TEXTILE FIBER ATLAS

Von Bergen — Krauss

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A Collection of Photomicrographs of Common Textile Fibers

by

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PREFACE

"IN NO other field of technology and technical chemistry does microscopy play such an important part as in the textile industry. Without the help of the microscope the chemist and technologist would be powerless when confronted with today's demands in regard to the differentation and identification of fibers in fabrics." This statement was made by Hoehnel in 1887, repeating a statement already made by Schacht 25 years earlier!

Today, with the labeling of fabrics, an established practice in the United States, the usefulness of the microscope is even greater, especially that in addition to the natural fibers, a number of entirely new fibers have appeared.

The purpose of this Atlas is to present for the first time, a set of photomicrographs of all important textile fibers. The idea originated from a series of photomicrographs used in the Forstmann Woolen Company Laboratory for the identification of wool and related fibers. The only Atlas we know of, covering the vegetable fibers, was published by A. Herzog in Munich in 1908. The Atlas in its present form is the result of combining the entire series of plates and articles which were published in the Rayon Textile Monthly during 1940 and 1941. Due to present conditions and the fact that the authors are engaged in defense work, the Atlas is not as complete as originally planned. However, so many requests for complete sets of this series of articles have been made, that it was decided to revise the articles and to reprint them in a loose leaf form. This form enables the preparation, from time to time, of new and supplementary plates which may be purchased and added to the Atlas, to keep it up to date.

It is very difficult to illustrate all the main characteristics of textile fibers necessary for their proper identification. The selection of these photomicrographs was made on the basis of twenty years' experience in the field and in those cases in which the authors did not feel competent to do the work, pictures were obtained from various other sources. We are especially grateful for the photographs and data we obtained from Dr. R. Webb of the Cotton Division of the United States Department of Agriculture, W. D. Appel of the Textile Section of the National Bureau of Standards; Dr. M. Harris of the Textile Foundation, and C. J. Huber of the United States Testing Company.

The text is, as much as possible, limited to a description of the properties that can be established microscopically since a number of excellent books on textile microscopy such as "Textiles and the Microscope" by Dr. E. R. Schwarz, give the necessary details in regard to microscopical technique.

In addition to the photographic reproduction of fibers, the most valuable tool for proper fiber identification and differentation is the measurement of fiber dimensions. In the past few years considerable improvements have been made in

PREFACE

these measurements. The improved technique makes it possible to measure the great number of fibers necessary to obtain a reliable mean in a short time. The importance of these methods is best illustrated by the fact that the United States Government accepted them as standard methods and that they are in daily use by government agencies such as the Quartermaster Depot, as well as in most textile mills. The best methods were developed in connection with wool research done to find a quick and accurate method of judging fineness. As the same methods were used by the authors in their research to establish the fineness variation and grades of many other fibers, it was felt essential to describe the procedure used in detail. Special emphasis is placed upon the discussion of the methods suitable for analyzing fabrics containing reprocessed and reworked wool. A valuable contribution of the Atlas is the color plate made by George Moro illustrating the cross-section of a fabric containing reworked wool.

The table showing the comparable scale for fineness of various textile fibers which was prepared for the first edition of the American Wool Handbook has been carefully revised.

A chart, illustrating the direct relationship between wool grades and the various staple fibers will, no doubt, be of special value.

The nomenclature, prolons and synthons, given to man-made protein fibers and to nylon and vinyon may be revolutionary. *Prolon* has been suggested as a generic term for fibers made from a natural protein base by F. C. Atwood of Atlantic Research Associates. *Synthon* was suggested as a generic term for fibers made from organic substances which in turn have been synthesized from simple raw materials, by Dr. H. deWitt Smith in a speech at the Textile School of the N. C. State College in May, 1941.

The authors wish to express their appreciation to the Forstmann Woolen Company and to Sears Roebuck & Company for the use of their technical equipment in the preparation of the plates.

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CONTENTS

NATURAL ANIMAL FIBERS

WOOL

Plates I and II

THE wool fiber is the hair of the sheep and forms the protective covering of the animal. The latest information concerning the fine details of structure of wool fibers was published by Hock, Ramsey and Harris.

A growing fiber consists of a root and shaft, the former being the living region situated beneath the surface of the skin, whereas the latter is the non-living portion that extends above the skin surface.

The root has a scallion like shape. The shaft is cylindrical and tapers to a point at its free end, provided the fiber has not been cut previously.

Since the cells of the root are alive and growing, whereas the cells of the shaft are dead, there exist profound physical and chemical differences between these two regions of the fiber. Several of these differences can be revealed by microchemical color tests. The differences established between the root and shaft are as follows:

Root	Shaft
Soft and easily crushed.	Tough and horny.
Cells roundish.	Cells elongated.
Positive test for nucleic acid.	Negative test for nucleic acid.
Nuclei stained with hematoxylin.	Nuclei unstained with hematoxylin.
Cytoplasm granular in appearance.	Cells distinctly fibrous.
Not birefringent.	Birefringent.
Positive test for sulfhydryl groups.	Negative test for sulfhydryl groups.
No Allwoerden reaction with chlorine water.	Many large Allwoerden "sacs."

Increase in length of the fiber is brought about by the proliferation of new cells in the root and the subsequent emergence of these cells into the shaft. The shaft is composed of dead cellular units which usually are arranged in three layers—the epidermis, an outer layer of scales, a middle region called the cortex, and a central core or medulla. See Cross-sections, Plate I.

EPIDERMIS: The outside or surface of the fiber is made up of flat irregular horny cells or scales. They overlap like the shingles of a roof with the free end projecting outwards and pointing towards the tip of the hair causing the surface of the fiber to present a "serrated" appearance. (See Plate I.)

Depending on the diameter of the fiber the number of scales necessary to cover the circumference of the fiber varies considerably. The average height of the scales is approximately twenty-eight microns and the average width approximately thirty-six microns. The thickness varies between 0.5 and 1 micron. In the finest wools each one of the scales is large enough to encircle the shaft of the fiber giving the impression of flower pots set into each other. With increased fiber diameter the number of scales necessary to cover the circumference increases proportionally. Except for a few indistinct markings on the surface, individual scales show little evidence of internal structure. The scales are arranged either shingle-like, overlapping longitudinally and circumferentially or in a manner whereby the surface of the fiber is given a tile-like appearance. These different types of epidermis may be found in the same hair. The visible scale height is an important characteristic for differentiation between wool and related hair fibers, such as mohair and camelhair. In fine wools these visible scale lengths are 8-10 microns. In coarse wools, the scale length may increase up to 18 microns. This decreases the overlapping of the scales and gives the entire fiber a smoother appearance. As the free edges of the scales fit into each other very closely, coarse wool is usually more hairlike and lustrous in texture. The number of scales per 100 microns or 1/253 of an inch average from 10 to 12, but may vary from 6 to 14.

CORTICAL LAYER: The cortex is found below the protective epidermis scales. It constitutes the principal body of the wool fiber and is made up of long, slightly flattened and more or less twisted spindle shaped cells. The average size of these cells varies from 80 to 110 microns in length, 2 to 5 microns in width and 1.2 to 2.6 microns in thickness. Cortical cells liberated from the fibers by the action of chemical agents show fimbriated ends and they are in most cases prominently striated. Hock has shown by micro-dissection that the striated appearance of the cortical cells is due to the presence of many fibrils which can be separated with microneedles. Near the center of each cell is a nucleus which has a granular structure. Between crossed nicols, the fibrillar part of the cortical cells appears birefringent, whereas the nucleus does not.

Nuclei are not easily observed in untreated cross-sections, but are clearly visible after the latter have been properly stained or swollen. In some of the cross-sections on Plate IV, which were dyed with Orange II, the outline of individual cortical cells and their nuclei can be observed. When wool fibers are mounted in water these longitudinal striations are clearly visible through the epidermis.

MEDULLA: In medium and coarse quality wools a third layer is found within the cortical layer, a cellular marrow or medulla. It is built up of many superimposed cells of various shapes, often polygonal, resembling a honey comb. The diameter of the cells varies from 1 to 7 microns.

Various porous channels pass through the medullary cells which are normally filled with air. The shape and size of the medulla varies greatly. It may consist of a single chain of cells or of several series arranged side by side constituting from 10 per cent to over 90 per cent of the volume of the wool fiber. According to the cell arrangement the medulla is classified as (c) continuous, (b) interrupted, and (a) fragmental medulla. (See Plate I.)

FINENESS: The average fineness of the wool fiber is the dominant dimensional characteristic. The diameter of the wool fibers vary greatly ranging from 10 to 70 microns. In carpet wools kempy fibers are usually present, the diameter of which varies from 70 to 200 microns. (See Plate II.)

The fibers not only vary between themselves, but they also vary considerably in shape and diameter over the whole length. The part nearest to the skin always shows the least diameter, whereas the middle or end is usually one or more microns coarser.

CROSS-SECTION: The cross-sections as seen in Plate No. II, illustrate the great variation in the shape of the fibers. Fine fibers are nearly circular, while others are irregular and have a varying degree of ellipticity.

The average ratio of the major to the minor axis known as the contour figure varies between 1.2 and 1.3. In kemp fibers this figure may increase to 3, as they are of a ribbon-like, irregular form.

NATURAL COLORED WOOL: The natural colored wools are recognized by the presence of pigments in the cross-sections, which are distributed through the cortical and medullary cells. There are two forms present: a diffused or non-granular, and the granular pigments. The darker the fiber, the greater the amount of pigment present. (See Plate II.)

RAW WOOL: The raw wool fibers, as clipped or pulled from the skin of the sheep, are surrounded by grease and dirt.

LAMB'S WOOL: A high number of tapering ends in a wool sample is characteristic of lamb's wool.

SHORN WOOL: Flat, cut ends indicate that the animal from which the wool was derived has been previously shorn.

PULLED WOOL: Pulled wool is identified by the presence of a high number of deformed and twisted root ends. Many of them are surrounded by minute particles of skin tissues and a dried up crust of salts used in the depilatory processes.

These root ends should not be confused with root ends and skin pieces which may be occasionally present in fleece wool due to shedding and careless shearing. Proper identification is possible through a swelling reaction with 0.1 Normal/Caustic Soda. Pulled wool roots hardly swell, whereas the root and skin particles of fleece wool increases in size 50 per cent or more.

According to the fineness distribution, wool can be classified into four main groups:

1. Fine wool, with approximate average diameter limits from 17 to 23 microns.
2. Medium wool, with approximate average diameter limits from 23 to 33 microns.
3. Coarse wool, with approximate average diameter limits from 33 to 42 microns.
4. Mixed or carpet wools are a mixture of group 1 and 3 wools. The fine, short wool forming the undercoat and the coarse, long wool forming the outercoat. In addition, various percentages of kemp fibers are present. Depending on the land of origin and the breed the average diameter varies in wide limits between 20 and 50 microns.

For trade purposes this classification is not specific enough, and, therefore, these main groups are further subdivided. Distinct systems of nomenclature are used, according to the country they originate in, such as the Blood or American system, and the numerical or English system. The following table illustrates the various designations for wool grades used in this country, and their approximate relationship to each other:—

Approximate Comparison of Wool Grades Used in the United States

U. S. Domestic		*English*	*French*	*German*	*U. S. Pulled*	*Approx. Microns*
Fine	80's	80's	—	AA	AA	19.0
Fine	70's	70's	110	A	AA	20.0
Fine	64's	64's	105	AB	AA	21.5
	62's	—	PM	—	A	23.0
½ blood	60's	60's	PC	B	A	24.5
½ blood	58's	58's	I	C^1	A	26.0
⅜ blood	56's	56's	II	C^2	B	27.5
	54's		III	D^1	—	29.0
¼ blood	50's	50's	IV	D^2	B	31.0
¼ blood	—	48's	V	E^1	B	33.0
Low ¼ blood....	—	46's	VI	—	C	35.0
Common	—	44's	—	E^2	C	37.0
Braid	—	40's	—	—	C	38.5
Braid	—	36's	—	—	C	40.0

OFFICIAL UNITED STATES STANDARDS FOR GRADES OF WOOL

Plates III and IV

The average fineness of the wool fibers immediately affects its value for manufacturing purposes. One of the principal problems of the wool research was to find a quick and accurate method of judging its fineness.

Sheep do not produce wool in a condition immediately suitable for yarn requirements, each fleece carries strikingly different qualities of wool, and *no two fleeces*, even from the same type of sheep and the same producing district, are exactly alike in quality and quality distribution. If the manufacturer were to use the fleece in its original form he could only produce coarse and uneven yarns.

From these facts it is obvious that prior to processing, the fleeces must go through a sorting process. Sorting, therefore, consists of subdividing a fleece into its different qualities, the number of "sorts" made depending on the character of the fleece and the standard of yarn required. In present commercial practice the routine grading of wool is done by men of long experience in the industry, who by merely handling and observing the material assign it intuitively to its proper grade. Such an estimate has many sources of error principally based upon mental and physical qualities of the sorter. At the same time other factors, for example: light or color and luster of the hairs, considerably influence the result. Through experience we found that by a weak light the estimate is too fine and by direct sun, it is too coarse. Because of all these disadvantages, for more than one and a half centuries the replacing of the system of manual sorting by a system of measurements in a scientific manner has been felt necessary.

In July, 1926, the U. S. Department of Agriculture promulgated the Official Standards of the United States for Wool and Top. After the adoption of this standard, the scientist had a foundation upon which to build an accurate method of measurement.

The most astonishing results were found by Winson as he carried out a painstaking research on the measurement of the standard top. He found that for a range of selected British tops (the same tops were used in making up the U. S. master set) the progressive scale of fineness ascending from 48's to 80's quality is in geometric progression. A similar relationship was found for the French, German and Italian standard tops and it proved that the fundamental basis underlying wool sorting was the same in all countries.

In 1860, Fechner in his "Elemente der Psycho-Physik" put forward the law now known as the *Fechner-Weber law,* which states: "In order that the intensity of a sensation may increase in arithmetical progression the stimulus must increase in geometrical progression." This law, holding good between certain limits only, is expressed in his general formula $I = C \log S$, where I represents the sensation, S the stimulus and C is a constant. If we regard the wool sorter's judgment as indicative of I, then it must immediately follow that any attempt on his part to form a gradation of fineness will result in a scale in which successive finenesses increase in geometrical progression. This is exactly the case in practice and in all countries.

It can be said that for the normal operation of the wool sorter the Fechner psycho-physical law is the fundamental basis of this work; therefore, for wool sorting the eye in the visual sense is the paramount factor.

For the wool top trade the United States Government, Department of Agriculture, has issued specifications covering the grades from 80's to 50's. These became effective January 1, 1940, and represent the fruits resulting from the enormous amount of wool research done to find a quick and accurate method of judging the fineness of this commodity.

To the original standard of 12 grades, a 13th was added, namely, 62's which had long been used in the American top trade. The standards today comprise 13 grades namely: 80's, 70's, 64's, 62's, 60's, 58's, 56's, 50's, 48's, 46's, 44's, 40's and 36's. Eight of the grades, from 80's to 50's are stated in terms of the average diameter of fiber and the distribution of fiber sizes as determined by microscopical measurements.

Whereas the previous standard top was produced from foreign wools, the first eight grades of the new top contain 100 per cent domestic wool. The selected lots as submitted by the trade were approved after microscopical measurements had been made by five mill laboratories and the Department of Agriculture and reasonable agreement had been obtained in the result. In this work over 86,000 measurements were made, using the width method as issued by the American Society for Testing Materials, Designation 472.

The cross-sections shown in Tables III and IV were made from the new government standard top samples and illustrate clearly the difference in the fiber size between the thirteen grades.

Methods of Tests

In the government method the determination of conformity of wool top with the grade required may be made by comparison or by measurement. In order to make a comparison method possible the department has issued practical forms as demonstrator types in accordance with customary trade and industry practices and procedures. The methods of test by measurements described by the U. S. Department of Agriculture follows in general that published by the American Society for Testing Materials (D 472-40) and by the National Association of Wool Manufacturers Bulletin, Volume 64.

Methods of Measuring

OPTIONALS.—The measurement of the test samples shall be made by the Width Method or Cross Section Method in accordance with the procedures hereinafter set forth.

Test Units

Number of fibers per test sample.—The minimum number of fibers required for each test sample shall be in accordance with the schedule given in table 1.

Number of fibers per determination.—The minimum number of fibers required for each determination shall be the number prescribed in table 1 for each test sample times the number of test samples submitted.

Number of fibers per test specimen.—The number of fibers comprising a determination shall be measured in units of 100 fibers for each test specimen.

Location of test specimens.—The test specimens shall be taken at random from various parts of the sample.

Width Method

PRINCIPLE—The width method employs the principle of the projection of the magnified longitudinal image of the fiber onto a wedge scale on which the width of the magnified image is recorded. The observations so made form the basis for the computations.

MICROSCOPE.—The microscope shall have a focusing stage, a fixed body tube, be built for projection, and be equipped with an 8 mm. objective and a 12.5 X eyepiece. For purposes of fiber measurement, the microscope shall be calibrated at a projection distance giving a magnification of 500 diameters in the plane of the projected image.

Note. Magnifications less than 500 *X may be used, but the dimensions of the wedge scale and projected field must be reduced proportionately.*

WEDGE SCALE.—The wedge scale shall consist of a strip of white paper or cardboard of suitable thickness, imprinted with diverging lines, to form a wedge having the dimensions shown in figure 1.

Note. A convenient wedge scale, of the dimensions shown in figure 1, *can be obtained from the Agricultural Marketing Administration.*

PROJECTED FIELD.—The portion of the projected field in which measurements are to be made shall not be larger than a circle 4 in. in diameter, centrally located in the projected field.

Preparation of test specimen.—The prepared test specimens should contain at least 120 fibers. For purposes of preparation of the test specimen, a strand of fibers approximately ⅜ inch in diameter is separated from the carded sample, if in sliver form, by pinching with the fingers or suitable forceps and the gripped section cut to 1 in. to 2 in. in length, figure 2 (a). From this portion, cut with scissors, razor blade, or scalpel, a small section of approximately ½ in. in length, figure 2 (b). Spread the fibers more or less uniformly with the aid of dissecting needles, taking care that none of the fibers in the final test portion is lost. If necessary, trim the fiber sheet thus prepared, figure 2 (c), and mount in glycerol C.P. on a glass slide, covering the fibers with a cover glass. The final arrangement of the fibers on the slide should be similar to figure 2 (d). If the sample is not in sliver form, small pinches of fibers should be taken at random from various parts of the sample for preparation of the specimen.

MEASUREMENT PROCEDURE.—After the slide is in place, move it by means of the mechanical stage until the extreme left or right hand edge of the cover glass is projected in the measurement circle. Disregarding the first few fibers, bring the image of a fiber into sharp focus on the wedge scale, adjusting the position of the scale until the image of the fiber is projected between the two lines of the wedge. Place a mark on the wedge scale at the point at which the width of the image and the width of the wedge correspond, figure 3. (The image of a fiber which is not uniform in width may be measured at a point which appears to be the mean value between the greatest width and the least width, figure 4.) Bring the images of the other fibers successively into focus and record until 100 fibers have thus been measured. Repeat the above procedure on additional test specimens until the required number of fibers per test sample as specified in table 1 has been measured.

CALCULATION.—From the observations recorded on the wedge scales, compute the distribution and average mean width or diameter of fiber in microns in accordance with the requirements of table 1. The calculations may be facilitated by condensing the observations into classes of 2½ microns. An example of the calculations for fineness is shown on page 11.

Cross-section Method

PRINCIPLE.—(a) In the cross-section method, the image of the cross section of the fibers is projected through a microscope upon sensitized paper at a magnification of 500 diameters. The sensitized paper is then developed, fixed, and dried. The images of the fibers on the paper are measured in two directions at right angles to each other by means of a celluloid wedge measure, graduated to read directly in microns, or by means of a bidiameter scale.

(b) For direct measurement the image of the cross section of the fibers may be projected on a sheet of white paper and the images of the fibers measured in accordance with paragraph (a).

APPARATUS.—(a) Microscopes.—Laboratory and dissecting microscopes and a projection microscope as specified previously will be required.

(b) Cross-section device.—The cross-section device illustrated in figure 5 shall be used in making the cross sections of the fibers. It consists of two parts—the fiber holder C with the fiber slot, and the slide holder D in which is rigidly held a flat-surfaced metal plunger with right angle flanges to fit in the slot of the fiber holder (sliding fit). When assembled, the shape of the cross-section device is that of a microscopic slide, 1 in. in width and 3 in. in length. The guides on each side of the slide holder keep the fiber holder steady and help hold the fiber and slide holder together, as shown in the side view, B, figure 5.

(c) Wedge measure.—The wedge measure illustrated in figure 6 shall be made from celluloid 0.0020 in. in thickness.

