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Caucasian Hair, Negro Hair, and Wool: Similarities and Differences

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Synopsis—Caucasian hair, Negro hair, and Lincoln wool are compared in terms of physical structure, mechanical properties, chemical composition, and rate of reaction with various reagents.

Several significant differences are found between wool and the two hair samples. The principal one is the extent of crosslinking, which is greater in the hair, as indicated by higher sulfur and cystine contents, and a higher proportion of the material found in the γ-keratose fraction after oxidation. The heavier crosslinking is reflected in greater resistance to attack by hot acid and in slower reduction by thioglycolate or sulfite solutions.

The main difference between Caucasian and Negro hair is in fiber geometry; the Caucasian fiber approximates a cylinder, the Negro a twisted oval rod. In their physical and chemical properties, the two fibers are very similar.

I. Introduction

Human hair, the wool of the sheep, and the hairs of the various goat species of textile importance (angora, cashmere) are closely related to each other morphologically, chemically, and physically. The similarities between them are, in most respects, so close that fiber investigators at one time developed the habit of treating them as almost interchangeable. It became customary to employ human hair for studies of fiber mechanical properties directed to the understanding of wool; the following quotation (1) is typical of numerous papers of the 30's and early 40's: "Human hair was selected for use in preference to wool

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because of the greater uniformity of cross-sectional area of the fiber along its length."

The practice came to be used as the realization grew that the various animal fibers differ significantly from each other in some important respects and that consequently caution needs to be exercised in applying results obtained on one fiber type to other keratin fibers. In Section II of this paper, differences between wool and hair are discussed; published data are the main source of the survey.

A narrower fiber comparison of interest to the cosmetic chemist is that between human scalp hair of different races. In this field, literature information is scanty except for data on fiber diameter and cross-sectional shape gathered in anthropological studies (2–5). A comparison of some chemical, physical, and mechanical properties of Caucasian and American Negro hair was therefore undertaken; a standard wool (Lincoln) was examined at the same time. The results are reported in Section III.

II. Wool and Hair

In evaluating published comparisons of wool and hair, the problem of intraspecies differences comes into play. Most of the literature data are based on Caucasian hair, but in the case of wool many breeds and crossbreeds have been employed. The interbreed differences in most properties are probably minor, but in the review which follows the breed is specified wherever known.

1. *Morphological*

Both wool and hair fibers have the same main morphological components—cuticle, cortex, and medulla. The cuticle, which consists of overlapping flat scale cells about 0.5 μ in diameter, surrounds the fiber. In wool, the cuticle layer is 1–2 scale-cells thick; in hair, 5–6 cells (6). The cuticle is more resistant to diffusion of reagents than the cortex (7) and more resistant to attack by chemical reagents, such as sodium sulfide (8). It thus acts as a protective barrier to the body of the fiber against chemical as well as mechanical degradation. The greater resistance of human hair to chemical attack by many reagents (see below) is at least partly due to the thickness of the cuticular layer.

The cortex of keratin fibers consists of spindle-shaped cells, oriented along the axis of the fibers. In wool, the cortex is divided into two components, differing from each other in their structure and reactivity:*

* They are named (9) *ortho-* (the more reactive component) and *para*-cortex (the less reactive one).

in Merino wool fibers, the two portions lie side by side, each comprising about half the cortex, and are wound around each other in phase with the fiber crimp (10, 11); in crimpless wools, the *ortho* component occupies the core of the fiber, and the *para* is located around it in the form of an annulus (12). No such differentiation is noted in Caucasian hair fibers; their cortex appears homogeneous, and it resembles the *para* component of the wool fiber cortex in composition and properties (13).

The protein within the cortical cells is organized in the form of parallel microfibrils, embedded in a matrix. The microfibrils, which represent the crystalline component of the structure, contain little or no sul-

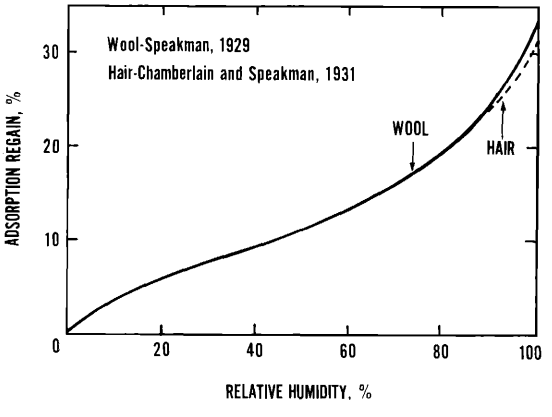

Figure 1. The adsorption regain isotherms of wool (19) and hair (20)

fur; the matrix is sulfur-rich and amorphous (14). In the *para*-portion of the fine wool cortex and in the cortex of hair, the microfibrils are packed in a hexagonal array. In the *ortho*-cortex of wool or mohair, the microfibrils are arranged in the form of whorls or spirals; the contrast between the microfibrils and the matrix, as revealed by staining with osmium, is much lower (14).

