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Some Observations on the Hair Cuticle

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Synopsis—Some PHYSICO-CHEMICAL PROPERTIES of CUTICLE are described and correlated to the function of the latter in the overall STRUCTURE of HAIR. Chemical analysis of the cuticular layer revealed significant differences in the amino acid composition of the cuticle and the cortex of the hair KERATIN. The cuticle is extensively crosslinked by cystine, is more hydrophobic than the cortex, and contains large quantities of serine, glycine, and proline. All this satisfactorily accounts for the function of the cuticle as a molecular sieve and a chemical barrier.

Introduction

It is not surprising that the lion's share of our present knowledge of mammalian hair structure has been derived from studies on wool, which as an industrial commodity commands the resources necessary for extensive biochemical and physical investigations. The similarity in morphology and chemical properties of mammalian fibers provides a scientifically acceptable rationale for regarding the results on wool as applicable to all of them, although such generalization from a specific case can be misleading.

For example, it has become customary to focus one's attention almost exclusively on the ultrafine structure and properties of the cortex, which is the dominant structural element of the wool fiber. However, the cortex appears to be more important in wool than it is in hair. Consequently, when one is concerned with the latter, the properties of the remaining morphological components (epicuticle, cuticle, cell membranes, medulla) should be taken more fully into account. In an attempt to do this, we are presenting here a brief discussion concerning the contribution of the cuticle to some of the physico-chemical parameters of human hair.

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Morphological Characteristics

Perhaps the most significant experimental fact which we should bear in mind at the onset of this discussion is that hair, unlike wool, is surrounded not by one, but by several (7 to 10) layers of cuticle cells (Fig. 1). Each of the cells is approximately 0.5 μ thick. Thus, on the average, a hair is encased by a 4.0-μ thick band of cuticular material. As the number