(d) Bidiameter scale.—The bidiameter scale, figure 7, shall be made on a 2- by 2½-in. piece of glass. The scale rulings shall cover an area of 3 by 4 cm. Each small division of 1 mm. is equal to 2 microns at a magnification of 500 diameters. The surface upon which the scale rulings appear shall be protected from being scratched by affixing a narrow strip of celluloid on each of the 2-in. edges of the scale.

TEST SPECIMEN.—Test specimens shall be prepared in the following manner: Separate a strand of about 150 fibers from the sample figure 2 (a), taking care not to disturb the distribution of the fibers as they occur in the sample. Insert this strand of fibers in the fiber holder and push the slide of the slide holder into the fiber slot until the fibers are held securely in place. The slide of the slide holder should have just sufficient tension upon the fibers to hold them without distorting their shape. With scissors, cut the fibers off close on both sides of the fiber holder. Apply a drop of celluloid solution on one side and allow to dry. Then cut the fibers off flush on both sides of the fiber holder by means of a sharp razor blade, the edge of which shall appear smooth and free from nicks when examined under the microscope at a magnification of 100 diameters. When cutting the fibers, keep the bevel of the razor blade parallel to the surface of the fiber holder. This may best be accomplished by using a binocular microscope, magnifying about 12 diameters. After the cross section is made, examine it under a microscope at a magnification of about 300 diameters. When the fibers are all smoothly cut and each fiber is clearly defined, the cross section is ready for projection.

PROCEDURE.—(a) Projecting cross section of specimen.—With the projection microscope set for a magnification of 500 diameters, the cross section device shall be placed on the stage of the microscope and the image of the cross section of the specimen shall be focused through an orange-colored filter upon a sheet of white paper. The illumination shall be uniform for different cross sections. To obtain this condition a filter of the proper depth of color should be used according to the intensity of the light passing through the cross section.

(b) Measuring fibers for fineness.—The cross section of the fibers, section 20 (a) or (b), shall be measured in microns for their greatest and least diameters, at right angles to each other. The first few fibers near any edge of the cross-section device shall not be measured. Measurement of successive fibers without skipping, shall be made in accordance with paragraphs (c) or (d) until 100 fibers have been measured.

(c) By means of the celluloid wedge measure (figure 6) the cross sections of the fibers shall be measured in microns for their greatest and least diameters, at right angles to each other. The horizontal unnumbered base line is kept tangent to the periphery of the cross section of the fiber. Keeping this line tangent, the measure is moved until one of the numbered sloping lines becomes tangent. This setting of the wedge measure gives the diameter of the fiber in microns. To facilitate the use of the scale and shorten its length, three sloping graduated lines appear on this measure.

(d) By means of the bidiameter scale (figure 7) the greatest and least diameters of the cross section of a fiber shall be measured as follows: Place the extreme left vertical line of the scale tangent to the periphery of the fiber cross section at a point of major diameter. With the scale in this position both diameters of the fiber can be read directly in microns with one setting. A reading can easily be made to one-half of a division, which is equivalent to one micron.

CALCULATION.—The fineness of each fiber shall be calculated by averaging its greatest and least diameters. From the values thus obtained, calculations may be made the same way as below.

Calculations for Fineness

Cell number	*Cell midpoint*	*Cell boundary*	*Deviation in cells from "A"* x	*Observed frequency* y	yx	*Cumulative frequency*	*Cumulative Percent*
5	11.25	10.00-12.50	0	3	0	3	0.50
6	13.75	12.50-15.00	1	20	20	23	3.83
7	16.25	15.00-17.50	2	73	146	96	16.00
8	18.75	17.50-20.00	3	123	369	219	36.50
9	21.25	20.00-22.50	4	139	556	358	59.67
10	23.75	22.50-25.00	5	116	580	474	79.00
11	26.25	25.00-27.50	6	62	372	536	89.33
12	28.75	27.50-30.00	7	34	238	570	95.00
13	31.25	30.00-32.50	8	16	128	586	97.67
14	33.75	32.50-35.00	9	10	90	596	99.33
15	36.25	35.00-37.50	10	3	30	599	99.83
16	38.75	37.50-40.00	11	1	11	600	100.00
				Ey = 600	Eyx = 2,540		

A = Midpoint of cell No. 5 = 11.25 microns

m = Units per cell = 2.50 microns

$$a = \frac{Exy}{Ey} = \frac{2540}{600} = 4.23$$

Average diameter of fiber in microns = Arithmetic mean = $\overline{X}$

= A + (m x a)

= 11.25 + (2.5 x 4.23)

= 21.83

The cross-section device described in the official method produces cross-sections about 1/64 of an inch thick and, therefore, depends largely for its efficacy upon the translucence of fibers, thus limiting its application primarily to white fibers.

In order to use the same technique on dyed and natural colored fibers such as human hair, camelhair, much thinner cross-sections are necessary. They can easily be produced by using the improved cross-section device by Hardy, with which sections as thin as three microns can be obtained.

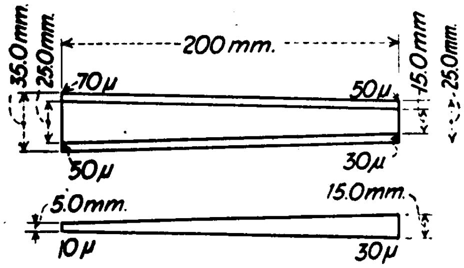
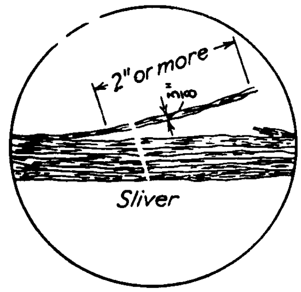
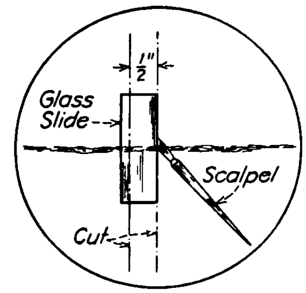


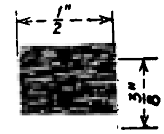
FIG. 1.—Wedge Ruler Consisting of Three Wedges.



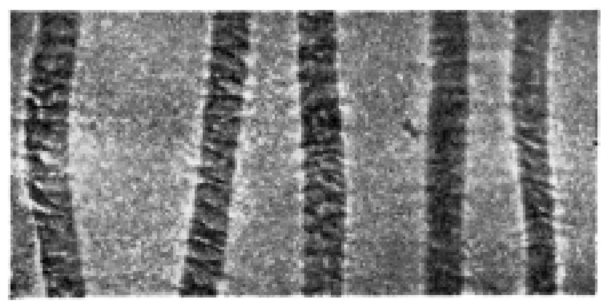
(a) Separation of Strand of Fibers from Sample.



(b) Cutting ½-in. Section.



(c) Cut Sample.



(d) Arrangement of Fibers on Slide.

FIG. 2.—Method of Preparing Test Specimen.

FIG. 3.—Marking Wedge Ruler Where Fiber is of Uniform Diameter.

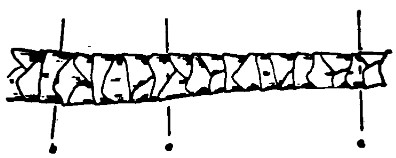
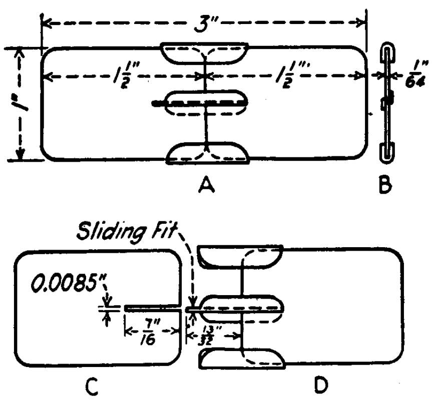


FIG. 4.—Marking Wedge Ruler Where Fiber is not of Uniform Diameter.



A = Assembly B = Side View
C = Fiber Holder D = Slide Holder

FIG. 5.—Cross-Section Device.

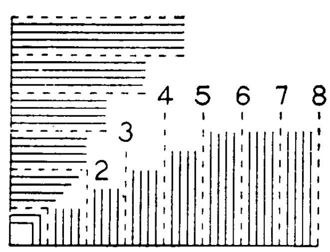


FIG. 7.—Bidiameter Scale.

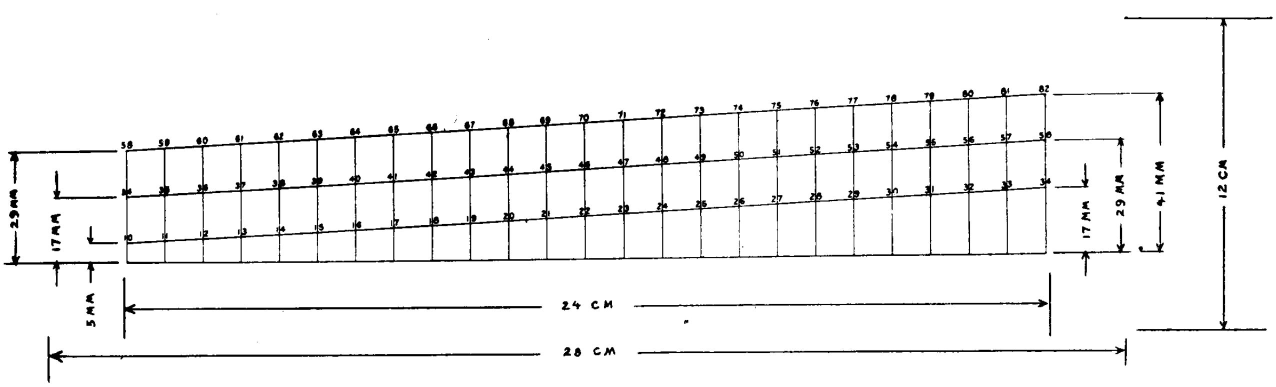


FIG. 6.—Wedge Measure.

The grade requirements for 80's to 50's inclusive in average diameter of fiber and distribution of fiber sizes for the standards and sub-standards with the minimum number of fibers required for tests are given in Table I.

The grades from 48's down to 36's are determined by the comparison method. In Table II are the results of measurements made on these lower grades by the Department of Agriculture and the Forstmann Woolen Company laboratory indicating that it is well possible to evaluate these lower grades by optical methods.

On the basis of these measurements the wool sub-committee of the American Society for Testing Materials has set up tentative specifications for the requirements of wool tops from 48's down to 36's with slight modifications.

Table I

Grade		80's	70's	64's	62's	60's	58's	56's	50's
Fineness Range									
Average diameter in microns:†									
Minimum		18.1	19.6	21.1	22.6	24.1	25.6	27.1	29.1
Maximum		19.5	21.0	22.5	24.0	25.4	27.0	29.0	31.5
Fineness Distribution									
Fiber diameter in microns:	*Per Cent*								
10 to 20 incl.	Minimum	60	50	36	27	18	16	9	4
10 to 25 incl.	Minimum	92	84	..	..	..	..	..	..
10 to 30 incl.	Minimum	..	..	94	88	83	74	64	45
25.1 to 30 incl.	Maximum	8	..	..	..	..	..	..	..
25.1 to 40 incl.	Maximum	..	16	..	..	..	..	..	..
30.1 to 40 incl.	Maximum	..	2	6	12	17	..	..	..
30.1 to 50 incl.	Maximum	..	..	..	..	..	26	36	55
40.1 to 50 incl.	Maximum	..	..	..	..	..	2	5	10
30.1 and over.	Maximum	0.25 (0.5)*							
40.1 and over.	Maximum	..	0.25 (0.5)*	0.333 (1.)*	0.50 (1.)*	0.50 (1.)*			
50.1 and over.	Maximum	..	..	..	..	..	0.75 (1.5)*	1. (2.)*	1.25 (2.5)*
Fibers Required for Test									
Minimum number of fibers required for test per sample		400	400	600	600	800	800	1200	1200

*Numbers in parenthesis represent maximum percentage of fibers of that range permissible in substandard grades.

†A micron is approximately 1/25000 of an inch.

Table II

Comparison of Measurements of United States Standard Top Samples United States Department of Agriculture and Forstmann Woolen Company

Type	*48's Grade*		*46's Grade*		*44's Grade*		*40's Grade*		*36's Grade*	
	U.S.D.A.	*F. W. Co.*	*U.S.D.A.*	*F. W. Co.*	*U.S.D.A.*	*F. W. Co.*	*U.S.D.A.*	*F. W. Co.*	*U.S.D.A.*	*F. W. Co.*
Number of Fibers	3500	1600	3000	1600	3800	1600	2600	1600	2700	1600
% of Fibers from:										
10 to 30 m	38.5	38.6	32.1	29.1	26.8	24.0	18.3	18.7	14.7	17.0
10 to 40 m	82.9	83.2	78.5	75.0	70.0	66.5	62.6	62.4	51.5	50.3
40 to 50 m	15.7	15.5	18.9	22.1	24.4	29.0	31.7	31.9	36.7	36.9
50 to 70 m	1.4	1.3	2.6	2.9	5.6	4.5	5.8	5.7	11.9	11.8
Average Microns	32.5	32.6	33.7	34.6	35.7	36.3	37.5	37.3	39.7	39.7
Deviation	7.9	7.9	8.0	8.0	9.1	8.5	8.0	8.2	9.3	9.5
Standard Error	0.13	0.20	0.13	0.20	0.15	0.21	0.16	0.20	0.18	0.24
Range:	32.1	32.0	33.3	34.0	35.3	35.7	37.0	36.7	39.2	39.0
	to	to	to	to	to	to	to	to	to	to
3X S.E.	32.9	33.2	34.1	35.2	36.2	36.9	38.0	37.9	40.2	40.4
Coefficient of Variation in %	24.3%	24.2%	23.7%	23.1%	24.3%	23.4%	20.5%	21.9%	23.4%	24.0%

Grade 52's/54's

This grade is recognized by the hand knitting worsted yarn manufacturers. The standard is as follows:

Average Fineness Range: 28.5-30.5 microns

Fineness Distribution

Fiber Diameter in Microns

10 -20	Minimum	7%
10 -30	Minimum	54%
30.1-50	Maximum	46%
40.1-50	Maximum	8%
50.1 and over	Maximum	1.25%

WOOL FIBER DAMAGE

Plates V and VI

The physiological features of normal wool and the various commercial qualities of wool have been described and illustrated in the previous pages.

The detection of damaged fibers and the subsequent identification of the cause of damage is as essential as the identification of the fiber proper. While the various tests and illustrations given specifically pertain to the wool fibers, the same causes for damage and tests for detection and identification of same are applicable for all other hair fibers.

Susceptibility to damage and sensitivity to reactions increases in wool and other hair fibers with increase in the fineness of the fibers.

A rough classification of causes is as follows:

I. Physical
- Deformities of the fibers
- Mechanical damage

II. Chemical
- Acid
- Alkali
- Chlorine
- Oxidation

III. Bacteria and Insect

While most of these damages can be observed microscopically, using regular mounting media, their proper identification is at times complicated and requires the use of various reagents for micro-chemical reactions.

In some cases different reagents or dyes are found to be suitable. Four of the most common reagents are mentioned repeatedly in various parts of this atlas. Their preparation and means of application is given at this point.

BENZO PURPURINE: Used as a quick means for qualitatively determining the degree of damage. It is applicable only to white fibers.

One gram of Benzo-purpurine 10B is dissolved in 1000 c.c. water. For one gram of sample 100 c.c. of solution is used. This is brought to a boil and the sample is immersed in it for one minute. After subsequent rinsings and drying the sample can be compared against known specimen. The higher the color absorption the greater the degree of damage.

ALLWORDEN'S REAGENT: This is concentrated chlorine water. Undamaged fibers mounted in this solution exhibit transparent gas filled bubbles arranged in pearl like manner along the surface of the fiber. The scales of the fiber are eventually dissolved. This reaction can be used for alkali damaged fibers.

CAUSTIC SODA SOLUTION N/10: A reagent for fiber swelling. The fibers are mounted in water and their diameter is measured. The caustic soda is then placed on one end of the cover glass and is sucked under the glass by means of a filter paper placed at the opposite end. The fibers are measured again after the swelling is complete.

KRAIS VIERTEL REACTION: 20 gm. of sodium hydroxide are dissolved under cooling and shaking in 50 ccm. concentrated ammonia. The solution is stable for about 2 months. Fibers are mounted in this reagent and the time recorded that is required to bring out characteristic granular air bubbles. This is a reliable reagent for the determination of acid damages.

I. Physical Damage

A. FIBER DEFORMITIES: Fibers obtained from sheep that were at one time or other sick or unproperly bred may exhibit pronounced deformities. The fibers show thick and thin places, and their lengths and number are dependent on the occurrences and duration of the sickness. The illness of the animal often yields tender staple wool. At one place the fibers may be reduced to less than half their original diameter. Severe cases may result in broken staple or double staple.

The cause of such a condition is that during the period of sickness the wool not only stops growing but actually sheds off. The new fleece starts growing as soon as health is restored. Held together by some hairs which have not been shed, and by the wool grease, the shed fleece remains on the back of the sheep. Thus, the newly grown fleece becomes the support for the shed fleece, therefore resulting in a broken staple.

B. MECHANICAL DAMAGE: Mechanical breaks, cuts and abrasions are described under reworked wool.

II. Chemical Damage

The various damages caused by chemicals are described in the order of their possible occurrence in manufacturing.

A. SUNLIGHT: Even while the fibers are still on the back of the sheep they are open to chemical damage. Sunlight and severe weather conditions are responsible for a photochemical decomposition of the fibers. The damage is especially noticeable in fibers from the back of the animal. It causes a yellowish brown discoloration, and a brittleness that results in the eventual loss of the scales. Aside from the decrease in strength, the sunlight-damaged fiber tips have an increased or decreased affinity for certain dyestuffs. The fibers become highly sensitive to alkali, and treatment with N/10 caustic soda causes the fibers to swell and eventually to curl.

Tests made on wools from various parts of the sheep, gave the following results:

Origin	*Place on the Animal*	*Width, Unswollen, u*	*End of the Width, Swollen, u*	*Staple Swelling, %*
Australian wool	back	23.08	44.46	92.63
	belly	27.27	29.88	9.6
Virginia wool	back	35.06	45.23	29.00
	belly	42.08	44.37	5.44
Wyoming	back	22.75	35.78	57.27

B. SCOURING—ALKALI DAMAGE: Wool, as all other hair, is extremely sensitive to alkali and by far the greatest amount of damage found can be attributed to the action of alkali. This is especially true of finished fabrics and garments in use by consumers.

Wool scouring while in all instances made under carefully adjusted and controlled conditions still accounts for a certain amount of visible damage. Fibers deprived of all of their natural greases at times exhibit small dots or holes within the cortex as well as in the epidermis. These holes are especially evident after severe extraction of oils and grease by means of solvents.

Further action may result in eventual removal of the scales. The fibers have a very harsh feel. By the use of the Allworden's reagent the failure of the reaction to take place is usually indicative of alkali damage. Quantitative conclusions cannot be obtained with this reaction.

C. ACID DAMAGE: Sulfuric acid used in carbonizing and hydrochloric acid used in stripping color are responsible for the characteristic brush ends sometimes found in certain wools. Though wool is not as sensitive to acid as to alkali a certain amount of damage can be ascribed to excess of acid left in the fibers.

A reliable test for acid damage is the Krais-Viertel reaction. The fibers are mounted in the reagent or the fibers are mounted in water and the reagent is drawn under the cover glass by means of filter paper. The time should be recorded from the moment the reagent comes in contact with the fibers to the appearance of the first characteristic granular bubbles. Viertel gives the following lapses of time for various degrees of damage:—

At to 2 min. ....strong acid damage
Between 2 to 6 min...acid damage
Between 6 to 10 min..acid treated but not damaged
Between 8 to 12 min..normal wool
15 to 30 min. and over.possible retention of reaction due to alkaline treatment or damage

D. CHLORINE AND BLEACHING DAMAGE: Chlorine is used in both liquid or gas form for shrinkproofing processes and printing of woolen fabrics. Wool unproperly treated with diluted chlorine solution becomes harsh, lustrous and loses its felting ability. At the same time the dyestuff affinity increases rapidly. Chlorinated wools have an appearance similar to sunlight damaged wool fibers.

Wools damaged through bleaching can be quantitatively checked with N/10 caustic soda. A swelling of over 20 per cent in N/10 caustic soda indicates serious damage to the fibers treated by chlorination or bleaching.

III. Bacteria and Insects

Both damages have such characteristic appearance that no special reagents are necessary for their identification.

The destruction of wool through bacteria can usually be detected by the moldy smell and the extreme weakness of the fibers or fabric. If wool is left in a warm place in a moist alkaline condition with lack of air, certain bacteria will grow and produce enzymes which break down the scales and hydrolyze the intercellular substance binding together the cortical cells.