The innermost morphological component, the medulla, is not invariably present either in wool or in hair, though it is more common in hair. In any case, it is believed to make little or no contribution to the chemical and mechanical properties of the fiber.

2. *Chemical Composition*

A keratin fiber does not constitute a single chemical entity. As already indicated, a complex substructure is present even within the individual morphological components. Thus, the whole fiber is clearly

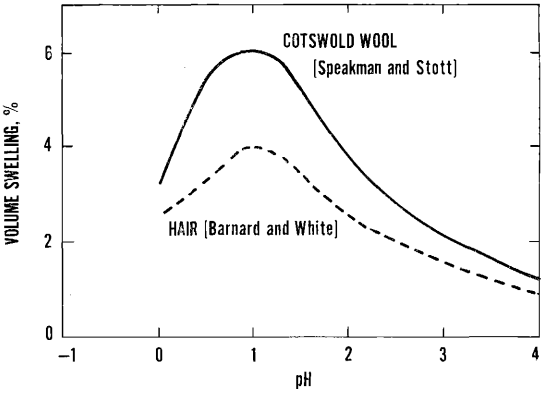

Figure 2. The swelling of wool (21) and hair (23) in aqueous HCl

a mixture of proteins, and a total analysis represents an average value.

The cuticle contains more cystine than the cortex (15), and there are differences in other amino acids, also (16); the *para*-cortex of wool contains more sulfur than the *ortho*-cortex (13). It is therefore to be expected that hair, with a higher ratio of cuticle to cortex and a cortex which is wholly *para* in nature, should differ significantly in its amino

Table I

Tensile Properties of Merino Wool and Hair at 21°C

Property	At 65% R.H. (24)		In pH7 Buffer (25)	
	Hair	Wool	Hair	Wool
Initial modulus, mg cm^{-2}	55	31	21	12
Stress at yield point, mg cm^{-2}	1.16	0.62	...	...
Stress at 20% extn., mg cm^{-2}	...	...	0.52	0.45
Extension to post-yield, %	...	...	27	29
Post-yield modulus, mg cm^{-2}	...	...	5.3	3.4
Extension at break, %	37	20	51	41
Stress at break, mg cm^{-2}	2.0	1.1	1.7	0.8

Table II

Dye Uptake of Different Fibers (7)

Fiber	Half-Dyeing Time (Hr)	Diffusion Coefficient (Arbitrary Units)
Human hair A	56	7.5
Human hair B	44	7.8
Human hair M	47	8.5
Human hair N	54	8.7
80's Merino wool	1.8	10.7
56's Down wool	2.0	17.4

acid composition from wool. A comparison of a human hair sample with those from several breeds of wool indeed shows the hair to be richer in cystine and proline and poorer in alanine, leucine, tyrosine, phenylalanine, glutamic and aspartic acids, lysine and arginine. Real, but smaller, differences are seen among the various wool samples (17).

3. *Acid Binding, Moisture Regain and Swelling*

The acid-binding of hair, which is an index of the number of basic groups present, is slightly lower for hair than for wool (18); this is in accord with the lower basic amino acid content of hair, noted above.

Wool and hair have practically identical moisture-adsorption isotherms at relative humidities up to 95%. Here, the regain* curves

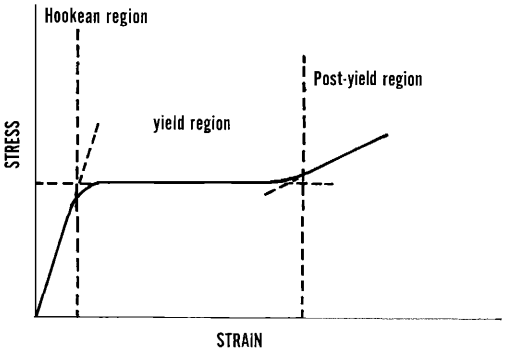

Figure 3. A typical keratin fiber stress-strain curve

diverge (Fig. 1); in saturated water vapor, wool had a regain of 33–34% (19) and hair of about 30% (20).