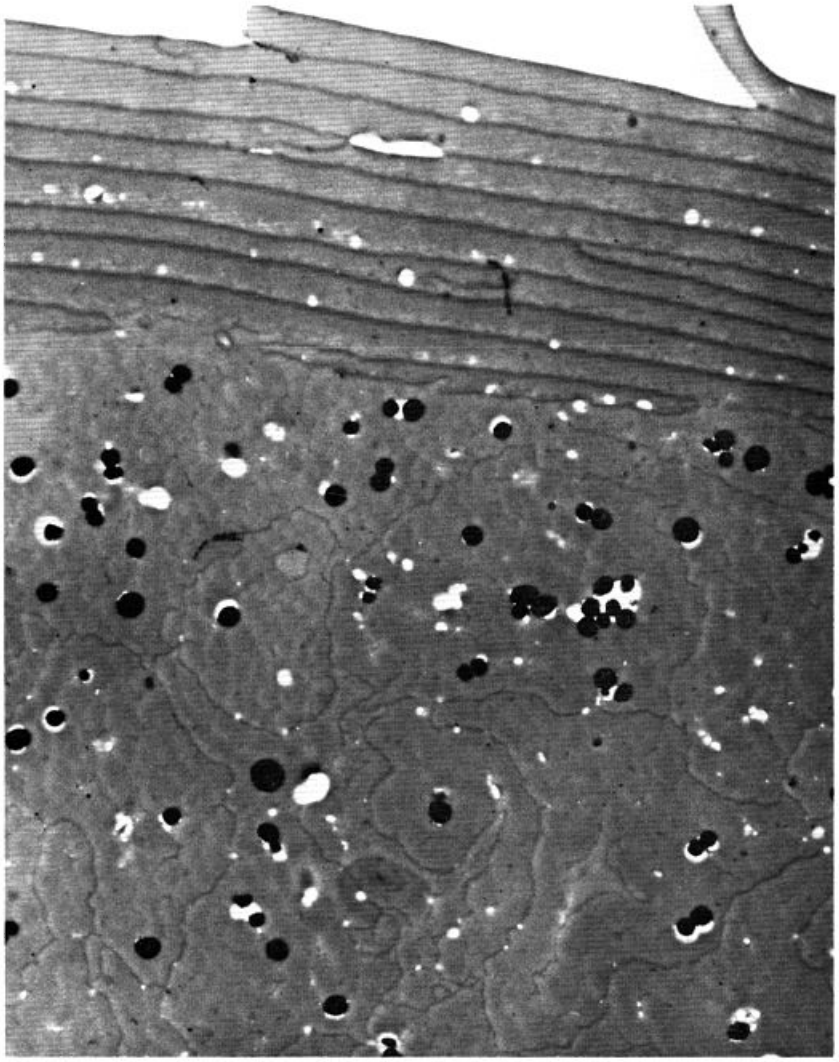

Figure 1. Transverse section of cuticle and cortex of an oriental hair. No contrast enhancing treatment was used. Magnification, 10,000

of layers and the dimensions of these cells are identical in fine and coarse hairs (Figs. 2 and 3), the fraction of the cuticular material varies with the diameter of the fiber; it may, in fine hairs, account for as much as 40% of the total weight of the hair.

The protective function of the cuticle has often been stressed. Indeed, in the case of human hair, nature, almost as if predicting some cosmetic misuse, has endowed the fiber with a formidable shield. That such a guard is an essential element of the integrity of hair is very apparent from Fig. 4. This is a scanning electronphotomicrograph of a hair fiber from which some of the scales have been abraded. The underlying filaments of the cortex are clearly visible, and the lack of any substantial lateral cohesion among the fibrils is evident. Fibrillation of the cortex occurs readily, as a result of either chemical or mechanical action. The tight ring of cuticle cells is often the only restrictive element the fiber has at its disposal.

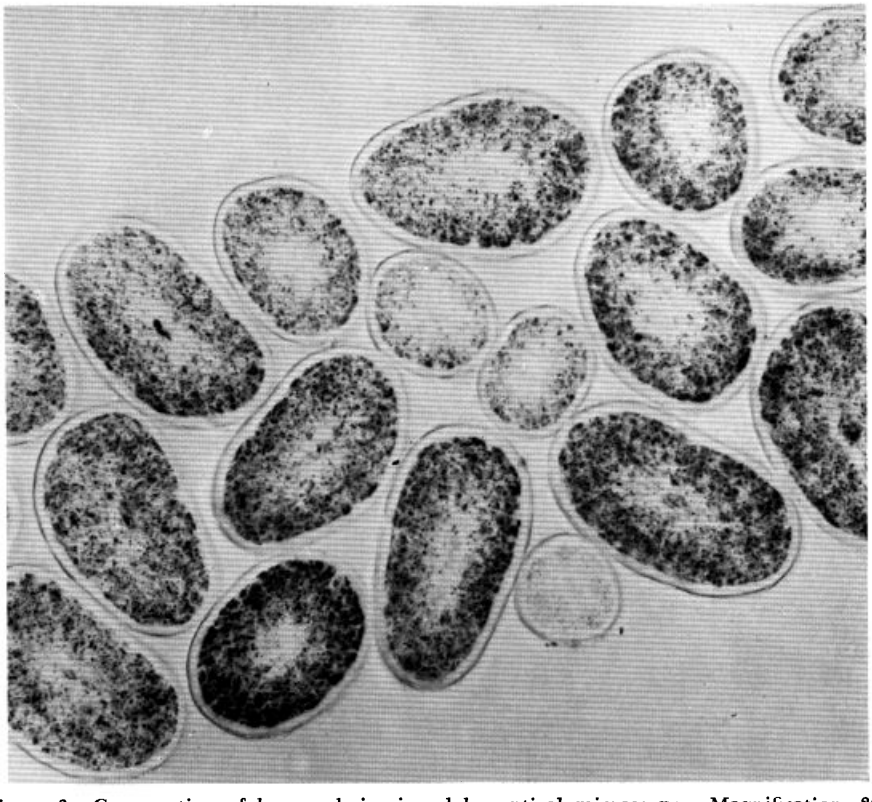

Figure 2. Cross-section of human hair viewed by optical microscope. Magnification, 360