Insect damage is characterized by the bite-marks of the moth or carpet beetle larvae on the fibers (see Plate V). No differentiation between damage caused by either animal is possible except where fragments or excrement of the animal is present.

Reprocessed and Reworked Wool

Since July 15, 1941, the Wool Products Labeling Act of 1939 which was approved on October 14, 1940, by Congress is effective. On May 25, 1941, the Federal Trade Commission issued 35 rules and regulations to guide the textile and apparel trades in properly labeling their products under this Wool Products Labeling Act.

In this act, the manufacturer as well as the retailers are required to label their product, not only as far as wool and other fibers than wool are concerned, but also to state the amount of reprocessed and reused wool present.

The definitions as laid down in the Act for wool, reprocessed and reused wool, are as follows:

The term "wool" means the fiber from the fleece of the sheep or lamb or hair of the Angora or Cashmere goat (and may include the so-called specialty fibers from the hair of the camel, alpaca, llama, and vicuna) which has never been reclaimed from any woven or felted wool product.

The term "reprocessed wool" means the resulting fiber when wool has been woven or felted into a wool product which, without ever having been utilized in any way by the ultimate consumer, subsequently has been made into a fibrous state.

The term "reused wool" means the resulting fiber when wool or reprocessed wool has been spun, woven, knitted, or felted into a wool product which, after having been used in any way by the ultimate consumer, subsequently has been made into a fibrous state.

In addition to the above three classifications of wool, which are mentioned in the law itself, the Federal Trade Commission recognizes a further classification known as virgin or new wool, which is defined as "wool which has never been used or reclaimed or reworked or reprocessed or reused from any spun, woven, knitted, felted, or manufactured or used product."

It is a well established fact that through the reconverting process and bringing a finished fabric back into a fibrous state through rigorous mechanical treatment such as garnetting and picking, the wool fibers are severely damaged. The protective scales are torn away and the fibrous cortical layer is splintered as well as broken. The five fibers illustrated on Plate VI show the various degrees of such damage. (Reprocessed wool.)

If, in addition to this treatment, a fabric has received considerable wear before reduction to the fibrous state, the percentage of damaged fibers is still higher. (Reused wool.)

The examination of fabrics made from reprocessed wool, reused wool or mixtures of both with wool is one of the most difficult problems for the textile microscopist. It requires a high degree of accuracy coupled with long experience.

As seen from Plate V, the mechanically damaged fibers generally have an appearance sufficiently different to tell them apart from fibers which are damaged by chemical or bacterial action. It is impossible to definitely recognize each individual fiber as being reprocessed or not. In a normal manufacturing process some of the fibers are damaged in a similar manner.

Despite certain difficulties in recognizing virgin wool, reprocessed wool and reused wool, in most fabrics it is possible qualitatively to determine just what the fabric contains.

In order to arrive at any just estimate, it is necessary to conduct many comparative examinations on known samples. Based on research made in this field Matthews, Skinkle, Hardy and von Bergen agree that the most important characteristics of reclaimed wool (reprocessed or reused) which may be employed in detecting its presence are:

1. *The Percentage of Damaged Fibers*

This percentage can be established in different ways. The method used in the Forstmann Woolen Company laboratory is as follows:

The fabric under test is separated into its individual yarns. Each yarn is then carefully opened and the fiber mounted on a slide, using glycerine as the imbedding medium. The slide is then examined unde the projection microscope (x 500 magnification) similar to the procedure used in establishing the fineness of the wool fibers. In going across the slide at three different places, at the top, in the middle, and at the bottom, the fibers are counted and all fibers showing damage of the cortical layer of the slightest extent such as breaks and cuts (similar to those illustrated in Plate VI) are recorded separately. Fibers where the epidermis scales are only missing are not counted as damaged because of their close resemblance to mohair fibers. Of each yarn, at least two slides are made and the minimum number of fibers examined is 500.

In the following table are results of research made with this method on fabrics containing various amounts of reprocessed wool in comparison with the same fabric made originally from virgin wool.

Percentage of Damaged Fibers Found in Different Samples

Fabric	*Velour Wool Dyed*	*Broadcloth Piece Dyed*	*Flannel Piece Dyed*	*Cheviot Piece Dyed*	*Cheviot Wool Dyed*
Original Blend	*½ Blood Missouri*	*64's Penn Delaine 6 Mo. Texas*	*70's Ohio Delaine*	*⅜ Bl. Minnesota B/C S.A. Lamb*	*50% Domestic 50% Aust. Lambs*
100% Virgin	2.04%	1.27%	1.79%	1.54%	1.39%
50% Virgin 50% Reprocessed .	4.45%	4.15%	4.91%	4.12%	.....
30% Virgin 70% Reprocessed .	.....	.....	.....	6.27%	.....
100% Reprocessed	6.58%	.....	6.90%	.....	6.46%

The figures represent the average of at least 3 tests of 600 fibers each.

Another technique developed by Hardy and used by the United States Department of Agriculture, Bureau of Animal Industry, is based on limiting the count to the fiber ends. In this technique the preparation of the slide is quite difficult in order to obtain the necessary amount of ends. At least 100 ends have to be recorded. In using this method the following results were obtained on the following three fabrics:

Blend	*100% Virgin Wool*	*50% Virgin Wool 50% Reprocessed Wool*	*100% Reprocessed Wool*
Percentage of Damaged Ends	21%	51.54%	62-64%

All these tests were made with fabrics containing reprocessed wool only. As stated in the beginning, the number of damaged fibers in reused wool is higher than in reprocessed wool. This fact is substantiated by three samples analyzed, with the following results:

Blend	*75% Wool 25% Reused Wool*	*65% Wool 35% Reused Wool*	*65% Wool 35% Reused Wool*
Percentage of Damaged Fibers	4.1%	6.1%	5.83%

As can be seen from these figures, 35 per cent reused wool has approximately the same amount of damaged fibers as blends containing 100 per cent reprocessed wool.

2. *The Presence of Fibers Other Than Wool*

Today much reclaimed wool is recovered from fabrics containing various amounts of cotton, rayon and silk. The presence of various percentages of cotton and especially of rayon fibers of different sizes and in their dull and lustrous form are indications of reworked wool. In establishing the proper percentage of these different fibers present, the microscopical count of a fine cross-section is preferable and the chemical analysis should be used (see color photomicrograph) in addition.

3. *Fibers of Many Colors*

The color of the fibers is also a characteristic appearance of reclaimed wool, as the majority of them are made up of variously colored wools. Though many of these fibers are redyed, covering up their original shade, the original color of the individual fibers is revealed through the medium of fine cross-section as illustrated in the color photomicrograph.

The fabric from which this cross-section was made was a green snow suit. By dyeing the fabric made up of white and multicolored fibers, a dark green shade, the green dyestuff penetrated most of the wool fibers not much further than the epidermis, leaving the larger part of the cortical layer as it was originally. As illustrated in the color photomicrograph we find four fibers showing a distinct pink in the center, one fiber blue, and another brown, all with the green on the outside.

The green snow suit from which the color photomicrograph was made was tested as follows:

Chemical Analysis:
Wool content—sulphuric acid method 86.4%
Microscopical Analysis:
Fiber Content:
Wool 84.6%
Viscose Rayon 8.0%
Cotton 7.2%
Jute 0.2%
Fiber Damage:
Percentage of damaged fiber 28.4%
Percentage of damaged ends 76.0%

From these facts it can be safely stated that this fabric contains at least 90 per cent reclaimed fibers of the reused type because of the presence of:

(1) extremely high number of highly damaged fibers.
(2) fiber presence of many colors.
(3) the presence of rather small percentage of cotton and rayon fibers of various sizes and in their dull and lustrous form.

There is no question that with the labeling of the fabrics a high number of samples to be studied will be available, and the accuracy of the microscopical procedure for the determination of reprocessed or reworked wool will be considerably improved.

SPECIALTY HAIR FIBERS

Plates VII and VIII

Mohair

Mohair is the hair fiber, which forms the long lustrous coat of the Angora goat. The goat is bred on a commercial basis in the United States, Turkey and the Union of South Africa. The hair grows in long uniform locks, which when scoured, are of a clear white color and of a silk-like luster.

MICROSCOPICAL STRUCTURE: In its microscopical structure the mohair fiber is similar to wool, but has some characteristics, which make its identification possible. (See Plate VII.)

The *epidermal scales* are only faintly visible and scarcely overlap. They lie closely to the stem giving the fiber a very smooth appearance. The number of scales per hundred microns are 5 against 10 to 11 in fine wools. The scale length varies from 18 to 22 microns.

The *cortical layer* is clearly visible as strong striations throughout the length of the fiber. In many fibers, air filled pockets or vacuoles of a cigar-like shape of various lengths are found. The percentage of such hairs containing vacuoles varies in wide limits.

MEDULLAE: The number of medullated fibers in well-bred mohair is normally below one per cent. As in wool, three forms of medullas are found with the continuous type the most common.

CROSS-SECTION: Mohair has a cross-section of high circularity. The ratio between the major and minor diameters is usually 1:1.20 or lower. In many cases the cross-section shows hairs with black dots or little circles caused by the air-filled pockets or vacuoles, already mentioned. In poor grade mohair, kemp fibers are present. They are similar to wool kemp.

FINENESS: Mohair fibers vary in diameter from 14 to 90 microns. There is a distinct difference in the fineness of the kid hair and the adult hair, with the latter several microns coarser. Mohair is graded and sorted similar to wool using fineness as the main basis of quality. Various systems of nomenclature are used and the trade has not yet arrived at a common standard. However, the following seven grades represent a good over-all cross-section of the United States mohair market:—

The Seven Grades of Mohair

Nomenclature		*Average Microns*	*Coeff. of Var. %*	*Dispersion Microns*	*Comparable Wool Grade*
1. Baby Kid	or 40's	23-25	19-22	10-40	62's
2. Super Kid	or 36's	25-27	19-22	10-45	60/58's
3. Kid	or 32's	27-30	19-22	10-50	56's
4. Super First	or 28's	30-34	22-25	10-50	50/48's
5. First	or 24's	34-40	22-25	10-55	46/40's
6. Second	or 20's	40-50	Over 25	15-60	36's
7. Third	or low	50-60	Over 25	20-90	below 36's

Natural colored mohair is of a reddish brown color. Small amounts are imported from Turkey and with the exception of the presence of color pigments the microscopic characteristics are the same as white mohair. (See Plate VII.)

Cashmere

Cashmere hair is obtained from the cashmere goat (capra hircus laniger), which is native in Tibet and northern India. The hair cover of the cashmere goat consists of two distinct coats namely: A fine undercoat or down made up of very soft, wavy silk-like fibers, the *cashmere wool* and an outer coat of long straight and coarse hairs, the *beard hair*.

The color of the wool hairs are white, grey or tan with the grey and tan mixtures predominating. The beard hairs may be white, dark brown and black. (See Plate VII.)

MICROSCOPICAL STRUCTURE: The cashmere wool fibers show clearly the scales which slightly project beyond the cortical layer, giving a serrated effect. The number of scales per 100 microns averages 6 to 7. The cortical layer of the white and grey hairs show distinct longitudinal streaks, while the brown hairs are covered completely with minute dyestuff pigments. Medullated fibers are absent.

FINENESS: The diameter of the cashmere wool hairs is extremely regular and uniform ranging from 5 to 30 microns with an average fineness range from 15 to 16 microns. The values, given in the following table illustrate this uniformity.

Fineness Analysis of Commercial Cashmere Samples

Types	*Scoured Grey*	*Top Grey*	*NOILS Grey*	*NOILS White*	*Fabrics of Four M'f'rs*
Number of Fibers	1000	1000	1000	1000	800
Average Microns	14.8	15.6	15.1	15.1	15.4
Coefficient of Variations in %	20.3	18.6	18.0	19.2	20.1

Since the hair is obtained by plucking it from the skin of the animal, most fibers retain their roots. The fibers have long fine tips which due to their fineness, are often broken off while still on the back of the animal.

CROSS-SECTION: The cross-section of the fiber is practically circular. The colored hairs show the dyestuff pigments very distinctly.

BEARD HAIRS: The beard hair consists of all three layers of cells. The medulla on the whole constitutes the largest part of the hair. The root and the end do not contain any medulla. Partially medullated hairs are rarely found.

FINENESS: The diameter of the beard hairs is extremely irregular. They vary from 30-150 microns with an average width of 62 microns.

Persian Cashmere

This hair often commercially marked as "Cashmere" is derived from goats in Persia. It is considerably coarser than the genuine cashmere, running on an average between 19 and 20 microns, which is very close to the width of camelhair. Another distinction is its occurrence in colors such as cream, fawn, and dark brown, which are not present in genuine cashmere.

Camel Hair

Camel hair is obtained from the Bactrian camel, raised chiefly in Mongolia. The animal sheds its hair annually. The color of the fibers is very characteristic, having a light, reddish brown shade. Like the cashmere goat, the camel carries a mixed fleece, a fine undercoat and coarse beard hairs. There is no clear line of demarcation between the two fiber types. Numerous fibers have characteristics of both wool and hair. (See Plate VIII.)

The trade recognizes three commercial grades: Fine, medium and coarse, or Quality 1, 2, and 3, respectively. These grades are based on the amount of coarse fibers present.

MICROSCOPICAL STRUCTURE: The width of the "down" ranges from 9 to 40 microns with the average around 18 microns. The epidermal scales are long and poorly visible. There are 7 to 9 scales in 100 microns. The diagonal edges of the scales are more or less sharply bent. The cortical layer is regularly striated and filled with color pigments. A small percentage of fibers having interrupted medullas is characteristic for camel hair. Beard hairs are dark brown to black, 30-120 microns broad with a wide and mostly continuous, medullary cylinder. The thin cortical layer contains strong accumulations of dark brown to black colored granules. The medullary cells are short, but broad, and are filled with color pigments. (See Plate VIII.)

The table below gives fineness measurements made on various samples of camel hair obtained in the trade:

Fineness Analysis of Commercial Camel Hair

Type	*Carded*	*TOP*		*NOILS*			*Fabrics*
	Fine	*Fine*	*Coarse*	*No. 1*	*No. 2*	*No. 3*	*Fine*
Number of Fibers	1000	1000	1000	1000	500	500	600
Average Microns	19.7	18.2	23.1	18.0	20.9	22.8	16.8
Coefficient of Variations in %	33.5%	30.1%	41.0%	29.9%	37.1%	40.8%	29.8%

Alpaca, Llama, Vicuna, Guanaco

All of these hair fibers are obtained from animals belonging to that of the camel. The habitat of the first three animals is the high Andes regions of southern Ecuador, Peru, Bolivia and northwestern Argentina. The Guanaco is chiefly confined to Patagonia (S. Argentina). The Alpaca and Llama are domesticated, whereas the Vicuna and Guanaco are not. All these animals produce a certain amount of fleece, but by far the greater portion, approximately 98 per cent, is derived from the Alpaca and the two hybrids, *Huarizo* and *Misti.*

The fleeces of the Llama and Alpaca are similar in character to that of the Angora goat. Through years of breeding the undercoat has disappeared and the hairs have become uniform in diameter and length. In the Llama wool a high percentage of kemp is usually present, whereas the fine alpaca wool has practically none.

The color of the hair of both species is variegated, being white, grey, fawn, brown, piebald and black.

The vicuna fleece is of the mixed type consisting of wool and beard hairs. The vicuna wool hair is the softest and finest wool fiber utilized in wool manufacturing. The color of it ranges between a golden chestnut and a deep rich fawn.

MICROSCOPICAL STRUCTURE: The epidermal scales of all hairs of the llama family are very indistinct. The cortex is regularly striated and except in the white filled with color pigment. The main characteristic of alpaca and llama wool is the presence of a high percentage of fibers containing interrupted medulla. In the beard hairs, the continuous medulla show contraction in the middle, appearing as a double channel, as is seen in the cross-section of the alpaca. (See Plate VIII.)

Vicuna is easily distinguished from Llama and Alpaca because of its great fineness. The vicuna wool fibers vary in width from 6-25 microns with the average between 13-14 microns. The Alpaca fibers cover a range from 10-60 microns with the average lying normally between 26-28 microns, of the fibers derived from the adult animals.

The fineness of the various hairs yielded by the members of the Llama family is indicated in the table below:

Fineness of Commercial Llama Hairs

Types	*LLAMA*		*ALPACA*	*HUARIZO*	*VICUNA*	
	Raw Mixes	*Baby Llama Scoured*	*Scoured Piebald*	*Tops Various*	*Scoured Carded*	*Scoured Carded*
Number of Fibers	500	400	1000	1200	500	1100
Average Microns	27.0	20.1	26.7	27.3	25.8	13.2
Coefficient of Variations in %	23.3%	21.9%	26.6%	29.3%	23.6%	17.4%

Expressed in wool fineness terms Llama, Alpaca and Huarizo range between a 56's and 60's wool grade with the baby llama as fine as 70's. The vicuna is between a 120's and 130's wool quality.

Guanaco

Measurements made by Whitford on Guanaco fibers place this fiber in respect to fineness between the Alpaca and Vicuna fibers. Width averages vary from 18 to 24 microns and 10-11 scales per 100 microns.

MINOR HAIR FIBERS

Plates IX and X

Other hair fibers found occasionally in textiles besides those mentioned previously, are human, horse, cow and common goat hair as well as hog bristles. These hairs are utilized in various fields for effect in woolen yarns, for linings, driving belts, carpets, filter and press felts, and especially bristles in brushes of all kinds.

In this group we find all the possible different varieties of hairs. They are distinguished according to their diameter, length, stiffness and shape as *Bristles, Bristle hairs, Beard hairs* and *Wool.* The coarse, long, stiff, elastic and tapering hairs of the hog are typical bristles. Bristle hairs are short, straight, stiff hairs with a pronounced medulla such as the body hair of the horse. Beard hairs are regular in diameter throughout, long, straight or slightly wavy, generally with a medulla. The human hair and the hair from the manes and tails of horses belong in this class. The fine, wavy underhair of the common goat is classified as wool.

The structure of these fibers is fundamentally the same as that of the wool fibers, the chief difference being that the minor hair fibers as a whole have a larger average diameter.

Hog Bristles

This fiber is chiefly employed in brushes of various types and for filling material in upholstery. The gold colored pig hair has found use as an effect hair in fancy blends of woolen yarns. (See Plate IX.)

There are numerous qualities of bristle depending on their color, length, fineness and place of origin such as domestic hog bristle, French, Russian and Chinese bristles. The outstanding character of the bristles against all other hair is that they are coarse, stiff and taper in diameter from base to tip, and that the tips are split or flagged. The flagged tip is caused by splits in the medulla, which separates the fine ends of the hairs into two or more sections as seen in the photomicrograph on Plate IX. As the bristles are normally obtained by pulling, the root ends are frequently present.

The epidermal structure of the hog bristles shows that the free scale ends form a system of very fine narrow lines. This formation is the most irregular of all animal hairs. The scales have fine jagged edges.

As a large amount of the bristles are of dark color, a study of the cross-section is valuable in identification. The shapes vary from fully round to oval. All fibers have a medullary channel, which diminishes or disappears usually at the butt end. Its size increases from the middle of the bristles toward the tip. It changes its shape from nearly round at its beginning to a star-like shape towards the tip of the fiber. Very often the circular structure of the medulla is missing, leaving only hollow spaces. The dyestuff pigment distribution in dark fibers is balanced, with the maximum amount of pigment in the center of the fiber, gradually diminishing towards the epidermis. Width measurements made on 15 fibers of French bristles showed the following results:

	French Bristles Average Width Microns	*Dispersion Microns*
Base	256	148—326
Tip	180	98—250

Horse Hair

Horse hair finds little use in ordinary woolen and worsted goods. The mane and tail hairs are used in linings, and upholstery cloth whereas the much shorter body hair is used as stuffing for upholstery.

The epidermis differs from the hog bristles in that the distance between the free protruding ends of the scale is larger in the horse hairs. The distance between the scale lines varies according to the diameter of the fiber. The scales of the fine pony hairs are farther apart than the much coarser horse hair. There seems to be little difference in the various species of horses.

The cross-section normally is highly circular and where a medulla is present it is very pronounced, occupying more than half of the fiber. (See cross-section of the pony hair, Plate IX.

A chief characteristic is the distribution of the color pigments especially in non-medulled fibers. They form a ring close to the epidermis and gradually diminish in number towards the center of the fiber. In some dark brown and black hairs, the pigment decreases toward the center in a star-like fashion. It gives a similar effect as the medulla in a hog bristle as is clearly seen from the cross-section of the black horse hair. This pronounced difference in the pigment distribution between hog and horse fibers was first utilized for identification purposes by E. Weirick.