The difference in saturation swelling is probably a function of the extent of restraint imposed by crosslinking. The effect is shown still more strikingly (Fig. 2) when the additional swelling caused by transfer from water to a strongly acidic medium is examined: Cotswold wool (21) and 64's Merino wool (22) exhibit a volume swelling of about 6% when transferred from water to HCl at pH 1, whereas human hair swells about 3½% under the same conditions (23).

4. *Mechanical Properties*

The fiber tensile properties vary within an animal species and even from one fiber to another within a lock. One may nevertheless state

* "Regain" is the moisture content based on the dry weight of the material.

broadly that hair is somewhat stiffer, stronger, and more extensible than wool, both in air and wet. Typical data are given in Table I.

The lower elastic modulus of wool indicated by such extensometric data is due partly to the perturbing effect of fiber crimp; a greater rate of stress relaxation, made possible by the lower degree of crosslinking, may also play a part. The dynamic moduli of hair and Lincoln wool, as determined by sonic measurement, are closely similar (26).

Another mechanical parameter exhibiting a difference between wool and hair is the post-yield turnover point. When wool fibers are extended in water at different temperatures, the location of this point on the strain axis (Fig. 3) is constant up to a characteristic temperature and then shifts to higher strains; this effect has been ascribed to a second-order transition in the keratin (27). As shown in Table I, the extension at which the post-yield slope begins is similar for wool and hair at room temperature. However, the transition temperature is 72 °C for B. A. fleece wool (1), 70 °C for Merino wool, and 85 °C for hair examined under the same conditions (28). It appears that a higher temperature

Table III

Fiber Mechanical Properties in pH 9.2 Buffer—Effect of Acid (34)

	Fiber			
	Human Hair		64's Wool	
Property	Intact	Acid-Treated*	Intact	Acid-Treated*
Stress at 20% extension, mg cm^{-2}	0.49	0.23	0.44	0.13
Stress at break, mg cm^{-2}	1.28	0.46	1.18	0.19
Energy to break, g $cm^{-2} \times 10^{-4}$†	30	11	30	4
Extension to break, %	58	51	51	30

* 0.04 *N* H_2SO_4, 16 hours at the boil.

† Per unit volume.

Table IV

Acid Hydrolysis: 0.5 g Fiber in 25 ml Solution, 105°C, 18 Hours

	Residue Weight, %	
Fiber	6 *N* HCl	6 *N* H_2SO_4
Lincoln wool	0.06	0.06
Caucasian hair		
Brown	2.5	2.2
White	1.0	0.7
Negro hair	2.7	2.3

is required in hair before disulfide-sulfhydryl interchange reaches sufficient proportions to have a significant effect on the mobility of the protein chains.

5. *Diffusion of Reagents*

Human hair fibers have a larger diameter than most wools; consequently, the penetration of a reagent to the core of the fiber would take longer even if its diffusion through the keratin substance were the same. In fact, for most large molecules, such as dyes, the diffusion is slower in hair.

Data derived from measurement of uptake of an acid dyestuff at 60 °C by several fibers are shown in Table II (7). The half-dyeing time, which is affected by both the fiber diameter and the diffusion coefficient, is 25 times longer for hair than for wool.

Table V
Amino Acid Contents (Micromoles/g)

Type of Side Chain and Amino Acid	Lincoln Wool	Caucasian Hair	Negro Hair
Aliphatic	*2830*	*2350*	*2470*
Glycine	590	539	541
Alanine	601	471	509
Valine	570	538	568
Leucine	740	554	570
Isoleucine	333	250	277
Aliphatic Hydroxyl	*1020*	*1520*	*1290*
Serine	541	870	672
Threonine	483	653	615
Aromatic	*540*	*260*	*380*
Tyrosine	266	132	202
Phenylalanine	273	130	179
Acidic	*1400*	*1330*	*1350*
Aspartic Acid	575	455	436
Glutamic Acid	828	871	915
Basic	*1040*	*790*	*800*
Lysine	310	213	231
Arginine	662	512	482
Histidine	71	63	84
Sulfur Containing	*750*	*1440*	*1380*
Half-Cystine	745	1380	1370
Cysteic Acid	6	55	10
Methionine	0	0	0
Heterocyclic			
Proline	490	672	662
Ammonia	*1030*	*780*	*985*