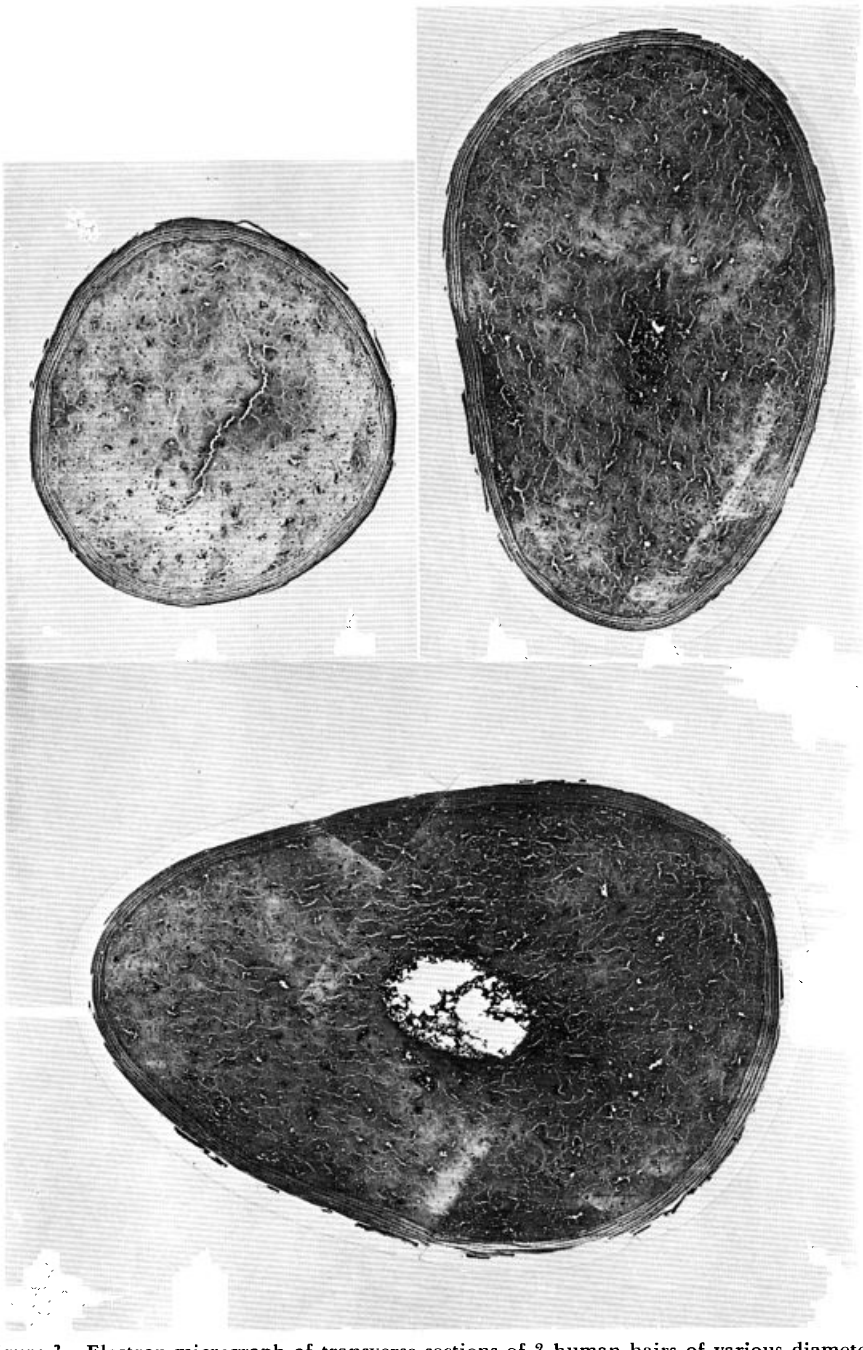

Figure 3. Electron micrograph of transverse sections of 3 human hairs of various diameters. Magnification, 950 in each case