By treating the fibers in warm 10 per cent caustic soda dark hog bristles when examined longitudinally will exhibit the pigment concentration in the center of the fiber as a heavy dark line. Horse hairs, on the other hand, swollen by the caustic soda, will show two heavy dark lines running along the fiber edges.

The diameter of the horse hairs varies considerably. The short body hairs, according to Mathews, vary in average diameter from 80 to 100 microns. According to the A.S.T.M. specifications, horse-tail hairs have an average diameter of not less than 140 microns, with the dispersion range from 75 to 280 microns, whereas the mane-hairs are finer with an average around 110 microns and a dispersion range between 50 and 150 microns. Measurements made on a sample of pony hair gave an average diameter of 43 microns and a dispersion range between 17 and 75 microns. All the hairs are rather regular in diameter. (See Plate XI.)

Width Variation in Horsehair

Sample Size 100 Fibers

Type of Hair	*Age of Animal Years*	*Average Microns*	*Variation Per Cent*	*Dispersion Range*	*Standard Error*
Tail	1	149	11.2	113-188	1.7
Tail	11	167	11.0	123-213	1.87
Tail	19	183	10.4	133-233	1.93
Mane	1	121	19.7	73-168	2.24
Mane	11	129	14.9	93-173	1.95
Mane	19	124	17.8	98-158	2.24
50% Tail }. 50% Mane }.		147	29.6	68-253	4.42

Courtesy of Dr. Appel, National Bureau of Standards.

Human Hair

Human hair is sometimes employed in linings to replace the more expensive and rarer horse hair, as well as in wigs, doll hair, hairnets and similar products.

As the hair is clipped only occasionally, hair with the root attached, as shown in the microphotograph, is found. The epidermis structure is similar to the one found in previously discussed hairs with the free ends of the scales running in parallel lines with small indentations and occasional pronounced notches. (Plate X.)

Hausman has found through his examination of hundreds of hair shafts from the different races, only one characteristic type of scales, that of the flattened type. This gives the hairs a very smooth appearance with the scales lying close to the shaft. He states that the coarser the hair, the finer the scales, and vice versa.

The cross-section of the human hair varies from elliptical to nearly circular or angular shape, with the former type predominating.

Tests made on a sample of head hair (male, white) showed a ratio between the major and minor diameter of 1.55. The epidermis in the cross-section can be seen as a pronounced ring forming the outer contour of the hair, having a thickness of about 0.5 microns.

The presence of medullated fibers varies considerably. It was noted that the medullary channel is either present in most of the hairs in one person, or is absent in all hairs. The medullary cell may form either a continuous or an interrupted core. The color of the human hair depends, as in other hairs, on its content of pigment and air. The pattern formed by these granules varies within wide limits. Hausman makes the following statement: "Within racial group limits, as well as within individual head limits, wide variations in hair shaft structure and pigmentation occur of such magnitude as to warrant the supposition that these variations are indicative of differences in racial sources of the samples."

The size of human hairs is usually very uniform. According to Febiger, the average diameter of the human hair ranges between 70 and 96 microns. Measurements made on the head hairs of a white man, a woman and their two children and of commercial Chinaman hair showed the following results:—

Width Variation in Human Hairs

Size of Sample 100 Fibers

Persons		*Average Microns*	*Variation Per Cent*	*Dispersion Range, Microns*
Father,	Age 45 Years ..	60.7	22.1	15- 70
Mother,	Age 38 Years ..	84.8	16.4	50-110
Daughter,	Age 7 Years ..	69.3	20.9	35-105
	Age 14 Years ..	58.6	20.9	27- 65
Son,	Age 8 Months .	41.7	29.8	18- 70
	Age 7 Years ..	60.2	26.1	12-100
Chinaman,	Mixed	61.5	29.8	18-110

Goat Hair

The hair of the common goat is used mainly in fancy woolen yarns, in low grade blankets and for carpets. Similarly to the cashmere goat, the hair covering of the common goat consists of two distinct types of hairs, namely, the fine wool hair and the coarse beard hairs.

In their microscopical structure the two types of hair are closely related to cashmere hair. The medullary channel is absent in the fine fibers but very pronounced in the beard hairs, having the continuous form. The average fineness for the wool hair of samples on hand was found to be between 13 and 15 microns with a dispersion range from 8-20 microns. The beard hairs vary in average diameter from 43 microns for the kid beard hair, to 102 microns for the adult animal. The dispersion range for the kid beard hair was found to be from 15 microns to 90 microns, whereas for the beard hair of the adult it is from 50 to 200 microns.

The cross-section of the fine hairs is round, while that of the beard hairs may vary from full-round fibers, having no or only a small medulla, to oval and elliptical fiber shape containing large medulla.

Cow Hair

Cowhair is extensively employed as a low grade fiber for the manufacturing of coarse carpet yarns, blankets and felts. It is used in mixtures with wool. Cowhair nearly always shows the hair root, as the fibers are removed from the hide by pulling. The coat of the cow is composed of three kinds of fibers: Thick stiff beard hairs, soft fine beard hairs and very short, fine wool hairs. (See Plate X.)

The epidermis structure is similar to horse hair. The medulla is quite prominent in the calf's hair but is smaller and at times fragmental in the cow's hairs. Fine wool hairs, occasionally found, have no medulla.

In the cross-section, both calf and cow hair show a full round to oval shape. Characteristic of white hairs when sectioned is the grainy appearance of the cortex.

The fineness range of the cow hair varies in wide limits. Measurements made on domestic calf and cow hair samples showed the following results:—

Width Variations in Cow Hairs

Types	*No. of Fibers*	*Aver. Micron*	*Var. Per Cent*	*Dispersion Range Microns*
Calf—Mixed	200	36	30.4	15- 75
Cow—Back	100	76	8.4	30-120
Cow—Head	100	81	4.6	40-110
Cow—Tail	25	187	—	128-230

FUR FIBERS

Plates XI and XII

While fur fibers are not in the strict sense textile fibers, various types of fur hairs are employed for effect purposes in women's and children's wear and in felts for men's hats.

In the class of animals known as the fur bearers, the examination of the fur coat discloses the fact that there is a double set of protective hairs similar to that found in the fleece of the cashmere goat or of the camel. There are the long, glossy, strong and elastic beard hairs, referred to as guard hairs in the fur trade. Surrounding these are the fine, very soft, smooth, curly and dull fur hairs. Normally the fur hairs are only 1/2 to 2/3 as long as the guard hairs. There is a third type of hair, the intermediary hairs. They are undeveloped guard hairs, showing partly fur and partly guard hair structure.

SHAPE: The guard hairs and fur fibers, when traced along their length are found to be *fusiform*, that is, the diameter of the hair is larger in the middle than at both ends. Both guard hairs and fur fibers have the same major structural features as the wool fibers, namely epidermis, cortical layer and medulla.

MEDULLA: The main difference between wool and fur hairs is the form of the medullary cells which in the latter are arranged in a pearl-like or ladder-like fashion and are known as the discontinuous form of medulla.

Among the various fur fibers, the medullary cells vary sufficiently in their pattern so that they have proven to be the best medium for identification and classification. All examinations should be based on the middle area, as all parts of the guard and of the fur hairs are not the same. In the guard hairs these medullary groups are of two distinct types: the chambered, and the net-like. The first type is quite characteristic for the hairs from the rodent family, whereas the net-like form is found chiefly in the carniverous type. They are arranged in rows from one up to eight or more.

In the fur hair the medullary groups are arranged in a single row with cells either round, disc-shaped or pocket-shaped. Between the medullary cells are air spaces or vacuoles, which vary in size and shape in proportion to the size and shape of the medullary group, which they separate. In the guard hair the vacuoles are more or less intercellular. The shape of these vacuoles and the medullary groups form the important combination that serves to determine the species to which the hair and the fibers belong.

PIGMENTATION: As in wool and specialty hair fiber, the color in a fur fiber is caused by the presence of color pigments, which in the coarse hairs are long and somewhat oval shape, and in fine hairs nearly round.

Only those fur fibers having some importance in textiles are described further. Of the fibers described and illustrated, the rabbit, hare, beaver, muskrat, and squirrel belong to the Rodentia family, while the raccoon and the fox are members of the Carvonica. It may at times be of advantage to know the zoological relation of the animals whose fibers are under question as in some cases hair from related animals will show similar characteristics, when observed under the microscope.

Angora Rabbit, Rabbit and Hare Fibers

Over 90 per cent of all fur fibers used in woolen clothing are selected out of this group. The angora rabbit hairs are derived from the domesticated, highly bred animals, and cut or combed from the living specie. The common rabbit hair fibers are obtained from the furs of the wild rabbit, which inhabits the northern countries such as Siberia, Sweden and Canada. The hair is recovered in pelteries by means of pulling. These fibers are relatively easy to distinguish from other fur hairs, but it is extremely difficult to differentiate between the various types of rabbit and hare fibers, especially if only a few fibers are available.

Hare and rabbit fibers differ from each other according to Fiebiger in the arrangement of the medullary cells in the guard hair. In the hare fibers the medullary rows are always continued and very rarely melt into each other, whereas in the rabbit hair the rows are often interrupted and show numerous fused joinings with neighboring rows. No such differences were observed by the authors on their samples. Due to the difficulty in proper determination of the various types of rabbit and hare they will henceforth be classed as rabbit hairs.

Microscopical Structure

FUR HAIR: Longitudinally examined, the fur hair shows the medullary cells arranged in one column with each cell separated from the other. In the extremely fine tapering end the medulla is absent or only evident as a fine line. (See Plate XI.)

The scale structure is of the coronal type, with one scale surrounding the fiber completely. The free scale ends are parallel to each other, either running crosswise, like in fine wool, or in twist fashion from right to left (S twist). Both types can be present in the same hair. In many instances the protruding edges of the scales terminate in a sharp point.

The cross-sectional shape of the fur fiber is round, with the medullary air space in the middle, resembling doughnuts. Where the scales have the sharp points, the contour has a more or less ragged appearance. This can be observed from the photomicrographs.

GUARD HAIRS: The microscopical appearance of the guard hair is quite different and outstanding from most other fur animals. The medullary cells are arranged in two or more columns up to eight, and sometimes more, arranged in a winding or spiral-like form. Starting with 1-2 medullary rows on the base the number increases steadily up to the largest diameter of the hair, which is normally in the middle or upper half, then slowly narrows down from 3 to 2 rows and finally at the tip, to a single row.

The epidermis scales are very close together and arranged in parallel fashion, approximately 18 per 100 microns against 10 in the fur hair. The cross-section of the guard hair has a variety of forms ranging from elliptical to the shape of bones or dumb-bells. *The latter form is very characteristic.*

The fineness of the fur hair varies from 8 to 30 microns and that of the guard hairs from 30 to 150 microns. (See Plate XI.)

Muskrat Fur Fiber

EPIDERMIS: The outer structure of muskrat hair is of little value in identification. Fur hairs have at their base smooth scale structure, which changes into arrow head shapes. The guard hairs have a scale structure which is repeatedly found on other fur fibers. The free ends are jagged and lie close to the stem. (Plate XI.)

MEDULLA: The medulla of the fur fiber is either continuous or discontinuous. Both forms can be found in one fiber. The medulla cells are long and angular. In the very fine hairs often only a thin line marks the presence of the medulla. Guard hairs have either a single column of flat cells or multiple columns of polygonal medullary cells. Dyestuff pigments, which are found throughout the cortex, are also found in the medulla.

CROSS-SECTION: The cross-sectional shape of the fur hair differ little from rabbit fur. It is the proportion of the medulla to the fiber, the fineness as well as the pigment distribution *which make an identification by means of the cross-section possible.*

The beard hairs are elliptical, one side usually slightly dented inward. The epidermis of the beard hair is clearly visible as a heavy layer in the cross-section.

Beaver Fur Fiber

This animal is closely related to the muskrat and the fibers resemble the latter in many ways. (Plate XII.)

MEDULLA: The medulla of the fur hairs are somewhat finer than that of muskrat. Toward the tip of the fibers, heavy color pigmentation is found and the medulla is reduced to a fine thin line. The medulla cells are usually continuous and joined together. The cross-section shows the comparative size of the wool hairs to the guard hairs as well as the roundness of the former. The guard hairs are elliptical with a somewhat larger medulla than the muskrat.

Raccoon Fur Fiber

This fiber differs somewhat from the aforementioned in its cross-section as well as longitudinal shape. The cross-sectional shape is oval. There is no definite limit between the fur and guard hairs, many having characteristics of both. The contour of the hair is rough at times, pointing towards heavy pronounced scales, easily visible in the longitudinal views.

Longitudinal views show the medullary cells arranged in one column. The cells are square to elongated, with color pigments between the individual cells. The medulla near the base of the fiber is much finer and the cells are more stretched than in the middle. The medulla of the raccoon occupies not more than 1/3 of the fiber.

Squirrel Fur Fiber

The squirrel hair cross-section varies from oval to elliptical in the fur hairs to kidney shaped in the beard hairs. The medulla take up considerable room, about 1/2 in the fur hairs and about 2/3 in the guard hairs. The chief characteristic of the fibers is the medulla which when the air is removed from the cells show their peculiar shape. The cells are arranged in columns and are like steps of a ladder. (Plate X.)

Fox Fur Fiber

In their cross-section, fox hairs are usually round to oval. The medulla make up over 1/2 of the fiber. At times the rough outline of the fibers, caused by the protruding scale, can be seen. The color pigments are clustered around the medulla as well as in the medulla of the fibers. Longitudinal views give a good idea of the size of the medulla to the rest of the fiber. Near the base, the medulla is very small and interrupted.

In the following table the fineness of the fur hair of the different species discussed are shown. They indicate that with the exception of the muskrat, which is finer than the rest, the small difference in fineness among the fur fibers is of little help in identification.

Fineness Analysis of Various Fur Hairs

		Angora Rabbit	*Rabbits Various*	*Muskrat*	*Beaver*	*Raccoon*	*Silver Fox*	*Squirrel*
No. of fibers		400	1000	100	100	100	100	100
Average microns		13.2	14.3	11.7	15.8	15.3	15.2	14.4
Percentage of fibers								
From	*— To*							
5	10 microns	15	11	24	3	10	3	4
10	15 microns	60	52	67	45	36	51	61
15	20 microns	22	29	6	45	47	41	28
20	25 microns	2	6	1	7	6	4	5
25	30 microns	1	2	1	—	—	1	2

SILKS

Plates XIII and XIV

Cultivated Silk

The general term "silk" refers to the filamentous secretions of the silk worm forming the cocoon of different species of moths. Silk, as usually understood, is the fiber from the cocoon spun by the larvae of the mulberry silk worm (*bombyx mori.*)

In spinning the cocoon the worm secretes a viscous fluid, the fibroin from two tube-like glands in its body. The two tubes join into a common exit in the head of the worm, into which the secretion of two other glands flows, the sericin or silk gum, which cements the two fibroin filaments together. Upon emerging from the spinneret in the head of the worm, the double fiber coagulates on contact with the air.

When the worm has finished spinning the cocoon and has changed into the chrysalis stage, the cocoons are exposed to heat in order to kill the animal before it changes into the moth which would, by eating through the cocoon, break the filaments.

Unpierced cocoons yield from 400 to 700 yards of usable silk, which is obtained on a commercial scale by the reeling process.

MICROSCOPICAL STRUCTURE (See Plate XIII): When raw silk is examined under the microscope, the fibers appear in bundles of 8, 10, or more, always in even numbers, due to the reeling of four or more double filaments together. The surface structure is very irregular, consisting of traverse fissures, creases, and folds, as well as uneven lumps. These markings occur in the sericin layer and are caused mainly by the deforming, breaking, and rubbing off of the silk glue in the reeling operation. The individual double fiber is easily recognized as the two filaments are normally joined together and enveloped by the silk glue.

DEGUMMED OR BOILED-OFF SILK: By boiling raw silk in a soap solution, the gum or sericin, which amounts to 18-23 per cent of the total fiber weight, is removed and the dual nature of the filaments is disclosed. The isolated filaments as seen in the photomicrograph are smooth and structureless, quiet regular in diameter and transparent. Occasionally dents, constrictions and swellings occur in some of the filaments as illustrated by 5 different examples.

Hoehnel is of the opinion that the silk fiber is composed of structural filaments, fused into one another in such a homogeneous manner that it is very difficult to recognize them. This view may be upheld by the following facts:

The common fault in silk called "lousiness" (see Plate XIII) was found by Clayton, Wagner and others to be due to fibrillations or splitting up of the silk filaments into fibrillae. Clayton reports three different types: (1) "Key hole" lousiness: In this case there is a much smaller diameter filament extruded along with one of the parts of true filaments. This small filament, completely surrounded by sericin runs parallel to the main double filament. Wagner found up to 15 such secondary filaments. It is usually broken up in degumming with the result that it forms small tangled masses of "louse" at intervals along the thread. The other two types which are only discerned after the boiling-off process, are both due to splitting up of the silk filaments into fibrillae. The most common of the two types appears to be inherent in certain grades of silk, whereas the third type is caused by abrasion in the various processes such as boiling-off, throwing, and dyeing. Carbonizing with sulphuric acid will also split up the filaments into fibrillaes.

FINENESS: The widths of the individual filaments, as measured on commercial samples, are shown in the table following later. There is not much difference in the dispersion range but there is quite a difference in the average. The Chinese silks are from 1-2 microns finer than the Japanese silks. The average varies between 10 and 13 microns.

CROSS-SECTIONS: The cross-section shape of the silk fibers is the main characteristic for their proper identification. The silk fiber cross-sections are elliptical or triangular in shape, with rounded corners. In raw silks the two joined filaments normally face each other with the flat side of the triangle. In the cross-section four fiber bundles of eight filaments each are illustrated.

The silk gum forms a coat around the fiber closely resembling the epidermis of a wool fiber.

Marked differences are observed in the cross-section shape between the three layers forming the cocoon. The fiber shafts forming the inner layer are usually very flat-shaped like a wedge. The middle layer is more uniform and rounded whereas the outer part exhibits many irregularities. Similar shape differences are also found between the middle layer of different lots of cocoons. When such lots are mixed they produce two-tone dyeing in fabrics as proven by Mennerich and Hougen. In their study they used the average diameter ratio of the silk filament as criterion. By diameter ratio is meant the ratio of the largest to the smallest diameter of a given cross-section. Measurements made on Japanese silk by the U. S. Testing Co. on 24 lots gave the following results:

	Diameter in Microns			*Diameter*
	Major	*Minor*	*Mean*	*Ratio*
Average of 24 lots....	13.9	9.2	11.5	1.51
Lowest	13.1	7.7	10.5	1.70
Highest	13.6	9.2	11.4	1.48

Mennerich and Hougen found that if the average difference of diameter ratio exceeds 0.09, two tone dyeings become noticeable, and extreme when it exceeds 0.30. This difference in diameter ratio is not noticeable to the eye by microscopic examination of cross-sections except in rare instances such as illustrated by the two cross-sections, one showing a diameter ratio of 1.64 and the other 2.51 where the difference exceeds 0.8.

It can be determined only by statistical measurements of 100 filaments for each yarn to obtain a desired accuracy of 1 per cent in the average value.

WEIGHTED SILK: Weighted silk, quite easily recognized by burning, it may also be studied microscopically. Since metallic salts, used in weighting, are fixed into rather than on the fiber, not much actual weighting can be noticed on the surface. It is by means of microchemical methods, that the presence and identification of the metal salts can be observed.

Wild Silk

The name applies to silk produced by various wild living species of moths, respectively their caterpillars. Due to the fact that such silk worms are not capable of being cultivated like the mulberry worm, the fibers obtained from them are called wild silk.

TUSSAH SILK: Commercially the most important representative of this group is Tussah silk. It is spun by several Indian species (*Bombyx, Mylitta,* and *Bombyx Selene*) and by a native of China (*Bombyx Pernyi*). The latter, according to Huber, feeds on oak trees and is the producer of the Tussah silk in the Shantung Peninsula with the city of Chefoo as the center, and in Southern Manchuria with Antung as the center.

The kind and quality of cocoon is largely controlled by the climate and soil condition in the locality. The cooler weather of Manchuria produces a darker, heavier cocoon than is raised in the mild climate of Shantung with its sandy soil.

The Tussah cocoons differ from the mulberry cocoons in that they contain more gum and also calcium compounds. This makes it necessary to treat them chemically in a boiling operation before the filament can be unwound. In this boiling operation batches of 10-12 thousand green cocoons are boiled for 1½ hours in 25 gallons of soda solution (20 lb. soda to 100 gal.). The boiling is repeated twice with fresh water without soda. Including the several rinsing operations and soaking in warm water the total time for the boiling operation amounts to approximately 24 hours. The reeling is then done directly from the semi-dry cocoons without further soaking, taking 8 as the usual number of cocoon filaments to form a single thread. The normal size of the thread produced is 30-35 deniers.