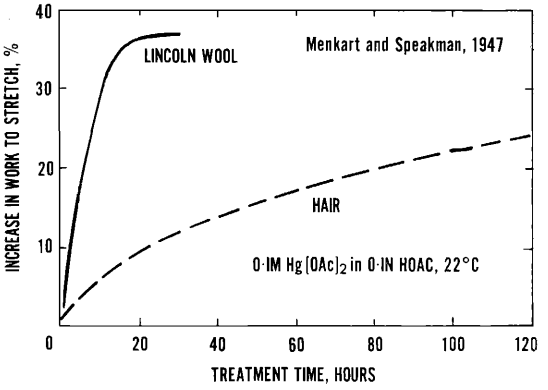

Figure 4. The rate of crosslinking of keratin by mercury, as indicated by the increase in work to stretch (29)

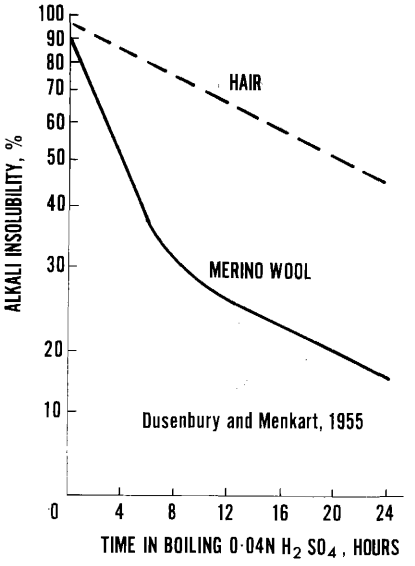

Figure 5. Alkali insolubility as a function of time in boiling 0.04 N H_2SO_4 (10)

All four specimens of human hair have very similar diffusion coefficients. Those of both wools are higher: one slightly so, the other substantially.

The phenomenon has also been examined for the action of mercuric acetate on human hair and Lincoln wool, as measured by the increase in work required to stretch the fibers as shown in Fig. 4 (29). The

slopes of the lines are in the ratio of 3.9:1; correcting for the difference in mean fiber diameter between the two substances, the rates of diffusion are in the ratio of 2.2:1. (The staining of cross-sections with hydrogen sulfide showed that reagent diffusion was indeed the rate-controlling factor.) The "half-reaction times" are 5 hours for the wool and 75 hours for the hair—a fifteen-fold difference.

6. *Rates of Reaction*

Differences in reaction rates among the keratin fibers are well demonstrated in the two standard solubility tests, in urea-bisulfite (30)

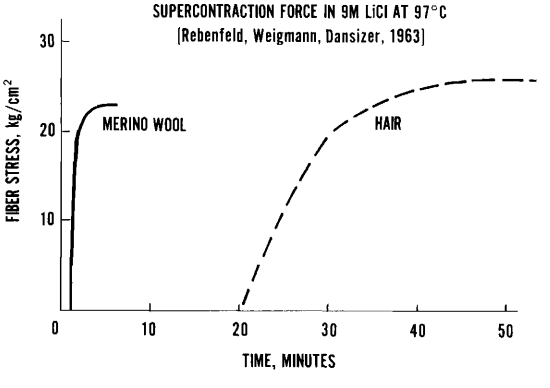

Figure 6. Rate of development of supercontraction stress (24)

and in alkali (31). The urea-bisulfite test distinguishes quite sharply between wool and hair, the former being soluble to the extent of about 50%, the latter about 15% (32).

In the alkali-solubility test, intact keratin fibers all exhibit fairly small weight losses (4–6% for hair, 10–12% for wool). The weight loss is increased by prior exposure to oxidizing agents or acids; this increase is much greater for wool (and mohair) than for human hair (10). The effect of exposure to boiling 0.04 N sulfuric acid is indicated in Fig. 5, where alkali *insolubility* (the weight fraction remaining after the test) is plotted, on a logarithmic scale, against the time of treatment with acid. The differences in ease of degradation are evident in microscopic examination: wool fibers, pretreated with acid and then examined in alkali, swell and lose their birefringence very rapidly, whereas hair is quite resistant (13). They are also reflected in the mechanical properties of the fiber, as indicated by the data of Table III (33).

Table VI
Fractionation

Fiber Type	Keratose (%)			
	α	β	γ	Total*
Merino wool (34)	56	10	25	91
Caucasian hair	43	15	33	91
Negro hair	43	14	33	90
	Sulfur Content (%)			
	α	β	γ	Whole Fiber†
Merino wool (34)	1.88	2.13	5.84	3.38 (2.72)
Caucasian hair	2.56	3.69	6.04	5.45 (3.65)
Negro hair	2.38	4.00	6.60	5.40 (3.77)

* The totals do not sum to 100%, due to incomplete recovery; the deficit is believed to reside mainly in the γ-fraction.