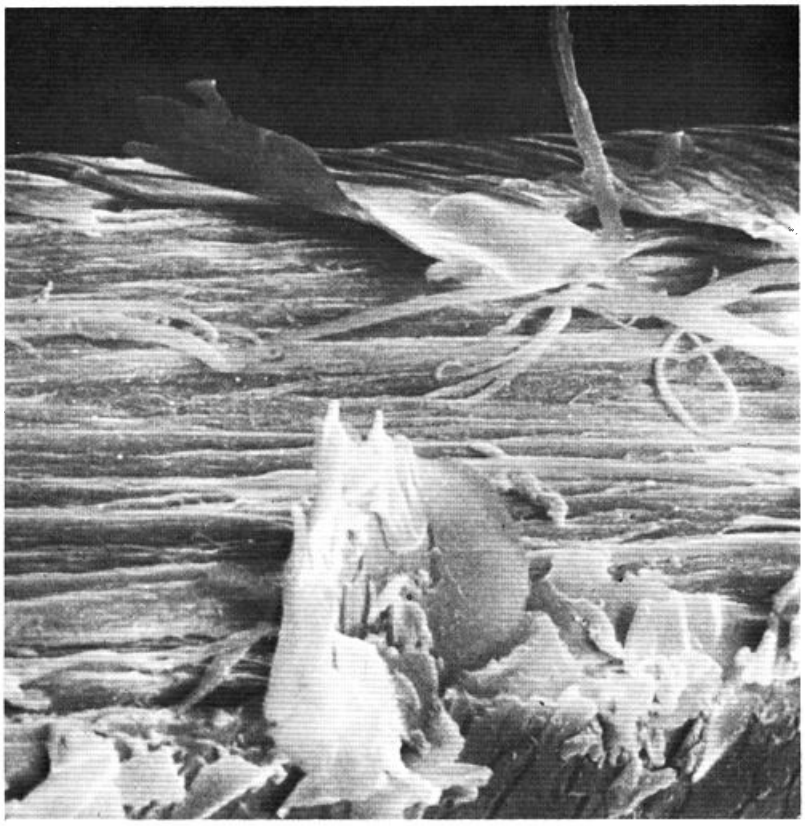

Figure 4. Scanning electron micrograph of hair abraded with a blade. Magnification, 1700

Chemical Composition and Reactivity

Several attempts have been made to determine the chemical composition of the cuticle cells after their separation by enzymatic or chemical methods (1–3). All these methods suffer because it is impossible to estimate the amount of degradation of the cuticle which had occurred during its separation from the cortex. In addition, almost all of the effort has been devoted to the analysis of wool with the result that little information is available regarding the cuticular material in hair.

Bearing in mind the relative thickness of the cuticle layer in hair an abrasion technique seemed appropriate in this case. Small tresses of Caucasian hair were scraped with a blade (single abrading stroke) and the scraped material was collected and carefully inspected under a microscope. In no case was any cortical contamination found, and it is very

likely that at the most only 3–4 cuticle cell layers were removed from the hair. The cuticle was hydrolyzed and its amino acid composition was determined. The amino acid content of the cortex was calculated based on the results of this analysis and the data for whole hair; these results are shown in Table I. The analyzed hair samples were of medium coarseness, and for the purpose of this calculation it was assumed that the diameters of the individual fibers were uniform and within the range of 65–75 μ.

The amino acid composition of the cuticle clearly differs in many important aspects from that of the cortex. The very extensive crosslinking of the cuticle by cystine and the high content of proline are indications of nonhelical organization of the protein chains. This implies isotropicity of structure in contrast to the strongly anisotropic fibrils present in the cortex. Some loss in the extent of electrostatic interactions (lower contents of basic and acidic amino acids) is compensated for by increased polarity due to the high contents of serine and glycine. Strangely enough, this intensification of polar interactions is accompanied by greater hydrophobicity.