KURIWATA SILK: Kuriwata silk (chestnut tree silk) is produced in Japan. It is sold in loose form as it cannot be reeled. It seems to represent the extreme in fiber size of wild silks. Its color is golden brown.

MICROSCOPICAL STRUCTURE: The wild silks, taken collectively, are all similar in their microscopical structure. It is hard to differentiate between the various species. They are distinguished from true silk in that they are more or less dark colored, having a ribbon-like form and are strongly fibrillous, with a wedge shaped cross-section. The photomicrographs shown on Plate XIV illustrate these characteristics very well.

LONGITUDINAL VIEW: The Tussah filaments are of a light tan color, broad, and ribbon-like in shape, showing pronounced striations running parallel through the fiber and frequent peculiar markings. These cross-markings are caused by the overlapping of one fiber on another before the substance of the fiber had completely hardened. The striated appearance of wild silk is evidence that structurally the fiber is composed of minute filaments. They are readily isolated by maceration in cold chromic acid. According to Hoehnel these structural elements are 0.3 to 1.5 microns in diameter. There are also noticed a number of irregularly occurring coarser striations, which are due to air channels or spaces between the filaments of the fiber. The cross-markings can be observed more advantageously under polarized light between crossed nicols, as a slight variation in the thickness will cause the appearance of other interference colors.

CROSS-SECTION: The cross-sectional contour of Tussah silk is definitely wedge shaped. In raw silk the two small sides of the wedge facing each other are surrounded by the silk glue. The filament structure can be easily observed in the cross-section as a grainy inner structure of the fiber and the saw-tooth-like contour on some of the fibers.

FINENESS: Microscopical measurements made on the Tussah as well as on the Kuriwata have proven that the width measurements made longitudinally are about equal to the average major diameter of the cross-section.

In the table below the results of the measurements made on various silks are given:

Silk Width Measurements

Origin	*No. of Fibers*	*Average Microns*	*Per Cent Variation*	*Dispersion*
Canton	200	10.80	19.5	5- 18
China Tram	200	11.75	24.0	3- 21
Japanese Organzine	300	12.75	28.2	3- 23
Tussah (China)	300	28.48	27.6	9- 51
Kuriwata (Japan)	100	87.42	14.3	50-126

Cross-Section Measurements

	No. of Fibers	*Major A*	*Minor B*	*Average*	*Diam. Ratio A/B*
Silk					
Japan	2,400	13.9	9.2	11.4	1.51
Tussah	50	30.5	8.6	19.6	3.55
Kuriwata	50	91.6	20.2	55.8	4.54

COTTON AND MINOR SEED HAIRS

Plates XV and XVI

All vegetable fibers employed in the textile or allied industries can be classified into three main types. This classification is based upon the physiological part of the plant from which the fiber is obtained or is a part of:—

I Vegetable Hairs
II Bast Fibers of Dicotyledonous Plants
III Structural fibers of Monocotyledonous Plants

Cotton

GENERAL: The cotton fiber is a single cellular seed hair of the various species of gossypium (family of Malvaceae) a plant found in moderate to tropical regions of the world. It is grown commercially in North and South America, India, Egypt and China. It was probably one of the first textile fibers used by man.

MORPHOLOGICAL: During its growth the cotton fiber appears as a thin hollow tube of round cross-sectional contour made of a thin film, primary cellulose and, according to Osborne, is encased in an all enclosing cuticle which bears the natural waxes and oils.

According to Schwarz and Shapiro: "The elongation and primary-wall deposition are completed in about twenty days (this time varies with the specie of the plant and climatic and seasonal conditions). After this, the formation of the secondary-wall (the major portion of the cotton fiber) is begun. Each day, a layer of cellulose is deposited concentrically within the primary wall. This continues for about twenty-five days (this is also a variable quantity—late-season cottons continue this secondary growth much longer)."

The cuticle is closely joined with the primary wall and covers the entire fiber and can be seen as collars and spirals on the balloon-shaped swollen fiber (Plate XV). The primary wall, the main body of the fiber during its growth, consists of cellulose chains whose long axis E. Berkley, found by means of X-ray diffraction patterns, to be lying in the traverse direction to the long axis of the fiber.

Secondary layers of cellulose are composed of fibrils spiralling about the axis and making angles up to about 25° with it. (See top, Plate XV.) The cellulose micelles are orientated parallel with the axis of the fibrils but at an angle of 25° to the fiber axis. According to Osborne these spirals may change at intervals the direction of their inclination from S to Z twist and vice versa along the fiber length. The micro-structure of the various layers of the cotton fiber, while in part can be observed with ordinary conditions under the microscope, can be studied by means of polarized light or by swelling reactions with cuprammonium hydroxide or both, as is employed by Hock and Harris.

Similar to animal hair, cotton and other seed hairs consist of three parts, the root or base, stem and tip. The root is cone shaped. Toward its free end the fiber tapers into a fine rounded point. (See Plate XV.)

FINENESS: Like other textile fibers, cotton varies in fineness among various species grown as well as similar species grown in different parts of the world. The average width may vary from 10 to 40 microns as is illustrated by the longitudinal and the cross-sectional views made by United States Department of Agriculture. Width measurements made by the Forstmann Woolen Co. laboratories on samples from the U. S. Department of Agriculture gave these results:

Width Measurements of Cotton Fibers

Types	*Number of Fibers*	*Average Width Microns*	*Coefficient of Variation per cent*	*Dispersion Range Microns*
Sakellarides	200	16.4	18.7	8-26
American Egyptian	300	16.2	20.9	6-26
Fine American Upland	200	17.1	22.4	8-27
Coarse American Upland	200	19.2	21.2	8-30
Indian	400	21.2	18.8	10-33

Cross Sectional Measurements made by Schwarz and Shapiro are given below:

Cross Section Measurements

Types	*Number of Fibers*	*Major Microns*	*Minor Microns*	*Major-Minor ratio*
American Upland	283	23.2	8.75	3.69
Egyptian Uppers	296	24.7	7.30	5.27
Pima	266	19.1	7.30	3.22
Soudan	281	21.9	6.65	4.29

The major-minor ratio represents the average of a series of quotients, and not the quotient of the major-minor average.

In the next table the Dept. of Agriculture, Division of Cotton Marketing gives average values of area of cross-section of the whole fiber, of lumen, of wall and maximum and minimum diameters of fiber and lumen, and shape factor:—

Average Cross Sectional Features of Cottons In Four Ranges of Fineness

	AREAS μ^2			DIAMETERS μ					
Samples	*Total*	*Lumen*	*Net*	*Major*	*Minor*	*Major*	*Minor*	*Major/Minor*	*Wall Thickness* μ
Very fine	98.90	10.54	88.38	9.77	1.20	16.73	6.20	3.07	2.50
Fine American Upland	155.26	11.89	143.37	10.92	1.05	20.02	7.83	2.77	3.39
Coarse American Upland	230.05	19.02	211.04	14.22	1.55	24.97	9.49	2.90	3.97
Very coarse Asiatic	374.26	27.49	346.78	12.53	2.24	27.26	14.57	2.07	6.17

BAST FIBERS

Plates XVII and XVIII

The fibers described below are all derived from stems of dicotylodoneous plants. They are, according to their importance:

Flax—Linum usitatissimum
Hemp—Cannibas Sativa
Jute—Corchorus capsularis
Ramie—Boehmeria nivea

The differentiation between various bast fibers and structural fibers is at times very difficult, as in the case of flax and hemp, and a slightly different approach has to be made than in the identification of animal fibers. Structural differences among the vegetable fibers originating from various plant species are usually very minute and have to be emphasized by swelling and part disintegration of the fibers or by the use of polarized light. Another quite helpful means for identification is the presence of non-fibrous parts of the plant of origin on the fibers in question. These adhering fragments of vegetable matter form an important link of evidence in tracing the origin of the fibers under examination. Wiesner and Herzog strongly emphasize the importance of such fragments as clues or guiding elements (Leitelemente). Needless to say a quantitative analysis of different vegetable fibers identified by means of such fragments is impossible as well as is the chance of finding such particles in a bleached or otherwise chemically treated fiber stock.

Most commercial bast fibers are in their raw, unbleached state, composed of bundles of bast cells of considerable length, joined together by thin membranes. Each cell tapers either into a sharp or somewhat rounded or forked point on either of its ends. After bleaching and repeated mechanical operation the bundles are separated into the individual bast cells. The fissures or markings found in some fibers are, according to Schwendener, breaks and pressure marks caused during the harvesting of the plant and the retting of the bast as well as during further treatments. Balls observed such markings or "slip planes" on cotton and believes they are caused by mechanical action and, further, that they most likely occur at right angles to the fibrils making up the fiber. Osborne made the most detailed study on this subject, i.e., flax, ramie and jute fibers.

Flax

Flax or linen is the best known of the bast fibers. In its raw state the fibers are in bundles, but after manufacturing and bleaching most of the fibers separate and can be seen as individual bast cells under the microscope.

It may be stated here that a very useful medium for microscopical examination of all vegetable fibers is a staining reagent made of iodine solution and glycerol-sulphuric acid. The preparation and use of this two-solution stain and swelling reagent, described on page 869 in Matthews' "Textile Fibers," is as follows:

Three grams of potassium iodide are dissolved in 60 cc. of water and add 1 gram of iodine. For use dilute with 10 parts of water. The sulphuric acid can be prepared by mixing 3 parts of glycerine, one part of water to 3 parts of sulfuric acid. After staining fibers in the iodine solution, they are blotted off the microscope slide and the fibers mounted in the sulfuric acid.

The use of stains is indispensable in the microscopic analyses of papers and those fibers most commonly used in the paper making industry. The Color Atlas for Fiber Identification by Graff, published by the Institute of Paper Chemistry is the outstanding work in this field. Many of Graff's staining methods may be successfully applied by the textile microscopist.

MICROSCOPIC APPEARANCE: — Raw flax, when stained in the above manner is of bluish color with yellow protoplasmic particles evident in the narrow lumen. The cross markings or nodes are stained a deep color and are quite pronounced. Usually a slight swelling takes place at these joints and fissures. The cell ends are pointed in most cases, but occasionally slightly rounded tips are found. When examining flax under polarized light (crossed nicols) the nodes are easily observed without stain. (See Plate XVII.)

Bleached flax shows few structural differences from the raw fiber except that the color of the latter is white. All non-fibrous parts found in the raw flax are removed. The cross-sectional contour of flax is sharp-edged polygonal, slightly elongated. The lumen is visible as a small round to oval opening in the fiber center.

When treating the raw fiber with a strong concentration of ammoniacal copper oxide or cuprammonium hydroxide, it swells rapidly and eventually goes into solution. The inner lumen containing the protoplasmic fragments appears as a wavy thread. On most swollen fibers a pronounced left thread spiral structure is evident. Differentiation between flax and cotton is quite easy by means of staining with iodine and sulphuric acid. The approximate diameter of the flax cells averages from 15 to 17 microns.

By shaking and rubbing together raw flax fibers and collecting the debries, the following plant parts or fragments can be seen after immersion in ammonical copper oxide:—Elongated epidermis cells, wood fibers and parenchyma cells without crystals.

Hemp

The fiber of the hemp plant (cannibas sativa) is chiefly used in twine and thin ropes.

MICROSCOPIC APPEARANCE:—After staining with iodine and sulfuric acid, the fiber, which is normally in the raw, unbleached state, is of dirty bluish green color, also shows the pronounced cross markings but usually has a wider lumen than flax. Yellow stained plasmatic particles in the lumen, seldom found, are grainy in appearance. The cross-section of the fiber, while sometimes exhibiting the symmetric contour of the flax fiber, is irregular varying from triangular to polygonal shapes. The corners are much rounder and softer than in flax. The lumen appears as oval to elongated hole or thin line in the fiber center.

When treating the fiber with cuprammonium hydroxide the fibers swell and dissolve much slower than flax and the lumen is pushed together giving it a ruffled appearance. The spiral structure visible in flax is absent or hardly visible and then the direction of the spiral is to the right.

Herzog found that by examining hemp and flax fibers under polarized light, he was able to differentiate between them by the variation in interference colors under crossed nicols (fibers in orthogonal position). After insertion of a selenium plate (Red I), flax shows at 0° addition colors, at 90° subtraction colors, while hemp shows at the former position subtraction colors and at the latter addition colors. It was found that bleached fibers only partially respond to the above test. The average fineness of hemp fibers varies from 18-23 microns. Characteristic elements found in raw hemp are epidermis fragments with pronounced surface hairs.

Ramie

China grass or ramie is derived from the Boehmeria nivea, a plant commercially utilized in Asia. The bast fibers of the ramie are much coarser than either the flax or the hemp fibers.

MICROSCOPIC APPEARANCE:—In longitudinal view, ramie appears as irregular knotty, often ribbon-like fiber. Iodine and sulfuric acid stain this fiber a pure blue. The main characteristics which enable the differentiation of this fiber from the previously mentioned bast fibers are the pronounced diagonal cracks in the surface and heavy thickening of ramie. Examination under polarized light clearly shows the cross markings and cracks. (See Plate XVIII.)

The cross-sectional shape of ramie is similar to cotton, and could be mistaken for the latter except for its much larger diameter. The average fineness varies from 30 to 70 microns. The cross-sectional contour varies from hexagonal to oval shape. Characteristic are the fissures running from the outer circumference towards the lumen. These are the diagonal cracks visible on the longitudinal view of the fibers.

Osborne came to the conclusion that the high number of fissures or cracks and their shape explains some of the characteristics of this fiber. They are responsible for the great reduction in strength from the theoretically expected strength. It also explains to a large measure the lack of extensibility and flexibility of ramie. If the fiber were not so riddled with imperfections, it undoubtedly would be much stronger and better spinnable commercially.

Jute

This fiber obtained from the Corchorus capsularis is easily distinguished from flax, hemp and ramie. When stained with iodine and sulphuric acid this fiber shows a golden yellow to brown color. The fiber is always found in bundle form even after manufacturing.

MICROSCOPIC APPEARANCE:—The individual bast cells are very fine, measuring about 15 to 20 microns and are much shorter than the other bast cells measuring only 2-3 mm. in length. The lumen of the fiber at various intervals narrows to a thin line or disappears completely. (See Plate XVIII.) Nodes or cross markings are usually absent, but are occasionally found. The cell ends vary from spearhead-shaped to tapering, points. The cross-sectional contour of the cells is polygonal with a pronounced oval lumen.

Jute—Single Cell—Measurements by Osborne

Ave. cross-sectional area (total)	118.0 sq. μ	(30)
Ave. cross-sectional area cell wall	108.9 sq. μ	(30)
Ave. cross-sectional area lumen	8.9 sq. μ	(30)
Ave. per cent of total area occupied by lumen	7.5%	(30)
Ave. length	2.4 mm.	(25)
Ave. width (filar micrometer)	10.0 μ	(240)
Ave. width 'x' cell (filar micrometer)	10.0 μ	(23)
Ave. width lumen of 'x' cell (filar micrometer	3.0 μ	(23)

In recent years a treated jute fiber was introduced by the Lanitin Corporation in the American market. The product's trade name is "Lanatin." It resembles wool, and is not to be confused with Lanital, a synthetic wool made of Casein.

The jute fibers are treated with an alkaline solution, preferably sodium hydroxide, which removes part of the substances holding the fiber bundles together and changes the tan color of the fibers to a light cream. As seen from the photomicrographs, the fibers still more or less retain their fundamental characteristics.

FINENESS:—Cross-sectional and width measurements made on fibers of flax, hemp, ramie, and jute gave the following results:

Cross-sectional Measurements

Number of Fibers	*Flax* 100	*Hemp* 100	*Ramie* 100	*Jute* 100
	Microns	*Microns*	*Microns*	*Microns*
Average	14.9	18.3	24.3	15.5
Major	16.1	23.6	32.4	18.6
Minor	8.8	13.1	16.2	12.3
Ratio: minor:major	1:1.9	1:1.8	1:2.0	1:1.5
Lumen				
Average	1.87	4.26	7.92	3.32
Major	3.82	7.30	13.96	4.58
Minor	1.12	0.72	1.85	2.05
Ratio: minor:major	1:3.4	1:10.2	1:7.5	1:2.2

Width Measurements

	No. of Fibers	*Av. Width Microns*	*Co-eff. of Variation Percent*	*Dispersion Range Microns*
Linen Irish Bleached Yarn	200	15.5	26.9	8—20
Ramie, Combed	200	24.9	31.6	10—47

STRUCTURAL FIBERS

Plates XIX and XX

The third group of vegetable fibers, as mentioned before, are the structural fibers obtained from leaves, leaf stalks and other parts of monocotyledonous plants. The more commonly used fibers belonging to this group are:

Sisal (*Agave sisalana*)
Manila (*Musa Textilis*)
New Zealand Flax (*Phormium Tenax*)
Piassava (*Attalea Funifera*)
Raphia (*Raphia Ruffia*)
Coir (*Cocos Nucifera*)
Spanish Moss (*Tillandsia Usneoides*)

Of these, sisal, manila and New Zealand flax are employed chiefly in ropes and twines; Piassava fiber in brooms; Raphia in plaited textiles; Coir in door mats; and Spanish Moss as stuffing material for upholstery.

In the differentiation between these vegetable fibers, various aids as swelling, staining, as well as the examination of non-fibrous particles of the plant, usually found in unbleached fibers have to be employed. In the case of the fibers discussed here, the Sisal, Manila and New Zealand flax cause difficulty in their identification while the other fibers are readily told apart from each other by their color and general appearance.

In all instances the fiber, as found in the commercial products is composed of one or more fiber bundles ultimately made of numerous bast cells. In this respect they are similar to the bast fibers such as flax, hemp, ramie and jute; with the exception, that besides the ultimate bast cells, other structural materials are found from that part of the plant from which the fiber was obtained.

Sisal

This fiber is obtained from a number of varieties of Agave of which the Agave rigida and Agave sisalana are the two more common species. The color of the commercial fiber is yellowish white. Its chief use is for ropes, but it is also employed as a stuffing material and as a substitute for animal bristles in low grade brushes.

MICROSCOPIC APPEARANCE: The cross-sectional shape of the fiber bundle is crescent though also oval bundles are found. The individual cells have a sharp polygonal shape with a pronounced oval to circular lumen.

In longitudinal view the bundle does not show many characteristics and the fiber cells should be separated by boiling in a 1-2 per cent solution of caustic soda. After separation the single cells, which according to Herzog are 1-5 mm. in length and average 24 microns in width, can be observed. The cell end is usually blunt and at times forked as shown in Plate XIX. The wide lumen can easily be seen. No cross-markings were observed on the samples examined. Spiral shaped sclerenchyma tissues are frequent. These spiral vessels and parenchyma cells contain single oxalate crystals up to 0.5 mm. long. By igniting the fiber and examining the ash microscopically these crystals of calcium oxalate are found, thus furnishing a means of identification. (See Plate XIX.)

Manila Hemp (Also Called Abaca)

This fiber obtained from the Musa textilis is chiefly produced in the Philippines. It is one of the most important of all structural vegetable fibers and is used in ropes of all types but chiefly for marine cordage, as it has greater resistance to salt water than sisal. Its natural color is yellow to reddish yellow.

MICROSCOPIC APPEARANCE: The cross-sectional contour of manila differs from sisal in that the fiber bundle is of oval to round shape and never of crescent form. The cells are of soft round polygonal to oval contour. The lumen is large and usually corresponds to the shape of the fiber contour.

Similar to sisal the cells have to be separated with caustic soda to observe their characteristics longitudinally. The fiber ends are long tapering to a fine point. Occasionally granular matter is found in the lumen. Highly characteristic of manila hemp are the strongly silicified tabular cells, the so-called stegmata which surround the fiber bundles for the most part in single rows. By macerizing the fiber in chromic acid or by ashing them, the stegmata remain behind forming what resembles strings of elongated beads. See Plate XIX. The ash of fibers is dark grey to black.

New Zealand Flax

This fiber, obtained from the leaves of the flax lily Phormium tenax, is employed in twines and ropes. The color of the fiber is brownish yellow.

MICROSCOPIC APPEARANCE: The cross-sectional contour of the bundle is oval to round. The individual fibers vary from circular to oval-polygonal contour with a lumen that is usually small and circular. The fibers are more readily separable mechanically or chemically than sisal and manila.

When examined longitudinally the fibers which average about 16 microns in fineness exhibit a fine tapered end. A large amount of parenchyma and epidermis fragments are characteristic of this fiber. When ignited the fibers leave a brownish ash.

As all of the three fibers mentioned are employed for cordage products, it is essential to be familiar with the means of differentiating between them. In the following table the principal physical and microscopic characteristics for differentiation are given.