† The figure in parentheses represents the sum of the sulfur contents of the three fractions.

Table VII
Moisture Regain at 22°C

Fiber Type	Desorption Regain at 65% R.H.	Absorption Regain at 87% R.H.
Lincoln wool	15.4	23.4
Merino wool	14.8	...
Caucasian hair		
White	15.2	23.3
Brown	16.2	24.1
Negro hair	16.0	24.4

Table VIII
Tensile Properties

Fiber Type	Denier	Yield Stress (g/denier)	Breaking Stress (g/denier)	Extension to Break (%)
65% R.H.				
Lincoln wool	20	1.10	2.04	43
Caucasian hair	46	0.93	1.68	44
Negro hair	37	1.11	1.81	40
pH 7 Buffer				
Lincoln wool	20	0.35	1.70	65
Caucasian hair	42	0.42	1.41	47
Negro hair	38	0.46	1.24	48

7. *Supercontraction and Set*

Different animal fibers exhibit a wide range of supercontraction values after an hour's boiling in several media (35). The kinetics of the process for different fibers have been examined in 9 *M* LiCl (24) and in cuprammonium hydroxide (36) with similar results: hair has a much longer initiation period before the onset of supercontraction and a slower rate of supercontraction (or generation of tension); the level of contraction or maximum force attained is sometimes also lower. Typical data are shown in Fig. 6.

In examining the acceptance of set by stretched keratin fibers in boiling water or borax, Mitchell and Feughelman (37) found that the amount of set diminished as the fiber diameter increased. On the other

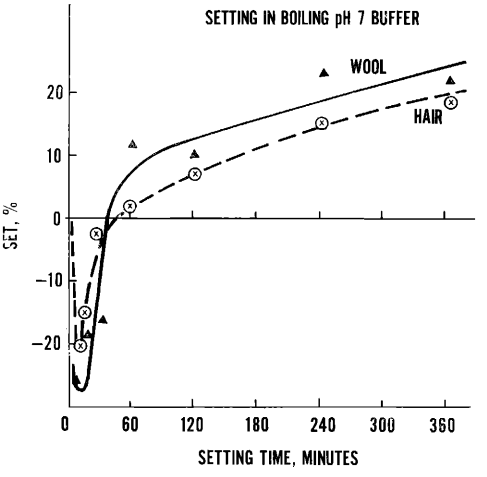

Figure 7. Rate of set generation as a function of time of setting, at 40% extension (one hour's release in the same medium)

hand, Whewell (38) reports some specific differences: in setting fibers in boiling water for 2 hours, he obtained 12% set in hair and values ranging from 6 to 21% for four samples of wool.

Data from these laboratories show that Lincoln wool accepts set more rapidly than hair. The curves of Fig. 7 illustrate the results obtained with fibers set at 40% extension in boiling pH 7 phosphate buffer for the time indicated and released for one hour in the same medium.

The amount of set is affected by holding the fiber under strain prior to exposure to the setting process; this fact was noted at an early stage of studies in this field (27). The authors find that the extent of super-

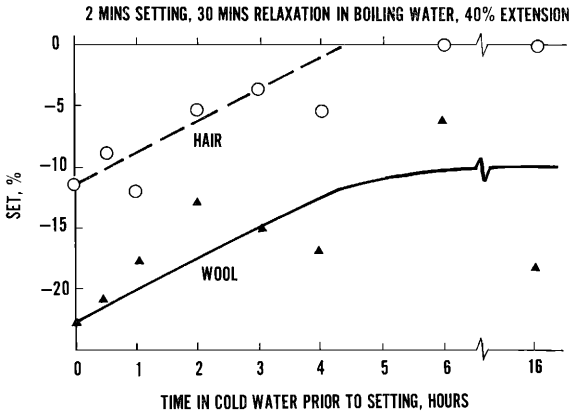

Figure 8. Set as a function of time extended, in cold water, prior to setting

contraction obtained after 2 minutes' setting at 40% extension, followed by 30 minutes' relaxation (both in boiling water), diminishes linearly with the time the fiber is held stretched prior to setting (Fig. 8); here again, hair has less supercontraction at any given time than Lincoln wool, but the decrease in supercontraction with time under tension runs in parallel for the two fiber types.