Table I
Amino Acid Composition of Human Hair and Human Hair Cuticle

	Content in μM/g		
Amino Acid	Whole Hair	Cuticle	Cortex (Calcd)
Cysteic acid	32	59	27
Aspartic acid	399	300	416
Threonine	554	412	580
Serine	967	1628	850
Glutamic acid	916	848	930
Proline	588	900	532
Glycine	437	836	368
Alanine	347	500	370
Half-cystine	1435	1880	1350
Valine	405	644	374
Methionine	13	39	9
Isoleucine	174	186	172
Leucine	457	404	466
Tyrosine	158	134	162
Phenylalanine	124	115	126
Lysine	196	331	172
Histidine	62	53	65
Arginine	466	289	496

Bigelow (4) has recently suggested a method for determining the hydrophobic character of proteins by calculating an "average hydrophobicity" index. This index is calculated from the amino acid side chain composition and the free energy weighting factor for each residue determined by Tanford (5) from the relative solubilities of amino acids in aqueous and nonaqueous solvents. Using the data in Table II we have calculated the hydrophobicity indices for both the cuticle and the cortex, and obtained values of 750 and 598 cal, respectively. Such a large difference in hydrophobicity between two histological components of a tissue is somewhat surprising, particularly in view of the fact that for many homologous series of proteins the hydrophobicity indices seldom vary by more than 10% (6). The intensity of hydrophobic bonding increases with a rise in temperature and it appears, therefore, that the cuticle also contributes significantly to the thermal stability of the fiber as a whole.

With the preceding results in mind, there is little doubt that both the structural and chemical differences between the cuticle and the cortex are likely to be important factors governing the response of the fiber to treatments such as bleaching, dyeing, or waving. The fact that the weight contribution of the cuticle depends on the fineness of hair implies signifi-

Table II

Amino Acid Side-Chain Hydrophobicities[a]

Amino Acid	Hydrophobicity (kcal/Residue)
Tryptophan	3.00
Isoleucine	2.95
Tyrosine	2.85
Phenylalanine	2.65
Proline	2.60
Leucine	2.40
Valine	1.70
Lysine	1.50
Methionine	1.30
Cysteine	1.00
Alanine	0.75
Arginine	0.75
Threonine	0.45
Glycine	0
Serine	0
Histidine	0
Aspartic acid	0
Glutamic acid	0

[a] Data from Goldsack (6).

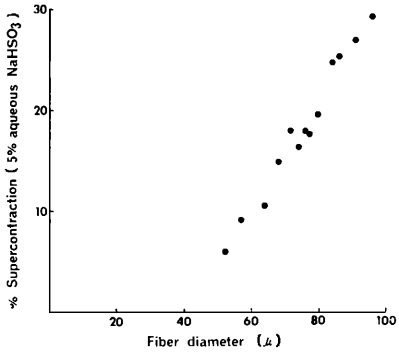

Figure 5. Effect of fiber diameter on the extent of supercontraction in 5% aqueous sodium bisulfite