	Sisal	Manila	New Zealand Flax
Color of Fiber	Yellowish white	Yellow to reddish yellow	Brownish yellow
Color of Ash after Burning	Grayish white	Dark gray to black	Grayish brown to dark brown
Cross-Section of Fiber Bundles	Crescent shape	Oval to round	Oval to round
Sewett Test (Chlorine and amm. fumes)	Cherry red	Brown	Sometimes red
Special characteristics	Calcium oxalate crystals in ash	Stegmata in ash	Numerous spirals and other non-fibrous matter on fibers

Cross-Sectional Measurements

	Sisal	*Manila*	*New Zealand Flax*
Number of Measurements	100	100	100
Fiber:	Microns	Microns	Microns
Average	14.8	17.0	13.0
Major	18.0	20.0	15.1
Minor	11.6	14.0	10.8
Ratio $\frac{\text{Major}}{\text{Minor}}$	1.55	1.43	1.39
Lumen:	Microns	Microns	Microns
Average	4.6	5.4	3.7
Major	6.5	6.7	4.9
Minor	2.7	3.6	2.5
Ratio $\frac{\text{Major}}{\text{Minor}}$	2.4	1.86	1.97

Width Measurements

	Sisal	*Manila*	*New Zealand Flax*
No. of Measurements	200	200	200
	Microns	Microns	Microns
Average	19.3	17.6	16.3
Percentage of Fibers from			
10.15 microns	16	28	40
15-20 microns	48	47	46
20-25 microns	27	19	13
25-30 microns	9	6	1

Piassava

The fiber is obtained from the Piassava palm grown in Brazil and Africa. The commercial fiber is thick varying from 0.8-3.5 mm. and is of brown to black color. It is employed in brooms. When examined microscopically the fiber cross-section show an oval to bean shape contour. The cells are tightly packed and have a polygonal shape. By macerizing the fiber in chromic acid small round to star shape silicous stegmata are found.

Raphia

The fiber is obtained from the cuticle of the leaves of the raphia palm. The commercial product is in the form of flat straw colored strips.

The cross-section (Plate XX) shows the cuticle with the bast cells bundles arranged at intervals along the inner wall of the cuticle.

Coir

From the outer husk of the cocoanut the coir fiber is obtained. Its color is brown to reddish brown and its chief use is in mattings and cheaper ropes. The commercial fiber is short when compared to other structural fibers. Its length average about 10 inches. The cross-sectional contour is full round. In the middle of the bundle usually a hollow space is observed. (See Plate XX). Longitudinal examination of the fiber cells which are short—0.4-1 mm. in length show a spiral structure in the lumen as well as occasional plate like stegmata at the cell tips. These stegmata cells are easily visible in the ash of the fibers.

Spanish Moss

Tillandsia or Spanish Moss found hanging from trees in Louisiana and other Southern states is used as stuffing material. The entire plant is employed for this purpose and only the cuticle and small protrusions are peeled off. This fiber is easily identified microscopically by its color which varies from grey to dark brown and its general appearance. The cross-sectional contour of the fiber varies from oval to round. Characteristic elements found on the fiber are the thin fan shaped scales.

FINENESS: Width and cross-sectional measurements made on Sisal, Manila, and New Zealand Flax are tabulated in the foregoing table. For the width measurements, the fibers were separated with a very weak solution of caustic soda.

RAYONS

Plate XXI and XXII

The generic term "rayon" refers to filaments made from various solutions of modified cellulose by pressing or drawing the cellulose solution through an orifice and solidifying it into the form of a filament. (A.S.T.M. definition.) As a cellulosic fiber, they are generally classified as vegetable fibers. Rayon is marketed in two forms, namely as continuous filament yarn and as staple fibers of spinnable length. The rayon staple fiber may be manufactured directly or by cutting continuous filaments.

Four distinct manufacturing processes are used to produce the following filaments named in the order of their commercial importance:

1. *Viscose Rayon*—Filaments composed of regenerated cellulose, which have been coagulated or solidified from a solution of cellulose xanthate.
2. *Acetate Rayon*—Filaments composed of an acetic ester of cellulose, which has coagulated or solidified from its solution.
3. *Cuprammonium Rayon*—Filaments composed of regenerated cellulose which has been coagulated or solidified from a solution of cellulose in ammoniacal copper oxide.
4. *Nitro Rayon*—Filaments composed of regenerated cellulose (denitrated nitro cellulose) which has been coagulated or solidified from a solution of nitrated cellulose.

All varieties are made in three grades, according to their luster, namely, bright, semi-dull and dull. The degree of luster depends upon the amount of pigments present such as titanium dioxide.

The original object in developing and manufacturing rayon was to imitate real silk. This is now outlived and the material occupies a unique position of its own. However, the fineness of the filament yarns as well as the rayon fibers are expressed in denier.

MICROSCOPICAL APPEARANCE:

The booklet on rayon identification of the American Association of Textile Chemists and Colorists in 1934, contains the following statements: *"Rayons are most easily, quickly and positively identified by means of a microscopic examination, we recommend that this method be used, whenever possible. A microscopic examination of rayon is very simple and can be successfully carried out by men previously unfamiliar with the use of the microscope after a few hours' practice."*

The media for mounting regenerated cellulose rayons, i.e., viscose, and cuprommonium may be either glycerine, colorless mineral oil, (refractive index about 1.46), or monobrom naphthalene (refractive index about 1.66): and for acetate rayon decane (refractive index 1.41).

Viscose Rayon: The filaments as well as the staples are made in finenesses ranging from one to twenty denier. In its longitudinal view, a multitude of striations running along the direction of the fiber axis, is characteristic. These striations are visible even in the dull filaments, where the presence of pigment shows up in numerous black dots. When water is employed as an imbedding medium, the fibers swell 25 to 40 per cent. (See measurements.)

The cross section may vary greatly in shape from fully round to ribbon-like forms. The factors responsible for their shape are the nature and strength of the coagulated bath, the size of the orifices and the difference in the stretching after coagulation. The chief characteristic of the viscose cross section is the strongly serrated contour. Some of the latest wool-like viscose rayon staples are exceptions, as they are nearly circular with a smooth contour.

Acetate Rayon: This fiber is somewhat different in its chemical property from the viscose, due to its cellulose compound nature. In its microscopical longitudinal view striations similar to viscose rayon are present. However, their occurrence is less numerous but more pronounced than in viscose. Usually from 2 to 3 pronounced striations are characteristic in acetate rayon. Quite a high percentage of the acetate rayon staple show twist formations as illustrated in Plate XXI. Acetate rayon swells less than 10 per cent in water.

There is a distinct difference between the cross section of an acetate fiber and viscose fiber. The acetates vary from kidney to cloverleaf-like shapes with the contours smooth and round.

Cuprammonium Rayon: Microscopically this fiber resembles closest the structure of the silk. Longitudinally the filaments appear as fine structureless fibers without striations. Only occasionally faint striations may be observed. In their cross-sectional shape the fibers vary from a circular to a slightly irregular oval shape similar to a fine wool cross section. The contour is very smooth.

Nitro Rayon: Nitro cellulose rayon is no longer produced in the United States and is therefore of minor importance here. In its microscopical appearance this fiber is similar to acetate rayon. It can be distinguished from the latter by means of stains such as iodine, which stains nitro rayons dark brown, while it stains acetates yellow.

Rayon Staple Fibers

The rayon staple fibers generally have the same microscopical characteristics as the continuous filaments of the same variety. But as rayon staple fibers are mainly employed in blends with various natural fibers, spun with different types of spinning equipment, it is necessary to make them in their physical make-up as closely as possible to the natural fibers. Because of this use, the fibers are at present produced in a number of standard diameters and lengths to suit the various fibers they are blended with, such as cotton and wool.

For mixtures with cotton, the preferred sizes are 1½ and 3 denier with staple lengths below two inches. The most common length is 1½" to 1 9/16". For the wool industry the denier sizes are chosen according to the wool grade. The most common sizes are 3, 4 and 5 deniers. Any length is available but the most common staple lengths are 3, 4, and 6 inches.

In the last few years the wool type rayon staples underwent radical changes. One was the introduction of crimp, as in the Teca staple of Tennessee Eastman, another the broadening of the diameter variation, a third, the changing of the cross-section shape more to a circular one to eliminate dirt retention.

DETERMINATION OF DENIER SIZE: To establish the fineness or size of the fiber, the width or the cross-section method can be used. The cross-section method is the preferred method of the American Society for Testing Materials, and described in their tentative method of testing rayon staple, Designation D 540-39-T. In this method the cross section is projected on a graph tracing sheet, magnification x 1,000. The outline of at least 25 different fibers is traced for each sample to be measured. From this tracing the area is determined by counting the number of square millimeters enclosed by the tracing outline. The average denier per fiber is then calculated as follows:

CALCULATION: Denier, per fiber $= \dfrac{A \times S \times K}{M^2}$

where:
A = average observed area in square millimeters,
S = specific gravity of the sample,
M = linear magnification, and
K = a constant numerically equal to 9,000.

Note:—The constant K is the theoretical denier of a fiber having a specific gravity of 1.0, and a cross-sectional area of 1 sq. mm.

The cross section photomicrographs as illustrated on Plate XXII show that the differences from one denier size to the next one are in most instances so great that by simple comparison an unknown sample may be determined.

In order to bring out the outline more distinctly some of the fibers are dyed. In doing this the dyestuff often does not penetrate the fiber fully, therefore the contours are much darker than the inside of the fibers. All cross sections were made with Hardy's fine cross-section device and imbedded in collodium. As collodium to a certain degree attacks the surface of the actate fibers, as can be seen in the twenty denier Teca, the interior of the fiber is strongly corrugated. *This corrugation should not be taken as a characteristic.*

WIDTH MEASUREMENTS: Whereas the cross section measurements are close to the theoretical value, the width measurements of the viscose and acetate rayons are considerably higher as seen from Table I. The theoretical curves of acetate and viscose differ because of the difference in the specific gravity, viscose 1.52, acetate 1.33. The actual measurements of both fibers form an identical curve. The reason for the difference is the uneven shape of the rayon fibers.

TABLE I

Theoretical and Actual Width of Rayon Staple Fibers

Number of Fibers 200; Medium—Glycerine C.P.

Denier Size	*Theoretical Microns*	*Aver. Microns*	*Standard Deviations Microns*	*Standard Error Microns*	*Percent Variability*
		Acetate Staple Fibers*			
3	17.8	19.55	2.48	.17	12.6
5	23.0	25.17	3.40	.24	13.5
8	29.1	32.88	3.91	.27	11.8
12	35.7	40.03	5.87	.41	14.0
16	41.2	45.00	6.43	.45	14.0
20	46.1	51.55	7.51	.53	14.5
		Viscose Staple Fibers**			
1.5	11.8	14.45	2.16	.15	14.0
3	16.7	20.55	2.35	.16	11.4
5.5	22.6	27.35	3.40	.23	12.4
10	30.6	36.80	5.25	.37	14.2
20	43.2	49.45	6.95	.48	14.0

*Teca Staple.
**American Viscose Corp.

TABLE II

Percent of Water Swelling of Rayon Fibers Average Width of 100 Fibers

Rayon Filaments

Sample	*DuPont Cordura 100 Dr. 40 F.*	*Am. Visc. Co. Tenasco Bright 40 Dr. 18 F.*
Glycerine microns	17.60	17.8
Water microns	24.50	23.7
Percent Swelling	36.8	32.9

Rayon Staples

	Dupont Viscose 3 Dr. Dull	*Am. Visc. Co. Fibro 5.5 Dr. Bright*	*DuPont Acele 3 Dr. Br.*	*Tenn. East. Teca 5 Dr. Dull*
Glycerine microns	20.85	27.35	20.95	25.17
Water microns	26.77	39.50	22.30	27.57
Percent Swelling	28.39	44.42	6.44	9.53

Acetate is more circular than viscose. Therefore actual data are closer to the theoretical figures.

Width measurements of staple rayons of different diameters were made according to the standard method for fineness of wool.

By measuring the width, the fact that the fibers are not round is disregarded and it seems that we are mostly measuring the major diameter of the fiber and therefore the difference in the case of the viscose fiber.

Where staple rayons are blended with wool, it is important to know the exact relationship between the denier size and the various rayons and the wool grades. Various charts were recently published to show for the convenience of the trade, on the basis of curves, the deniers and their corresponding diameters in microns, based on theoretical circular cross-sections.

A similar chart showing not only the relationship between viscose and acetate rayon, but also nylon and glass fibers was especially prepared for this Atlas and illustrated on page 36.

PROLONS AND SYNTHONS

Plates XXIII and XXIV

Prolons

The man-made protein fibers refer to filaments or staple fibers made from various solutions of modified proteins by pressing or drawing the protein solution through orifices and solidifying it into the form of a continuous filament. The proteins used are: (a) Casein (milk), (b) Soya bean protein, (c) Zein (corn), (d) Fibroin (silk).

Casein Fibers

Probably the most extensive research was made on the possibilities of producing fibers from milk casein. The first fiber of this class produced on a commercial scale originated in Italy. It was introduced in 1935 under the trade name of "Lanital." Today casein fibers are produced commercially in several European countries as well as in the United States and marketed under the trade names such as: *Lanital* (Italy), *Aralac* (United States of America), *Lactofil* (Holland) and *Tiolan* (Germany).

LANITAL: As mentioned previously, this fiber was the first of its kind and introduced as "synthetic wool." Small amounts of this product were imported into this country previous to Italy's entry into the war.

Microscopical Appearance: Longitudinally the fibers are very even in width, showing a rough surface with small dots and faint longitudinal streaks. The cross-sections are nearly circular and highly uniform. Occasionally a number of small indentations or notches are observed around the cross-sectional contour.

ARALAC: In this country various concerns are experimenting with casein fibers. Aralac, a product of the Atlantic Research Associates, Inc., was introduced in the Spring of 1940. The fiber is made in two forms, natural and opaque or delustered.

Microscopically the fiber differs little from Lanital. In its longitudinal view faint striations and a grainy surface are characteristic. The difference between the natural and the pigmented fibers is very marked as may be seen from Plate XXIII. The cross-section is highly circular, but the contour is perfectly smooth with no notches present. Where an inner channel is present it is seen as a perfectly circular hole in the center of the fiber.

SOYA BEAN FIBER: This fiber was first introduced to the American people at the New York World's Fair of 1939 at the Ford exhibit. Its base is a protein of the soya bean produced by the Drackett Product Co., Cincinnati, under the trade name of Alysol protein. In its microscopical appearance as seen from Plate XXIII, the fiber is very similar to Aralac and Lanital.

Proper differentiation of soya bean and casein fibers is possible on the basis of their variation in the amino acids present by qualitative color reactions, as reported by Williams and Tonn.

Fineness: The high circularity of the casein and soya bean fiber makes the accurate diameter determination easily possible by the width as well as the cross-section method. In all width measurements glycerine should be employed as the imbedding medium to avoid any swelling. Width measurements made on various samples are as follows:

	Lanital Top	*Aralac Top* 1	2	3	4	*Soya Bean Loose*
Type	*4 Den. Dull*	*Lab. Sample*	*Oil Combed 20 Microns Ther-molized*	*Dry Combed 24 Microns Ther-molized*	*Oil Combed 28 Microns*	*Lab. Sample*
No. of Fibers	200	200	200	200	200	200
Average	24.3	11.4	21.5	23.9	27.9	26.8
Standard Deviation	3.65	0.9	3.05	4.29	4.47	2.04
Coefficient of Variation	15.0%	7.9%	14.2%	18.0%	16.0%	7.6%

The data indicates that the variation in the fiber sizes is similar to the variation found in rayons. In the determination of the swelling in water and N/10 caustic soda, there is an excellent tool in studying the state of the fiber in regard to its properties, such as strength, because the lower the swelling in the various mediums, the better the fiber. Swelling measurements made on various samples with water and caustic soda gave the following results:

Type	*Lanital Top, 1937*	*Aralac Top*			*Soya Bean*
	Dull	*Regular*	*Dull*	*Dull Ther-molized*	*Regular*
Glycerine, microns	25.2	21.5	20.5	20.6	26.6
Water, microns	28.0	23.8	23.2	23.4	32.8
n/10 Caustic Soda, microns	36.75	29.0	27.8	26.8	43.6
Per Cent Swelling: Water %	11	10.6	13.4	13.4	23.0
n/10 Caustic %	46	34.9	35.6	29.9	63.5

REGENERATED SILK: This fiber was first heard of in 1937. The country of origin is Japan where it is obtained by dissolving silk wastes, such as broken cocoons, in a suitable medium and re-solidifying it in a manner similar to the casein and rayon fibers. The few samples imported into this country at that time were found of very low strength and high brittleness. Microscopical examination shows the filaments to be of ribbon-like shape with strong striations running along the length of the fiber. Occasionally some of the fibers are twisted similar to Tussah silk. The cross-section of the fiber reveals the unique narrow ribbon shape. The longitudinal striations are caused by the folding up of these ribbons.

Cross-section measurements made on two samples were as follows:

Type	*60 Denier, 125 Filaments*	*1500 Denier, 500 Filaments*
Major diameter	20 microns	45 microns
Minor diameter	3 microns	9 microns
Ratio: $\frac{\text{Major}}{\text{Minor}}$	6.7	5.0

Synthons

Recently two fibers, nylon and vinyon, have been introduced in the market, which can be classified as purely synthetic fibers.

NYLON: Nylon is the first really synthetic textile fiber that has found practical use. The fiber is produced by the E. I. du Pont de Nemours Co., and is covered by United States Patent No. 2,130,948, granted September 29, 1938.

The basic principle of the process is the condensation of amino acids through extensive heat treatment resulting in a hard, opaque molten mass. This mass is capable of being spun into a continuous filament similar to the spinning of glass.

Microscopic Characteristics: In their longitudinal view as seen on Plate XXIV the filaments appear very even in width over the whole length and smooth like a glass rod, showing no surface structure or sign of any twist.

The dull filaments show the same characteristics with the exception that pigments—titanium dioxide—are present. The cross-sections of dull and bright nylon fibers are circular and extremely uniform in their diameter. The contours are absolutely smooth and not corrugated. The dispersion of the pigments in the dull nylon filaments is similar to that in a medium dull rayon. In their general microscopic characteristic nylon fibers closely resemble the filament of cuprammonium rayon.

Fineness: Nylon filaments, according to the patent, can be drawn to any desirable size from less than 10 microns (1/2500 of an inch) up to several hundred microns depending on the use, either as a regular fiber for textiles or for the manufacturing of bristles. The fineness of the single filaments of the three samples tested gave the following characteristics:

Fineness Characteristics of Nylon Filaments

Type	*Nylon* 45 *Dr. Yarn*	*Nylon Neophil* 195 *Dr.*	*Nylon*
	Luster	*Luster*	*Dull*
No. of Fibers.............	100	100	100
Average Microns	18.53	19.97	24.52
Standard Deviation—microns	1.00	1.25	1.25
Variation	5.4%	6.3%	5.1%

The measurements reflect the extraordinary uniformity of this new fiber, which is indicated by the low variation of 5 to 6 per cent against 8 to 10 per cent in the most uniform rayons and 17 per cent and up for natural fibers such as silk and wool.

VINYON: Vinyon was originally made by Carbide & Carbon Chemicals Corporation and described in a U. S. Patent, No. 2,161,766, granted to Rugeley, Field Jr. and Conlon in 1937. Later in 1939, the American Viscose Corporation took up the manufacture of the filament yarn and textile fiber.

Vinyon is produced by polymerization of vinyl chloride or vinyl acetate. The raw polymer in the form of a white fluffy powder is dispersed in acetone and a dope is obtained containing 23 per cent of the copolymer by weight. After filtering and deaerating, this solution is spun the same as acetate rayon and coagulated by the dry or warm air process.

Microscopical Appearance: When viewed under the microscope longitudinally, the fibers in their natural form resemble mercerized cotton with a lumen-like channel running through the middle of the fiber with occasional twist. The illusion of a lumen is caused by the peculiar cross-section shape. At 500 magnifications, the two thick ends cast a shadow as shown on the right side of the cross-section. The delustered fiber as shown on the left side of the cross-section on Plate XXIV shows a somewhat rough surface structure. By examining vinyon in organic solvents, for example in bromonapthalene, the fiber gradually dissolves by disintegrating first into splinters which, as they diminish more and more, start to undulate.

Fineness: Measurements made on three samples gave the following results:

Vinyon Fineness Measurements

Types	*1*	*2* S T	*3* H S T
No. of Fibers	200	100	100
Average Width, microns....	18.47	16.77	16.72
Standard Deviation	5.97	3.23	4.03
Coefficient of Variation.....	32.4%	31.19%	24.1%
Cross-Section:—			
Major Diameter, Microns..	17.7		
Minor Diameter, Microns.	3.7		
Ratio $\frac{\text{Major}}{\text{Minor}}$	4.7		

It is interesting to note that the average width on the first sample of 18.5 is very close to the average diameter 17.7. This proves that all the fibers lie on their broad side.

