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## ELECTROPHORETIC STUDIES OF NYLON

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## ABSTRACT

The surface electrical properties of "unoriented" and of highly "oriented" nylon fibers were investigated by a microelectrophoretic technique. Both types of fibers exhibited definite reversals of charge but at different pH values—the unoriented fiber at pH 3.9 and the oriented at pH 2.7. Since nylon consists of hydrocarbon chains linked together by amide groups, it appears that reversal of charge is principally dependent on the presence of the amide groups, especially since hydrocarbons do not exhibit reversal of sign of charge under comparable conditions. This suggests that amide groups may also influence the electrophoretic behavior of other substances, such as proteins. The difference in the electrophoretic behavior of the two types of nylon is attributed to the difference in their degrees of "crystallinity."

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## I. INTRODUCTION

The development of new synthetic textile fibers frequently makes it necessary to alter common practices in the textile industry. Thus, new fibers may require new types of scouring, dyeing, or finishing agents depending on the nature of the material. A well-known example of this was the necessity of developing entirely new types of dyestuffs to dye cellulose acetate fibers. That the development of nylon has also presented new problems is not surprising since the chemical and physical properties of this fiber are very different from those of any of the other textile fibers. A number of these problems, such as those involving finishing treatments, are dependent in part on the nature of the surface of the fibers, and more especially on their surface electrical properties. Accordingly, an investigation was undertaken of the surface electrical properties of nylon by the microelectrophoretic technique as previously used in this laboratory for studying similar characteristics of wool [1],<sup>2</sup> cotton [2], and silk fibers [3].

In addition to these considerations, it appeared that such an investigation might be of value in the general problem of interpretation of electrophoretic data of protein materials. While it has long been recognized that the net charge of proteins under ordinary condi-

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<sup>2</sup> Figures in brackets indicate the literature references at the end of this paper.

tions depends primarily on the degree of ionization of acidic and basic groups (the content of COO<sup>-</sup> and NH<sub>3</sub><sup>+</sup> groups), it has more recently been recognized that other groups may play a part as well [4]. Of such groups, the amide groups are present to a large extent in both the proteins and nylon. In the latter, however, they are practically the only polar groups and their role should be more readily interpretable than in the proteins, where many different polar groups are present.

## II. MATERIALS AND METHODS

Two types of materials were used. One consisted of the so-called "undrawn" or "unoriented" fibers which are obtained by extruding the molten polyamide from a spinneret. The second type of material was the "drawn" or "oriented" fibers obtained by stretching the unoriented fibers approximately fourfold in length.

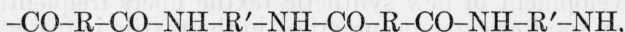
Both of these materials were extracted with ether to remove surface greases. The method of reducing fibers to a convenient particle size for electrophoretic measurements, the preparation of the suspensions, and the method of measuring the electric mobilities of the suspended particles have been described elsewhere [1, 2, 3].

All measurements were made in buffer solutions of 0.02 *M* ionic strength. In the pH range between 2.0 and 2.8, hydrochloric-acid-potassium-chloride solutions were used. Above pH 2.8, acetic-acid-sodium-acetate buffers were used.

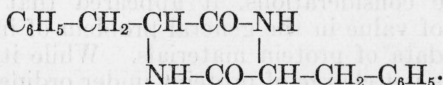
## III. EXPERIMENTS AND DISCUSSION

Figure 1 shows the mobility as a function of pH for samples of the oriented and unoriented nylon fibers. The oriented nylon exhibits a reversal of sign of charge at about pH 2.7 and the unoriented material at about pH 3.9.

Nylon is a polyamide prepared by the interaction of a diamine and a dicarboxylic acid and has the following type of structure:



where R and R' may represent 4 and 6 methylene (-CH<sub>2</sub>-) groups. Chemically, therefore, nylon consists principally of hydrocarbon chains linked together by amide groups. Presumably the ends of the chains may contain free basic or acidic groups, but the presence of such groups in a polymer of this type may be very difficult to detect [5]. Regardless of this, however, the proportion of these groups which may be expected to be free in the nylon polymer is extremely small and should not appreciably influence the behavior of the material. It appears then, that the reversal of sign of charge may be principally dependent on the presence of the amide groups, especially since a number of hydrocarbons already studied [6] have been shown not to exhibit reversal of sign of charge under comparable conditions.<sup>3</sup> A similar result was also noted earlier in this laboratory [7] in investigating the electrophoretic behavior of dibenzylidiketopiperazine. This



<sup>3</sup> The sign of charge of these substances can undoubtedly be reversed in solutions of much lower pH than are used in this work and than are generally used in similar investigations on proteins. It should also be noted that substances which do not show reversals of sign of charge in the presence of uni-univalent salts frequently do so when polyvalent ions are present.