III. Caucasian and Negro Hair

A. *Materials*

1. *Caucasian Hair*—Brown European hair, from mixed women's combings, purchased from a New York hair dealer, was employed. The hair was about 28 cm long, in the "remis" state (bundled, root-to-tip oriented).

In one experiment (Table IV), white hair from the same source was used.

2. *Negro Hair*—A blended batch of barber's clippings from a Chicago barber shop, 3–6 mm long, from some thirty male heads* was the material used in all the work other than the tensile tests (Table VIII); these were carried out on fibers from one female head, purported to have had no hot combing or chemical treatment.

3. *Lincoln Wool*—This was a sample (SW 296) of one of the "Standard Wools" derived from pen-reared sheep maintained in the CSIRO

* Kindly provided by J. L. Underwood, The Toni Co., Chicago, Ill.

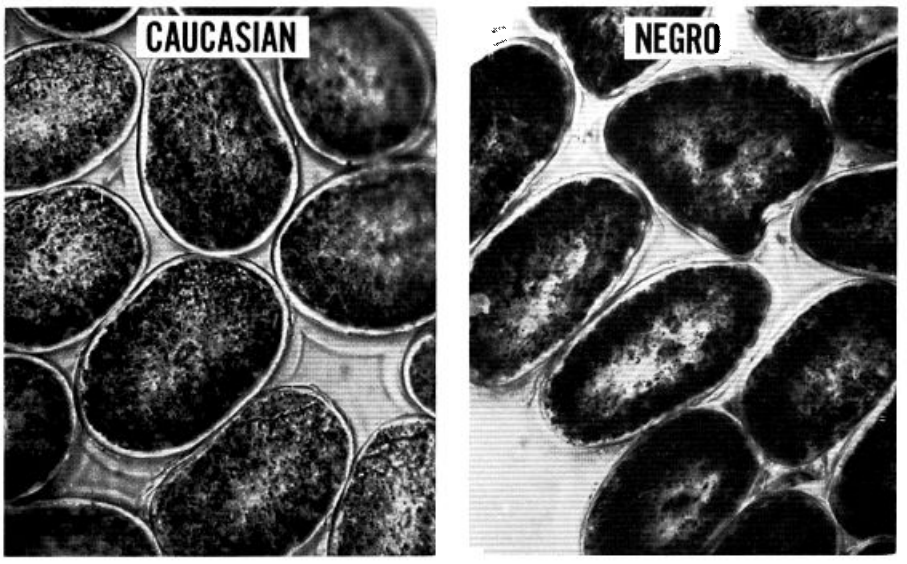

Figure 9. Cross-sections of Caucasian and Negro hair

Ian Clunies Ross Laboratory, Prospect, N.S.W., Australia (39).* This wool is essentially nonmedullated, of 36's quality (mean diameter about 40 μ).

4. *Merino Wool*—Australian, of 64's quality.

5. *Fiber Preparation*—The fibers were Soxhlet-extracted with methylene chloride for 4 hours and then with absolute ethanol for 2 hours. They were then rinsed three times with deionized water, soaked in 0.01 *N* HCl overnight, and washed in repeated changes of deionized water until the rinse water has a pH of 5. The fibers were then dried by exposure to an atmosphere of 65% R.H. and 70 °F, in which they were stored throughout the work.

6. *Reagents*—All the chemical reagents were of purified or higher grade.

B. *Results and Discussion*

1. *Morphological*—Two features distinguishes Negro and Caucasian hair at the morphological level: the irregular crimp of the Negro fiber, presumably developed by the same mechanism which is responsible for the formation of crimp in wool (40), and the more oval shape of its cross-section† which twists irregularly as it progresses along the fiber axis;

* Kindly supplied by J. F. P. James, CSIRO Division of Textile Physics, Ryde, N.S.W.

† The average ellipticity indices (ratio minor axis/major axis) for the two hair specimens of this study are: Caucasian 0.71, Negro 0.56.

fibers of irregular section are occasionally evident (Fig. 9). In other respects—thickness of cuticle, shape and size of scale and cortical cells, for example—there is no discernible difference. Mercer (11) reports finding evidence of a bilateral structure (see II, 1) in the Negro hair cortex. Observations here suggest that, if there is any such differentiation, its magnitude is much smaller than that found in wool.