Swelling of Nylon and Vinyon

	Average of 100 Fibers				
	Glycerine Microns	*Water Microns*	*Per Cent Swelling*	*n/10 NaOH Microns*	*Per Cent Swelling*
Nylon ..	18.5	18.6	+ 0.54	18.6	+ 0.54
Vinyon .	18.5	16.2	—12.44	...	...
H S T...	16.7	16.0	— 4.20	18.4	+10.17

The synthetic fibers are the only ones which do not swell in water. Vinyon even seems to do the opposite. The explanation of this may be the curling of the ends.

MINERAL FIBERS

Plate XXV

There are two mineral fibers of commercial textile importance, namely, asbestos and glass.

Asbestos

The principal and, strictly speaking, the only mineral fiber is asbestos, which occurs in nature as a mineral of that name. It is a fibrous silicate of magnesium and calcium, though often containing iron and aluminum in its composition, especially in the dark-colored varieties.

The composition of asbestos from different parts of the world differs considerably. Canadian asbestos is considered best, and provides about 75% of the world's consumption of this material. The asbestos mineral though in the form of a hard rock, can be easily separated into slender white fibers sometimes inclining toward a greenish color. See Plate XXV.

MICROSCOPIC CHARACTERISTICS.—The individual fibers of asbestos are so fine as to surpass the limits of microscopic fiber measurements. They measure less than half a micron and it is impossible to record them on a wedge ruler at 500 magnification. The fibers cling together in bundles. Where these bundles are reduced to a few fibers it was found that they are naturally arranged in a twist-like formation.

Owing to the extreme fineness of the individual fibers it is difficult to determine their proper form.

At the present time a variety of fabrics are manufactured from asbestos fiber. On account of its incombustible nature, and as it is a very poor conductor of heat, it is made into fabrics, in which these qualities are especially desired.

Glass Fiber

The spinning of glass into fibers is not particularly new. The Venetian Glass makers of Merano produced the exquisite lace glass, the highest development of thread glass in the 16th century. Spinning glass for commercial uses is a twentieth century achievement, it started in Venice around 1920. In the United States, the Owens-Corning Fiberglas Corporation has built up an important fiber glass industry.

The manufacture of fiber glass, is, in essence, quite simple. The glass is first formed into small balls, about the size of marbles. Next the glass is melted, pulled out, forced through tiny holes (spinnerettes) and solidified on contact with air.

Fiber glass is made in two basically different types of textile fibers: continuous filament yarn and staple fiber.

THE FIBER GLASS CONTINUOUS FILAMENT YARN is made in unbroken lengths, limited only by problems of packaging. The filaments are drawn 200 or more at a time (occasionally 102) to form a strand, which is subsequently given a twist and plied with other strands to form yarns of various constructions. These yarns have a high luster and are exceedingly smooth.

THE FIBER GLASS STAPLE FIBERS have average lengths of about nine inches with the longest individual fibers up to fifteen inches. The staple fibers are gathered first as a webbing and then drafted slightly to form a sliver, the draft functioning to draw the fibers into a substantially parallel alignment. The silver, thus formed, may be given a slight twist to become a roving or further drafted and twisted to form a yarn of the desired size. Such yarns are not lustrous as they have a slight fuzziness similar to that of cotton or worsted yarns, which they resemble.

MICROSCOPICAL CHARACTERISTICS: In their longitudinal view as seen on Plate XXV, the filaments are perfectly even in width over the whole length and absolutely smooth, showing no surface structure at all and no twist. The cross sections are perfectly circular. The diameter variation lies between 15% and 20%, which is above other man-made fibers such as nylon and the various rayons. Because of the hardness of the glass and its brittleness it is quite difficult to produce good cross-sections.

FINENESS:—Continuous filament and staple fiber yarns are each made at present in three filament diameters as given in the following tables:

Designation	*Average Fiber Diameter in Inches Continuous* Min. to	Max.	Designation	*Average Fiber Diameter in Inches Staple* Min. to	Max.
D	0.00021	0.00025	E	0.00026	0.0003
E	0.00026	0.0003	G	0.00036	0.0004
G	0.00036	0.0004	J	0.00046	0.0005

The high transparency makes glass fibers difficult to measure because of the lack of contrast in the regular imbedding medium such as water and glycerine. It was found that by using a water solution of methylene blue that sufficient contrast is obtained to make good measurements.

Diameter Measurements on Glass Fibers

Type	*ESE*	*ESG*	*ESJ*
Number of Fibers	100	100	150
Microns:			
0- 5	2%	—	—
5-10	91%	51%	—
10-15	7%	48%	42%
15-20	—	1%	54%
20-25	—	—	3%
25-30	—	—	1%
Average Microns	8.03	10.17	15.75
Deviation μ	1.56	1.64	2.47
Standard Error μ	0.16	0.16	0.20
Variation	19.4%	16.1%	15.6%

Width measurements made on three glass staple fiber yarns of the Owens-Corning Fiberglas Corporation, gave the results shown in the above table.

USES OF FIBER GLASS:—Fiber Glass was originally produced mainly for filters such as air filters, laboratory filters and for insulation purposes. The first yarn spun was for covering electric wires and for airplane coverings. Today the yarn is also used to produce ignition cables, awning materials, neckties, table cloths, and draperies.

Wool Grades Versus Denier

In order to facilitate the selection of the proper types of viscose, acetate, or nylon staple fiber to blend with any given grade of wool, we have prepared the accompanying chart. (See also chart on page 37.) The values are weighed for specific gravity according to Mennerich's formula:—

$$\text{Denier} = .000706\ D^2\ (\text{Density})$$

and give theoretical values since they are based on the assumption that all the fiber cross-sections are circular. From this chart, the type of viscose, acetate or nylon to blend with wool on either the comparable basis of diameter (micron thickness) or of the comparable weight basis (denier) may be read directly. For example, reading horizontally, for the same thickness, 23.3 microns, which is the average width of a 62's wool, the corresponding denier sizes are:

Viscose	5½ denier
Acetate	5 denier
Nylon	4½ denier

Reading vertically, the 62's wool is equal in denier size to a

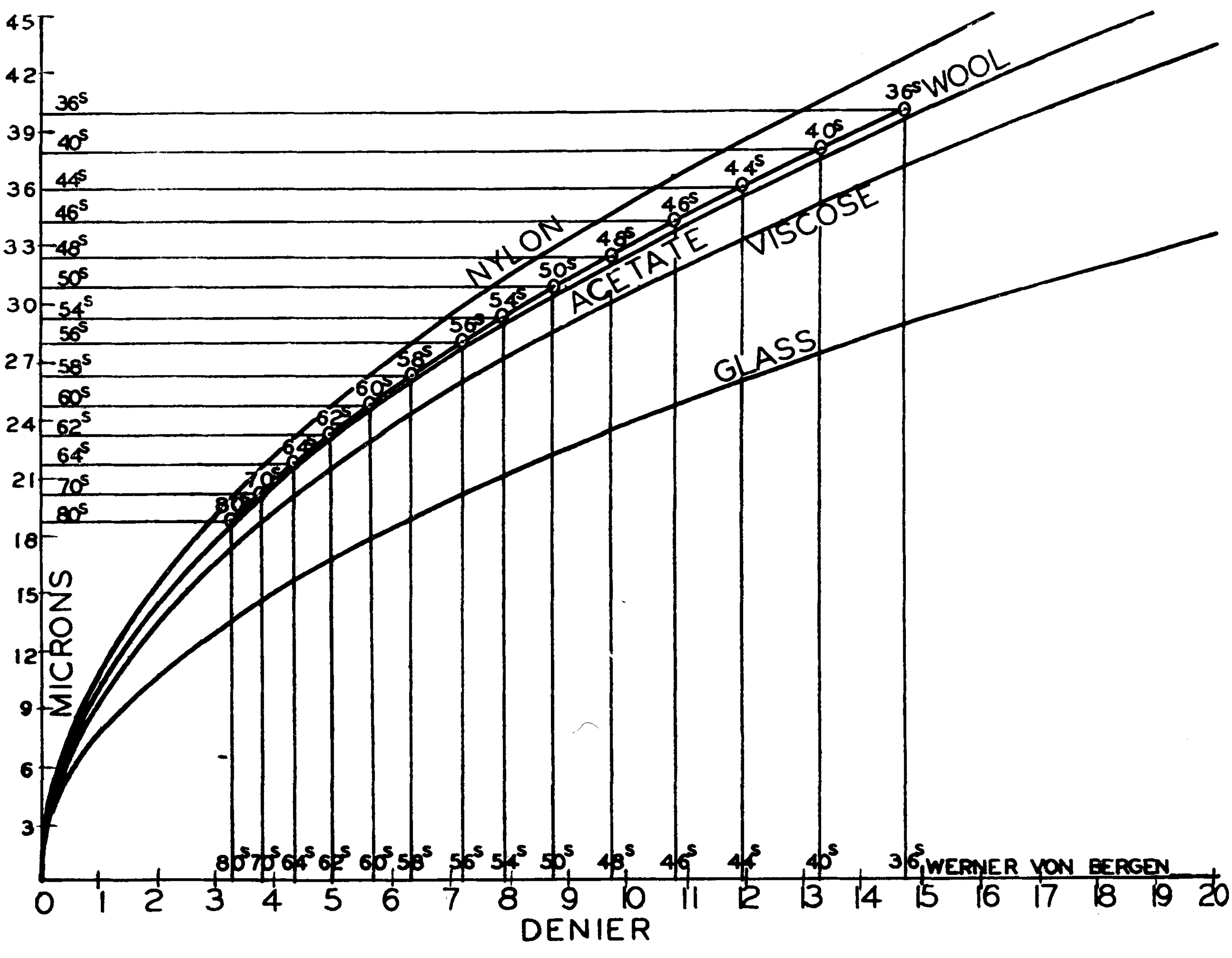
21.5 microns Viscose
22.9 microns Acetate
24.8 microns Nylon

The curve of the glass fiber was only used to illustrated further the influence of the specific gravity on the diameter size of the fibers. The following specific gravities were used:

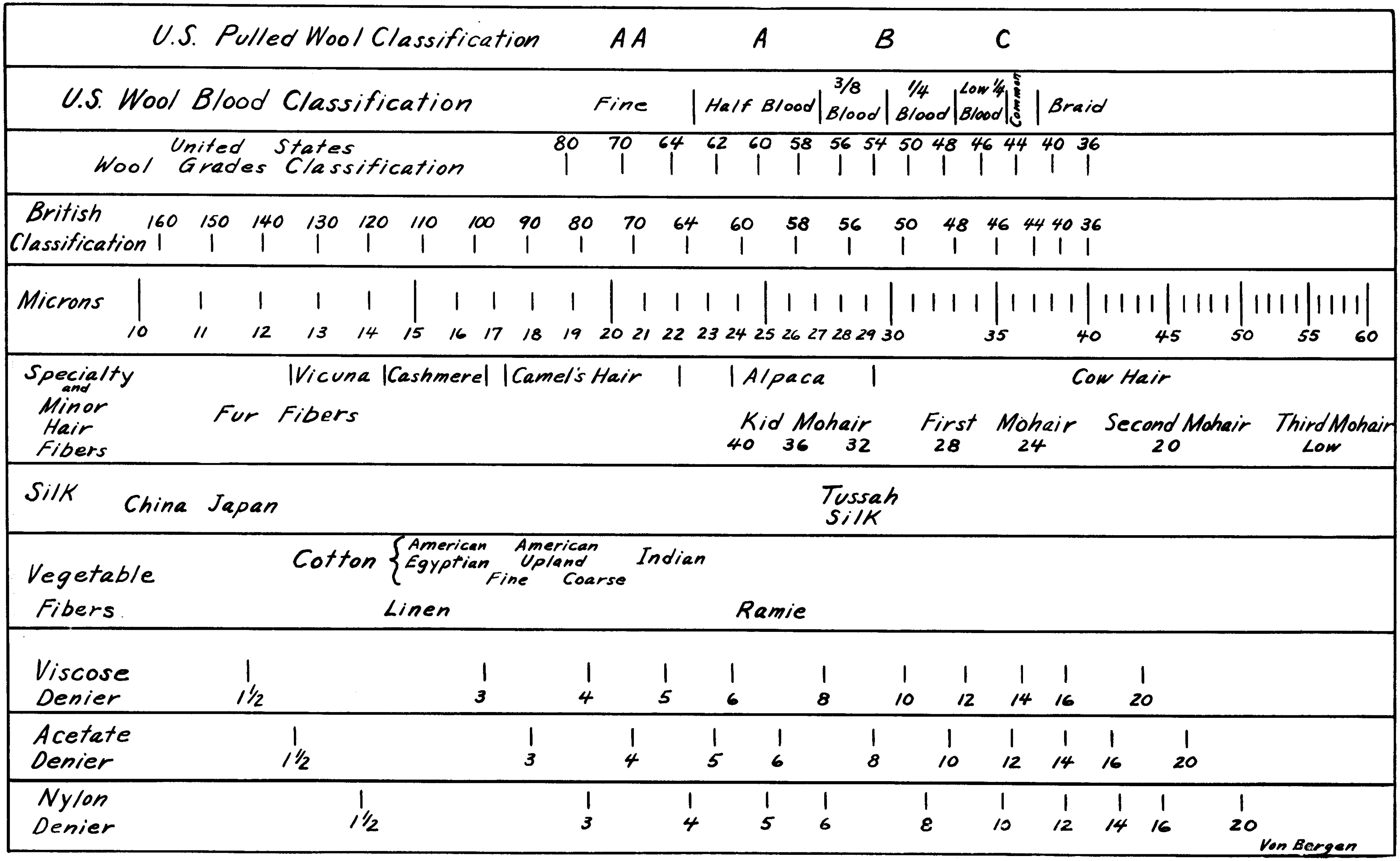
Wool	**1.30**
Viscose	**1.52**
Acetate	**1.33**
Nylon	**1.14**
Glass	**2.50**

The values obtained with the width method, using glycerine as the imbedding fluid do not correspond with the theoretical values in the case of viscose and of acetate rayons, as already discussed under "rayons." In order to find the correct micron values, the actual values have to be multiplied by the following correction coefficients:

Viscose	.832
Acetate	.902

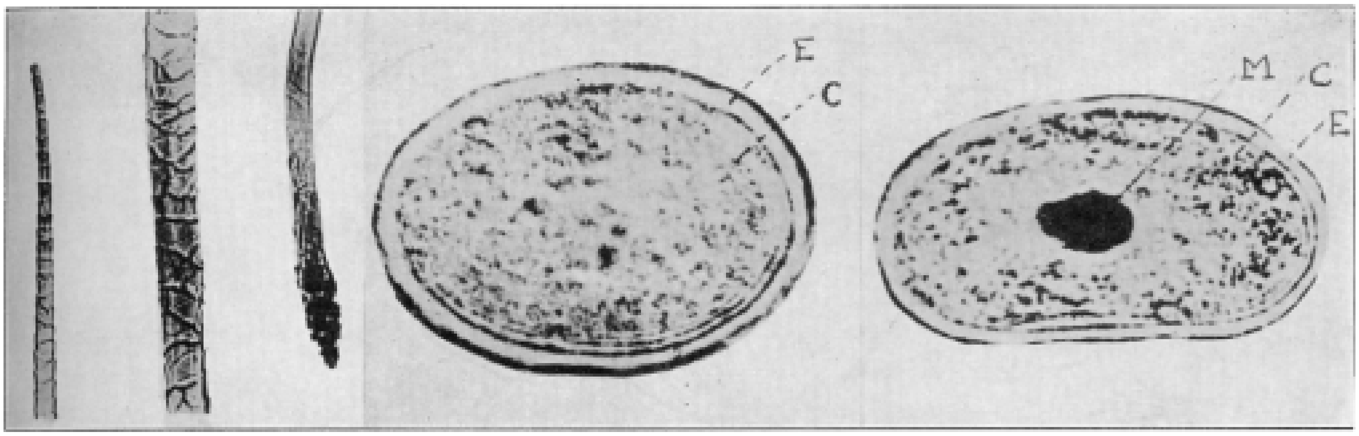


COMPARATIVE SCALE FOR FINENESS OF VARIOUS TEXTILE FIBERS



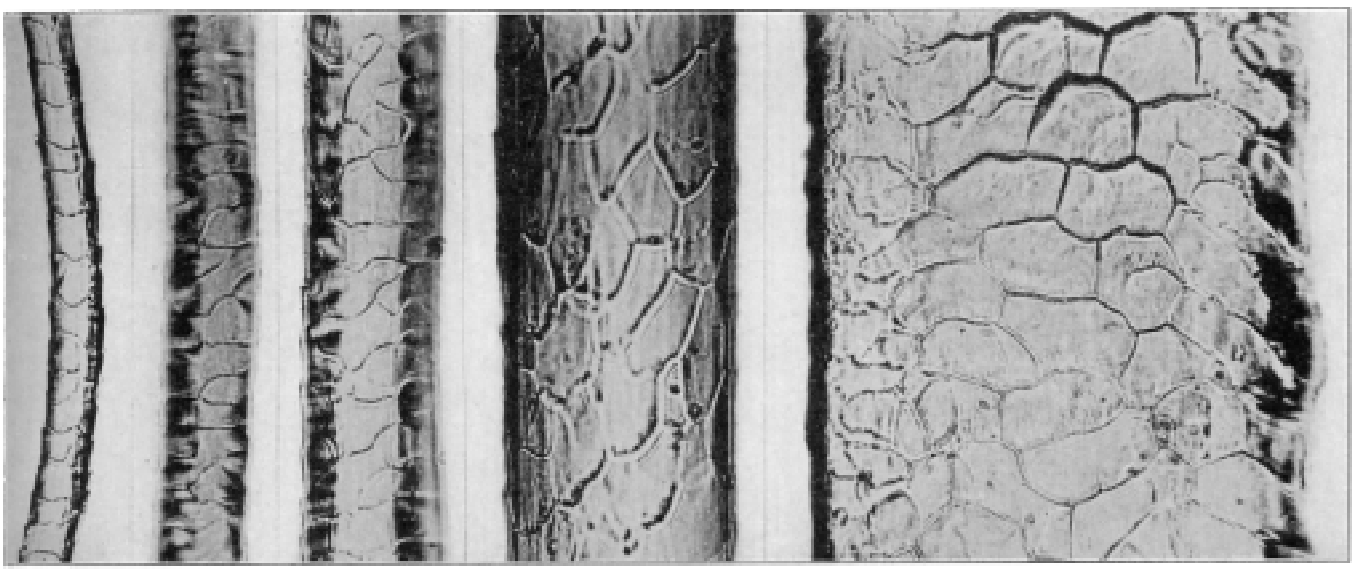
IN producing these photomicrographs illustrated on the following plates, the authors found that the best results are obtained by using the Wratten M plates of the Eastman Kodak Company. In order to bring out the best details the use of various filters is essential. The longitudinal fiber views were generally taken with the fibers imbedded in glycerine. The cross-sections with a few exceptions were made with Hardy's fine cross-section device using Collodion as an imbedding medium and Canada Balsam as a mounting medium.

The pictures revealing the surface structure of the animal fibers were all produced by the impression technique. One of the best and simplest methods for this technique is the one described by Hardy and Plitt. The imprints are made on thermo-plastic film, such as "ethofoil," held with clamps under some pressure and heated at a uniform moderate temperature in an oven. Positive impressions are obtained with this method.