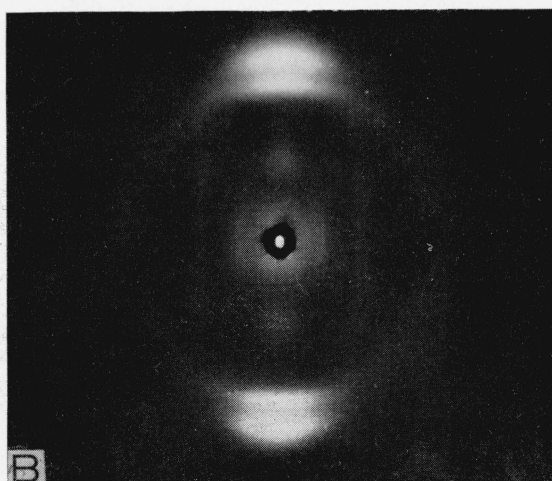
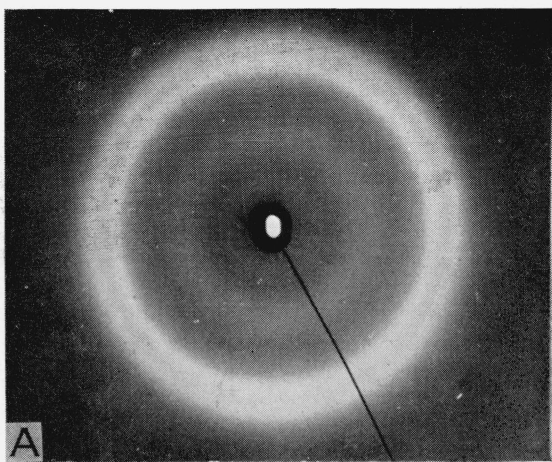


FIGURE 2.—*X-ray diffraction patterns of nylon.*  
A, unstretched; B, stretched.

substance, which is not amphoteric in the usual sense (in that it contains no free carboxyl or amino groups) but contains two amide groups, exhibited a definite reversal of charge at pH 2.9. Thus the possible influence of the amide groups on the electrophoretic behavior of some substances, such as proteins, must be given consideration, although such influence may be obscured when large numbers of acidic and basic groups are present.

That different pH-mobility curves and different isoelectric points were obtained for the oriented and unoriented nylons is of considerable interest, although it was not unexpected. Similar differences have been noted for the electrophoretic properties of other substances when

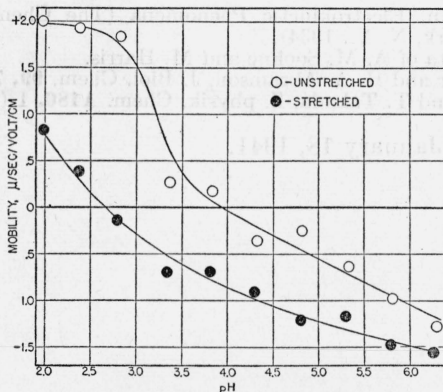


FIGURE 1.—pH-mobility curves for stretched and unstretched nylon.

studied in both the amorphous and crystalline states. Earlier work by Wintersteiner and Abramson [8] showed that the isoelectric point of amorphous insulin was at pH 5.35, while that of insulin crystals was found at pH 5.0.<sup>4</sup> It was further shown by Abramson and Moyer [4] that the isoelectric points of various amino acid crystals all occur at pH values below the values found for the amorphous or dissolved substances. Although it has not been common practice to consider fibers crystalline in this same sense, nevertheless, the X-ray diffraction patterns do indicate a far more orderly or "crystalline" arrangement in the oriented nylon, as shown in figure 2. Stretching the unoriented nylon probably produces a fairly parallel arrangement of the long-chain molecules. Such a process tends toward a maximum of interaction between the molecules, and thus changes the character of the surface. This would be expected to alter the electrophoretic mobility of the substance. On the basis of these considerations, it may be concluded that the difference in the electrophoretic behavior of the two types of nylon used in this investigation is related to the difference in their degrees of "crystallinity."<sup>5</sup>

<sup>4</sup> It was not known in this case how much adsorbed insulin was on the surface of the crystalline insulin. The difference might have been greater if no dissolved insulin had been present.

<sup>5</sup> A similar phenomenon was recently reported by Kanamaru and Takada [9], who found that the  $\zeta$ -potential of viscose varies with the velocity at which the fibers were originally spun—i. e., with their degree of parallelism.

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