Negro hair is typically heavily pigmented (Fig. 9). However, using the residue of hydrolysis in 6 *N* HCl as a measure of the melanin content (41), it appears that brown Caucasian hair and black Negro hair are very much alike (Table IV). A significant weight of insoluble material is obtained when white Caucasian hair is subjected to this test; microscopic examination of this residue shows it to consist largely of cell

Table IX
Urea-Bisulfite and Alkali Solubilities

Fiber	Solubility, %	
	Urea-Bisulfite	Alkali
Lincoln wool	52.5	10.4
Caucasian hair	27.0	5.0
Negro hair	37.2	4.1

Table X
Cysteine and Cystine Contents, %

Fiber	Original Fiber		Alkali Sol. Residue		UB Sol. Residue	
	CySH	CySSCy	CySH	CySSCy	CySH	CySSCy
Lincoln wool	0.31	9.8	0.43	0.77	0.91	4.42
Caucasian hair	0.78	17.2	0.46	2.23	1.66	11.4
Negro hair	0.66	17.8	0.46	2.57	0.96	11.0

Table XI
Acid Hydrolysis, 0.04 *N* H_2SO_4, Reflux

Fiber	Weight Loss (% After)			
			Alkali Solubility Test, Following	
	4 Hours	18 Hours	4 Hours*	18 Hours*
Lincoln wool	0.4	21.1	82.7	97.6
Merino wool	...	21.4	...	...
Caucasian hair	1.8	6.0	13.8	74.4
Negro hair	0.2	8.0	10.5	57.4

* Based on original weight, prior to acid exposure.

membrane fragments. The values of the last column in the Table show that 6 N H_2SO_4 leaves a similar amount of residue.

One racial difference in the pigment has been reported, though on the basis of a very limited sample. Using the electron microscope, Swift (42) had measured the size of isolated melanin granules and found those from Negro hair to be larger than those from Caucasian (and also Chinese) hair.

2. *Chemical Composition*—Table V lists the results of amino acid analyses, performed by column chromatography on the three fiber samples.* Acid hydrolysates were used; tryptophan, if present, was thus destroyed. Methionine was not detected in any of the samples.

The results for the Lincoln wool and Caucasian hair are in general agreement with those reported by others (17). The main interest resides in the Caucasian-Negro hair comparison. Here, the only notable differences are the deficiency of serine and threonine and the excess of tyrosine, phenylalanine, and ammonia in the Negro hair. One cannot place any meaningful interpretation on these data at present.

Another indication of the chemical structure is given by fractionation into "keratoses," using the method developed by Alexander (43), which is based on oxidation with peracetic acid and dissolution in aqueous ammonia. The fraction insoluble in the ammonia, which is termed β-keratose, is believed to consist of cell membranes and similar material. The fraction precipitated by the adjustment of pH down to 4, called α-keratose, is thought to originate from the crystalline portion of the protein and the residue, γ-keratose, from the amorphous protein of high sulfur content.

The values for the two hair samples were determined by the procedure of Corfield, Robson, and Skinner (34); the sulfur contents were determined by the oxygen combustion method of Parisot (44). The results are given in Table VI, along with those reported by Corfield *et al.* for Merino wool.

The two hair samples fractionate almost identically. Compared with the wool, they are higher in β- and γ- and lower in α-keratose, which indicates that the hair contains a higher proportion of amorphous, high-sulfur material. The sulfur contents of all three fractions are higher in the hairs, which is indirect evidence to the effect that the fractions are themselves complex mixtures of proteins and protein degradation products. Interestingly, the proportion of the sulfur content of the

* We are indebted to Dr. E. Gross of the NIAMD, NIH, Bethesda, Md., for these data.