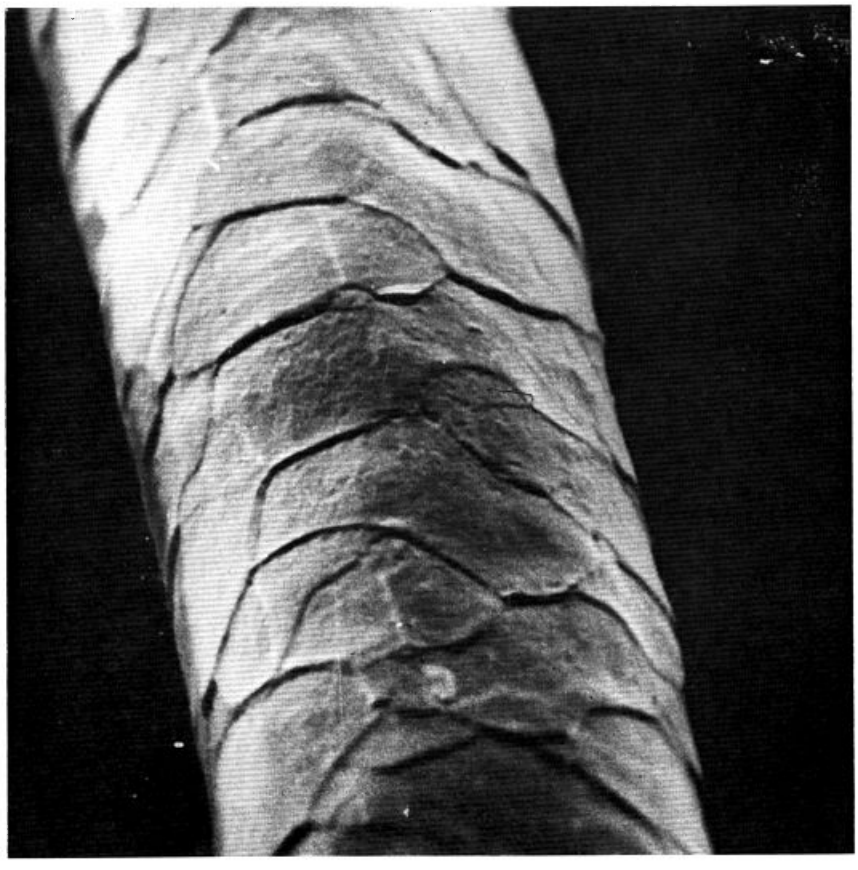

Figure 6. Scanning electron micrograph of intact mohair. Magnification, 2750

cant variation in the reactivity of hair as a function of its diameter. Experimental evidence supporting this view has been obtained by us in the course of an investigation of the supercontraction properties of hair. Fibers of varying diameter were boiled slack in 5% $NaHSO_3$ for 30 min and their contraction was determined after rinsing in water and drying. The results are given in Fig. 5. The level of supercontraction decreases with increasing relative cuticle content (decreasing diameter) of the fiber. The direct reason for this negative effect of the cuticle may be more structural than chemical. This is apparent from the scanning electron microscopic examination of supercontracted fibers. Figure 6 shows an intact mohair fiber, and Fig. 7 the same fiber after supercontraction in hot, aqueous bisulfite. The cuticle cells show little change in their dimensions but are tightly folded over to conform to the length changes

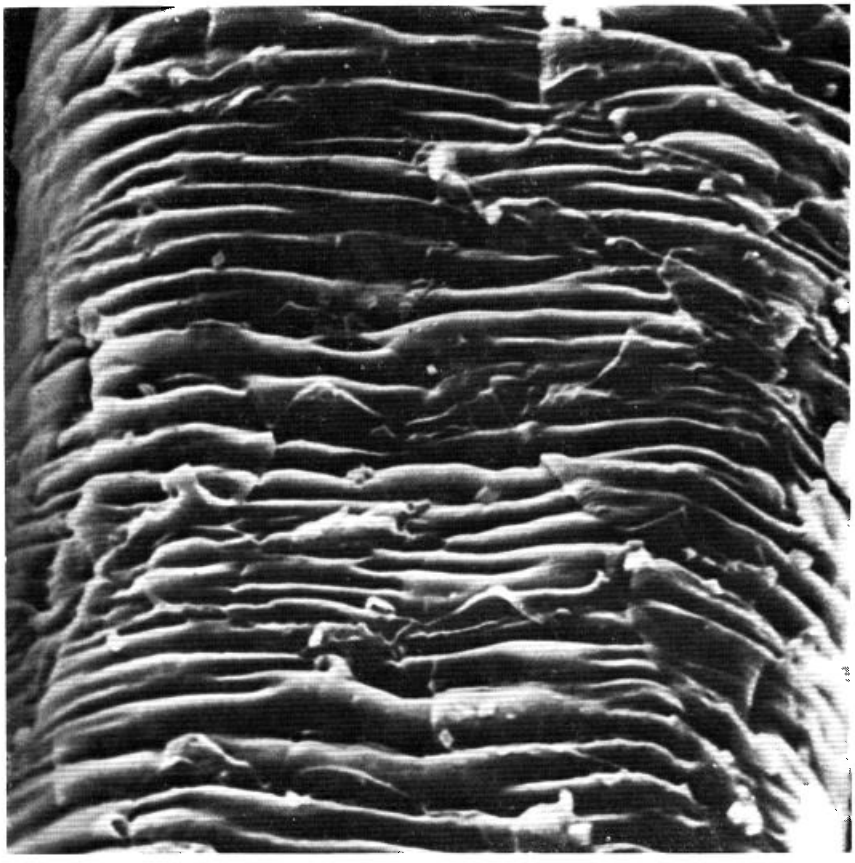

Figure 7. Scanning electron micrograph of supercontracted mohair. Magnification, 2250

