared with the unexposed roots of wool staples above pH 8, has been referred to the presence of excess sulphydryl groups in exposed wool[1]. On treatment with cyanamide, however, sulphydryl compounds are converted into derivatives of isothiourea[2], and the pH-stability region of exposed wool, which normally ranges from pH 5 to 7 in buffer solutions, should be capable of extension to pH 10 by treating the wool with cyanamide, especially as the amino groups of lysine side-chains are simultaneously converted into more strongly basic guanido groups[3].

The truth of this deduction has been established by comparing the elastic properties of untreated and cyanamide-treated exposed wool in buffer solutions of varying pH. Fibres from the middle portion of a Cotswold wool staple were purified by successive extraction with alcohol, ether and distilled water, and a curve illustrating the reduction in their resistance to 30 per cent extension at 22·2° C. in buffer solutions of varying pH, as compared with water at



Curve A, untreated; curve B, cyanamide treated.

pH 5·5, is given in the accompanying figure. The increased ease of extension between pH 8 and 10 is due to the fibre-swelling which follows combination of sulphydryl groups with alkali. When, however, the fibres had been treated with a 10 per cent cyanamide solution for 47 hours at 22·2° C., their resistance to extension was independent of pH between pH 5 and 10, as shown in the figure, owing to the conversion of cystein side-chains into corresponding isothiourea derivatives. The extent of the pH-stability region of cyanamide-treated wool, which has been confirmed by comparing the titration curves