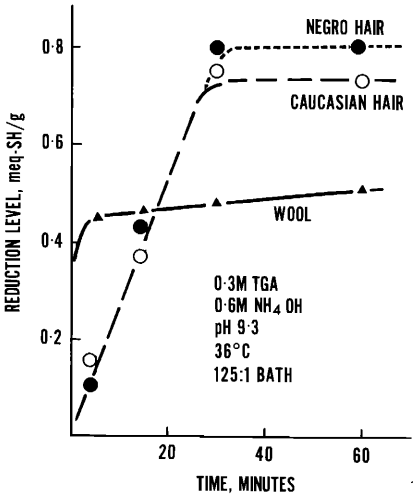

Figure 10. Rate of reduction in alkaline thioglycolate

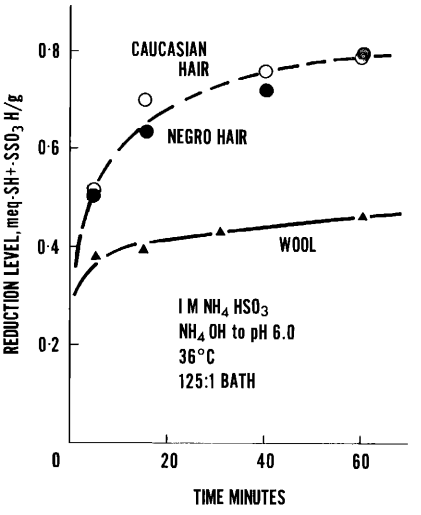

Figure 11. Rate of reduction in sulfite at pH 6

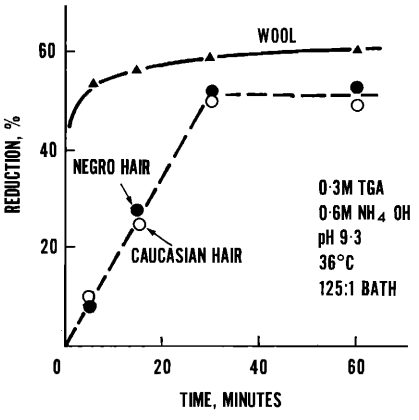

Figure 12. The data of Figure 10 replotted in terms of fraction of disulfide bonds ruptured

wool recovered in the three fractions is lower in hair (68–70%) than in the wool (78%). The proportion of material unrecovered is the same; this must, therefore, have a higher sulfur content in the case of the hair.

3. *Acid Binding and Moisture Regain*—The acid binding of Caucasian and Negro hair has been compared by Sagal (45); no difference was found. The absence of pigment has no influence on the result in either kind of hair.

Data for the moisture regain, determined under desorption conditions at 65% R.H. and under absorption conditions at 87% R.H., are given in Table VII. Only slight differences among the various fibers are seen.

4. *Mechanical Properties*—The data of Table VIII were obtained in single cycle force-extension tests to break on an Instron tensile tester, 2.54 cm fiber specimens being extended at 2.54 cm/min, the broken fibers being subsequently weighed on a torsion microbalance to establish their linear density. (As noted in Section III, A, 2, the Negro hair fibers are a different material from that used in the rest of the study.)

The two hair samples behave very similarly; the wool is stronger and more extensible—a finding in direct contrast to that in Table I. This strikingly illustrates the variability resulting from differences between samples and test procedures.

5. *Diffusion of Reagents*—Diffusion appears to be the rate-determining step in the reduction of keratin by mercaptans (46) and by sulfites (47). Thus, the rate of reduction may be used to compare the diffusion of the reagents in different fibers.

The results of such measurements at 36 °C, using ammonium thioglycolate at pH 9.3 and ammonium sulfite at pH 6.0, are given in Figs. 10 and 11. The two types of hair give practically identical curves, except for the slightly lower reduction level of Caucasian hair in the later stages of the reaction with thioglycolate; the wool is reduced much more rapidly. When the data are considered in terms of the fraction of the disulfide bonds ruptured, the equilibrium is found to be somewhat higher for wool in the case of thioglycolate (Fig. 12) and identical for all three fibers in the sulfite experiment.

6. *Rates of Reaction*—The solubilities of the three fibers in the urea-bisulfite and the alkali tests are recorded in Table IX.

As expected, the hair is more resistant to attack than wool in both media. In the UB test, a difference between the two hair types appears, the reasons for which are not clear.

When the cystine and cysteine contents of the residues from the tests were determined by the Zahn-Traumann method (48), the two hairs again behaved very similarly to each other and differently from the wool (Table X).

The response to boiling dilute acid was measured by determining the weight change (a) in the acid exposure itself and (b) in subsequent alkali solubility test. The results, which are summarized in Table XI, again show a large difference between the hair and wool, with the two hair samples quite closely matched.

IV. Conclusions

A comparison of the morphological structure, chemical composition, diffusion of reagents, rate of reaction with various agents, and setting and supercontraction behavior reveals some significant differences between wool and hair; the two hair types, Caucasian and Negro, appear very similar in all the features examined.

In acid binding and moisture regain, all the fibers are similar. The fiber mechanical properties exhibit considerable variations even within a fiber type.

The slower rate of diffusion of reagents into hair and its greater resistance to chemical modification are due to structural differences at both the morphological and molecular level; specifically, the important factors are the thicker cuticle and the more extensive covalent cross-linking of the hair keratin.

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