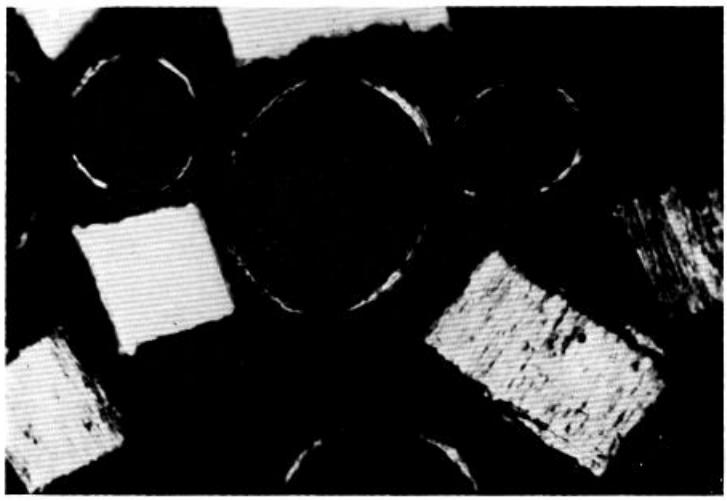

Figure 8. Cuticle birefringence observed on cross-sections of human hair in formic acid under polarized light. Magnification, 440

sustained by the contractile cortex. In wool fibers, which contain only a single layer of cuticle cells, the restraining effect of the cuticle is marginal. In human hair, it becomes a dominant factor.

The most likely explanation for the resistance of the cuticle material to contraction is its isotropic character. The breakdown of disulfide bonds (or for that matter secondary bonds) may cause an intensification of swelling, but there is no vectorial force which could develop and bring about significant change in the axial direction of the fiber.

The combination of the thickness of the cuticle and its heavy cross-linking is also responsible for the stress birefringence phenomenon which can be observed on cross-sections of hair immersed in formic acid (Fig. 8). Here again, the cuticle acts as a restraining element on the expanding cortex interior. In the course of this, some preferential arrangement of this isotropic material takes place, and this can be readily perceived under polarized light.

Mechanical Properties

The contribution of the cuticle to the mechanical performance of hair has been usually regarded as marginal, the similarity of the stress-strain curves of wool and hair being used as an argument in support of such a view. However, while the cortical elements may be dominant in the overall mechanical characteristics, it is difficult to see how a heavily cross-

Table III
Resistance to Extension of Hair of Varied Diameter

Diameter (μ)	Cuticle/Cortex Ratio[a]	Yield Stress (g/den)		Breaking Stress (g/den)	
		65% RH	pH 7 buffer	65% RH	pH 7 buffer
50.2	0.41	0.93	0.42	2.07	1.24
65.1	0.30	0.92	0.37	1.88	1.02
84.8	0.22	0.93	0.37	1.85	1.17

[a] Calculated assuming 4-μ thick cuticular band.

linked histological component amounting often to 25% of the fiber substance could be without an effect. Indeed, our preliminary experiments on fibers of varying diameters tend to substantiate a view that the response of the cuticular material to mechanical stimuli (in extension mode at least) can well be as important as that of the cortex (Table III).

The mechanical properties of dry fibers show little difference with the change of the cuticle/cortex ratio while on wetting the fine fibers appear the strongest. This may be due to a lesser hydration of the cuticle as compared to cortex, although the effect of medullation in the coarse fibers cannot be neglected. Some additional work in this area with particular attention being given to the torsional characteristic of hair appears to hold great promise.

Conclusion

In this brief discourse we have attempted to draw the attention of workers in the field of keratin chemistry and physics to some aspects of the structure/property relationship which tends often to be disregarded or treated superfluously. Owing to a strategic position in the architecture of hair, the cuticle offers a rewarding subject for study with all its structural and chemical implications. We have barely touched upon some physico-chemical aspects of its function. Viewing the results in retrospect, it may well be that the known resistance of fine hair to many chemical treatments, but particularly to waving, can conceivably be accounted for by the cuticle factor alone.

Acknowledgment

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