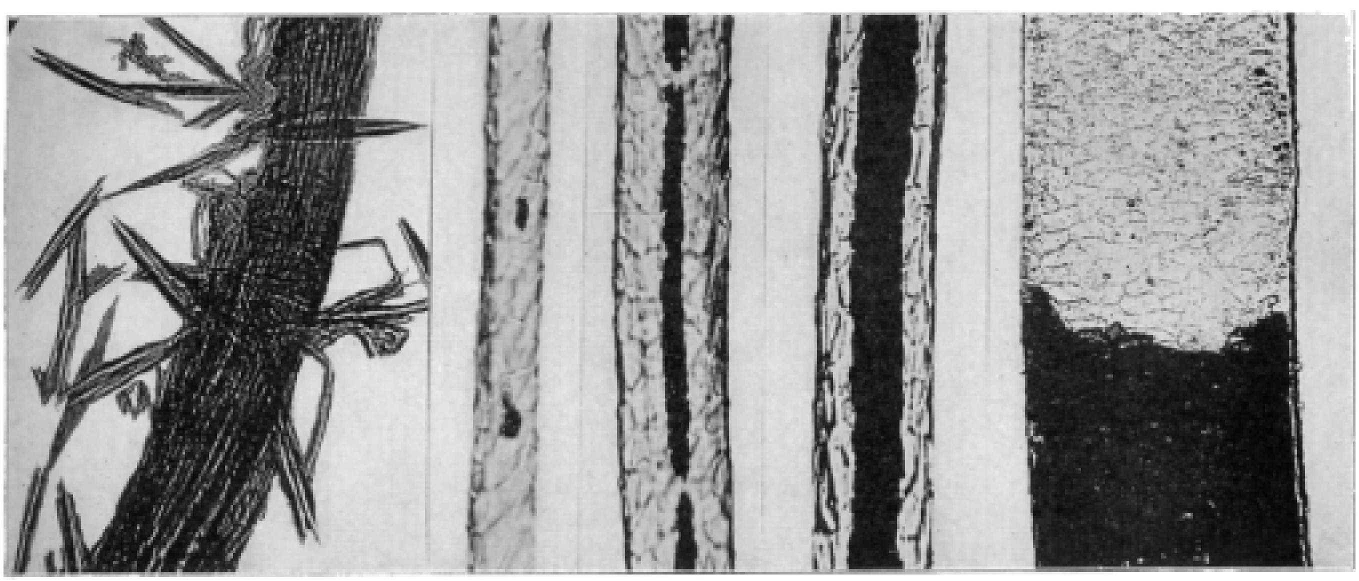
Parts of a Wool Fiber (X 250)
A—Tip B—Shaft C—Root

Cross Sections of Hair (X 500)
E—Epidermis C—Cortex M—Medulla



Various Types of Epidermis Structure of Wool Fibers (X 500)

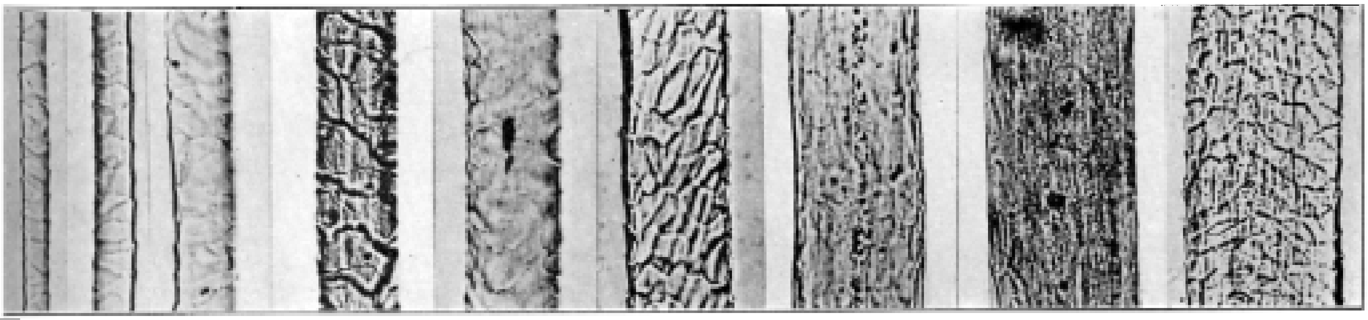
A B C



Cortical Layer and Loose Cells (X 500)

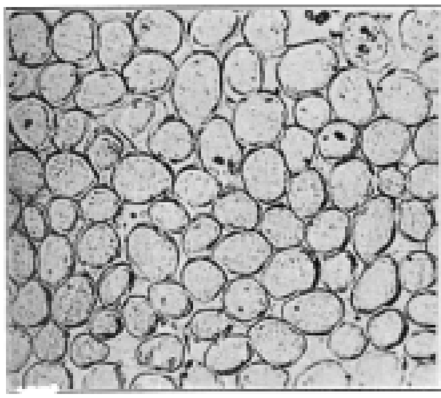
A—Fragmental, B—Interrupted, C—Continuous Types of Medullae (X 250)

Kemp (X 250)

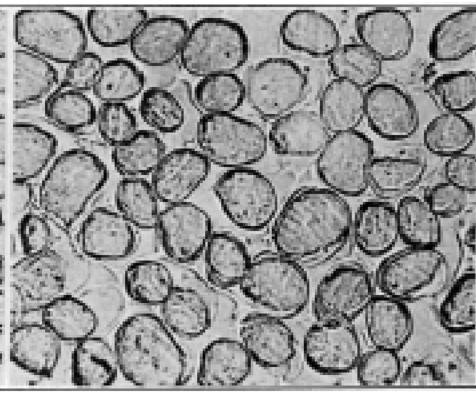


14 20 30 40 48 60 70 80 100 Microns

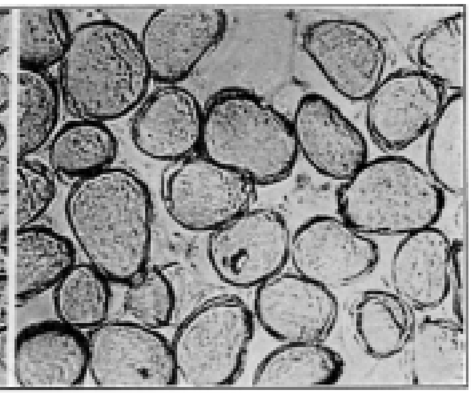
Variation in Fineness or Width of Wool Fibers (X 250)



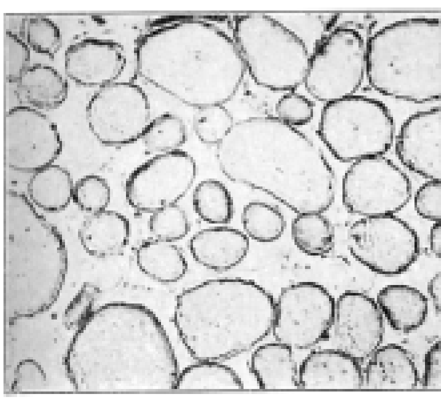
Fine Wool (X 230)



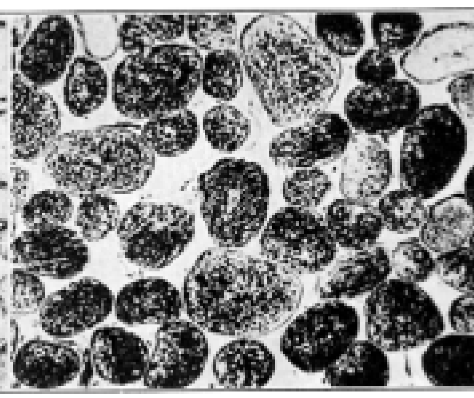
Medium Wool (X 230)



Coarse Wool (X 230)

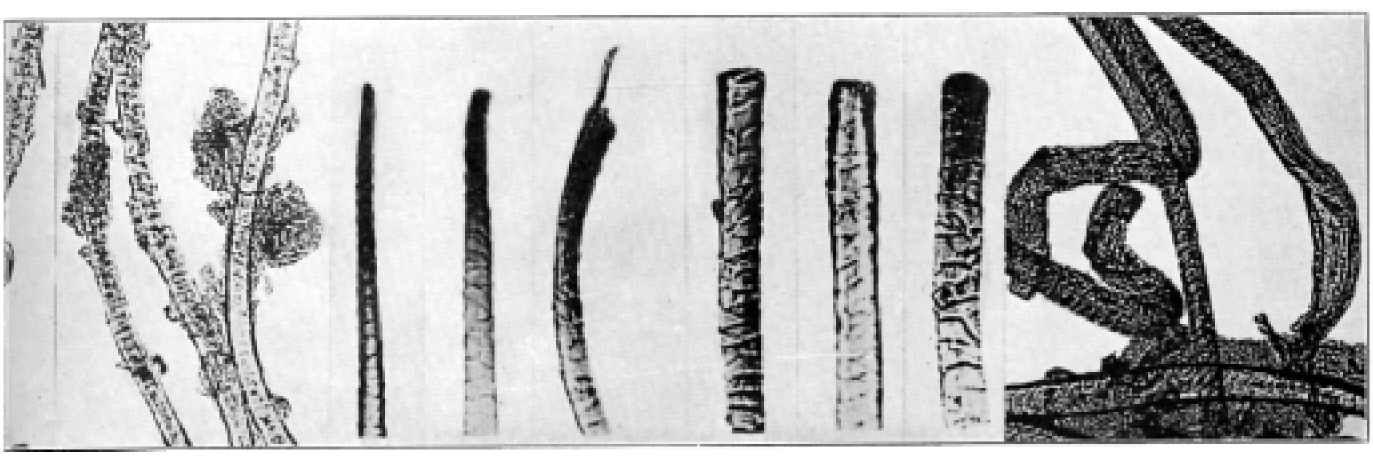


Mixed or Carpet Wool (X 230)



Natural Brown Wool (X 230)

Kempy Wool (X 230)



Grease Wool (X 120)

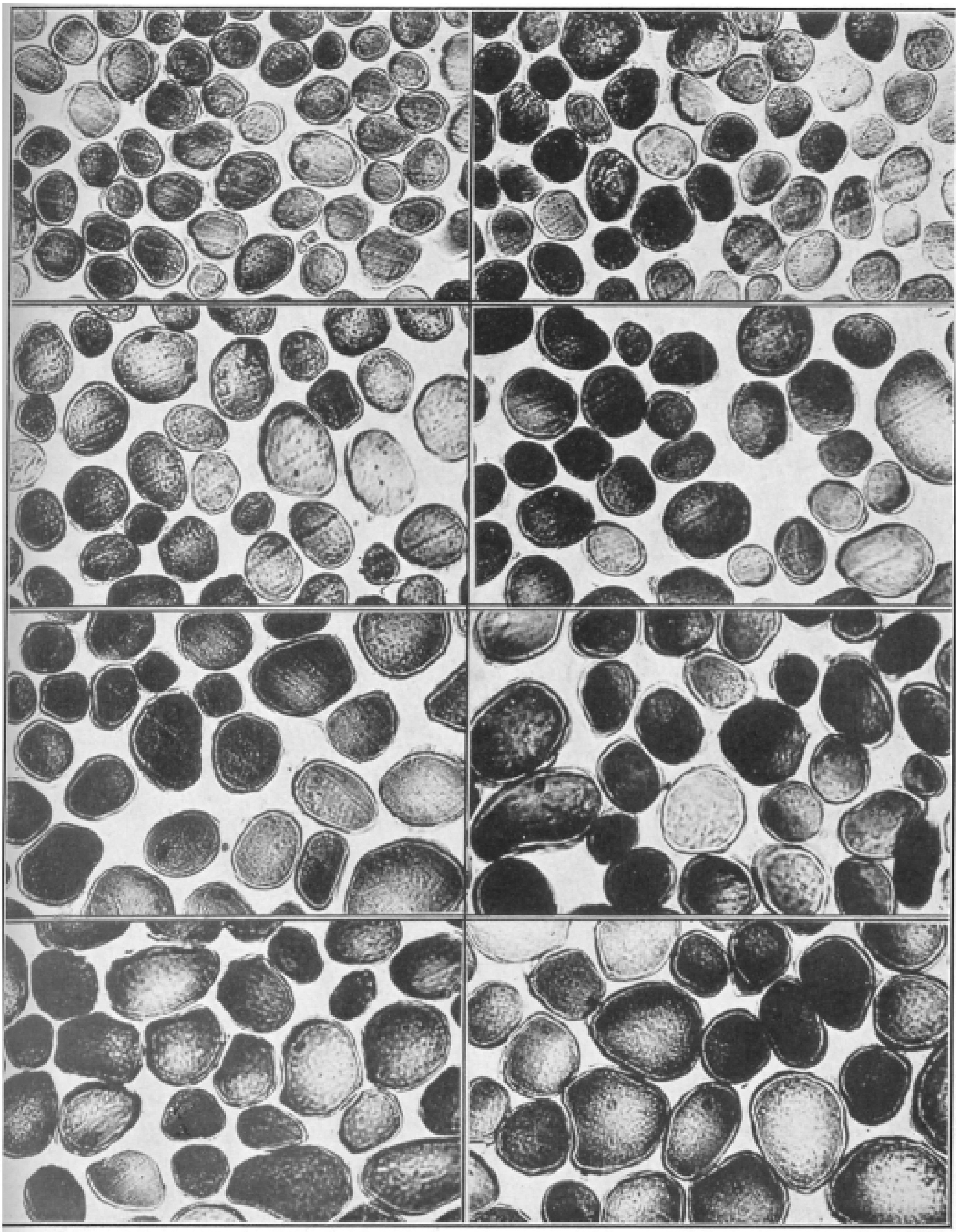
Tips of Lambs Wool (X 250)

Tips of Shorn Wool (X 250)

Pulled Wool Roots (X 160)

U. S. WOOL TOP STANDARDS — PLATE III

80's
70's
64's
62's
60's
58's
56's
50's



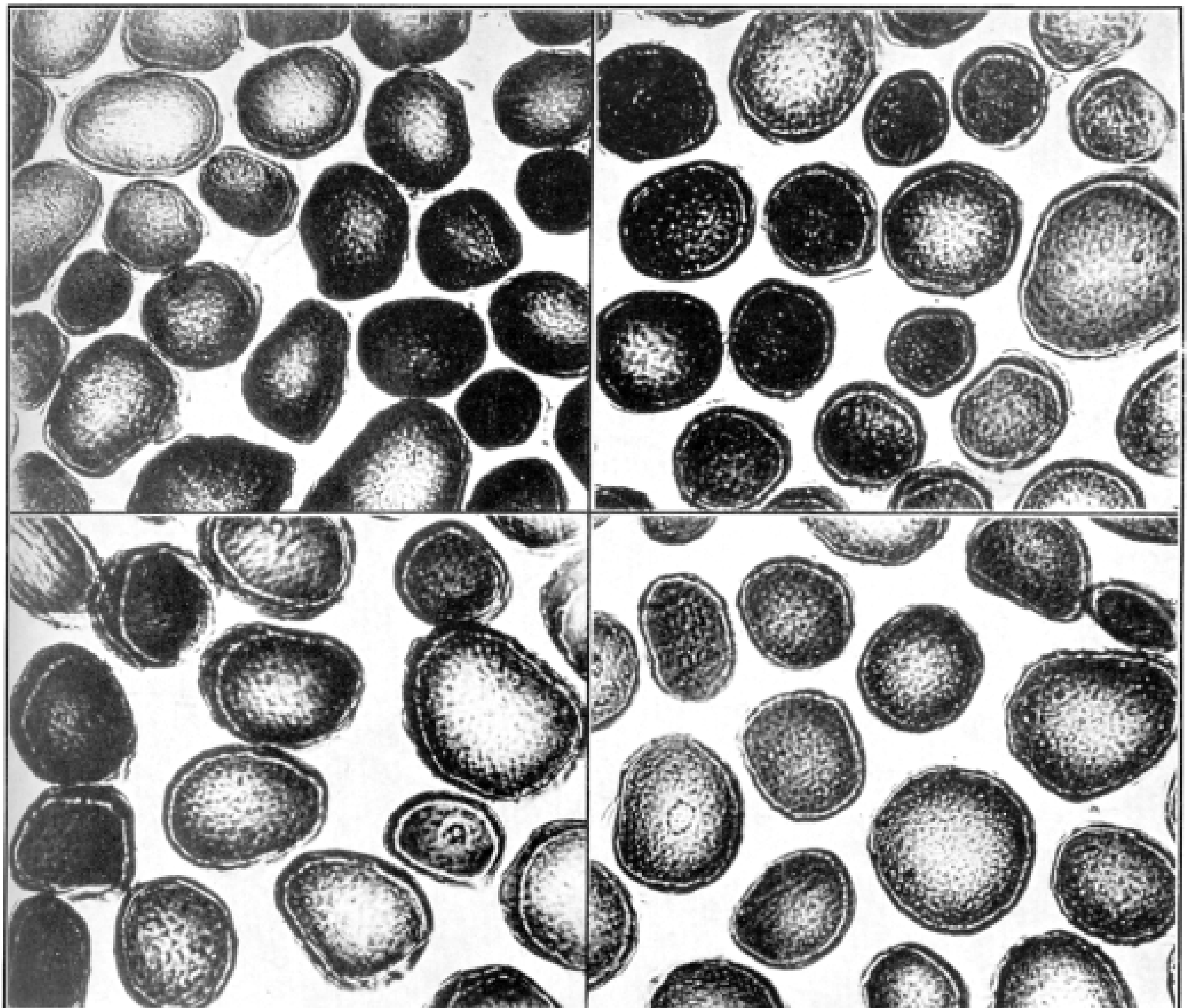
CROSS-SECTIONS (x 500)

U. S. WOOL TOP STANDARDS

PLATE IV

48's

46's



44's

40's

PLATE III		
Grade	Av. Mic.	Stand. Dev.
80's	19.45	3.49
70's	20.07	3.94
64's	21.86	4.56
62's	23.52	5.22
60's	24.70	5.56
58's	25.78	6.45
56's	27.64	7.10
50's	30.34	7.61

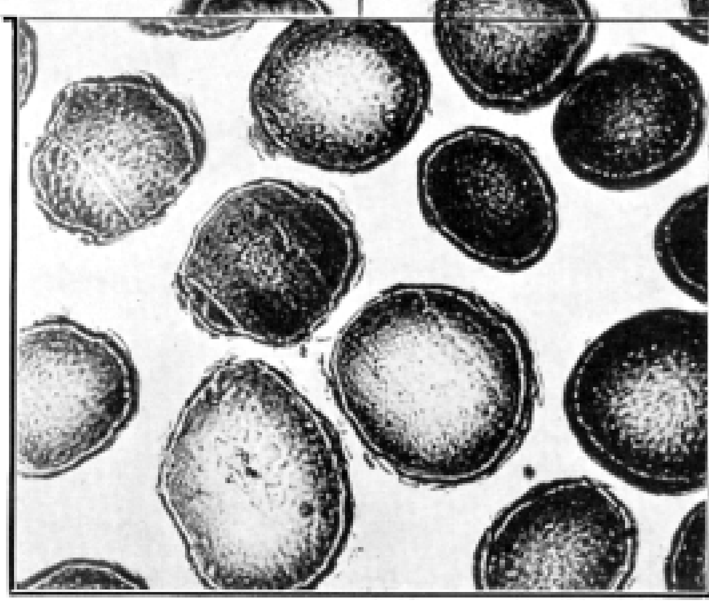


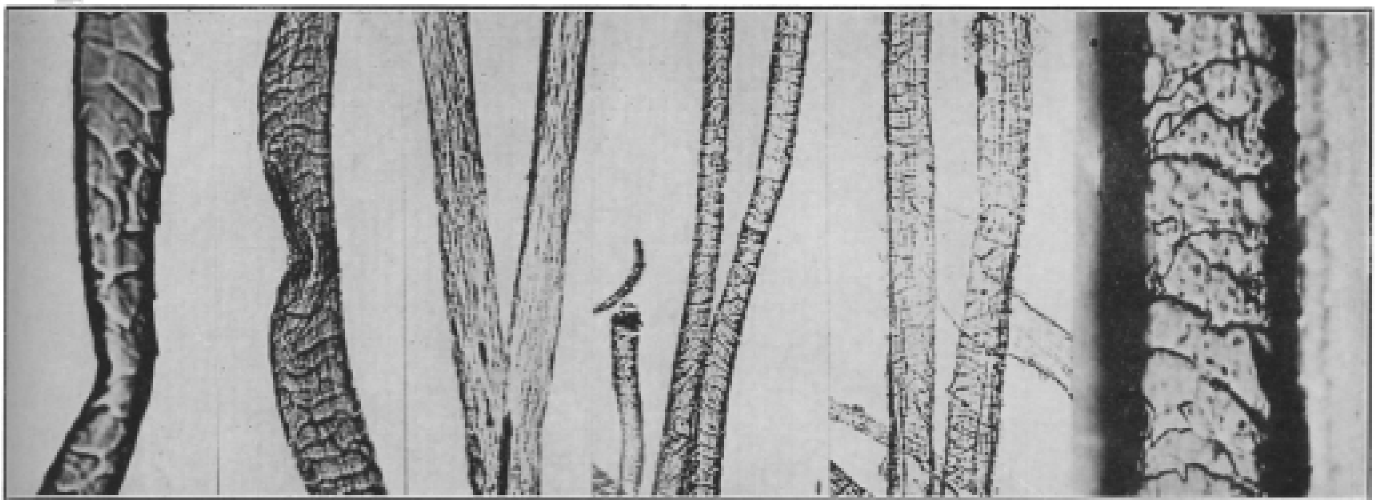
PLATE IV		
Grade	Av. Mic.	Stand. Dev.
48's	32.55	7.90
46's	34.15	8.0
44's	36.00	8.8
40's	37.40	8.1
36's	39.8	9.4

Note:— Cross-sections were dyed with Orange II which accounts for the light and dark fibers.

36's

CROSS-SECTIONS (x 500)

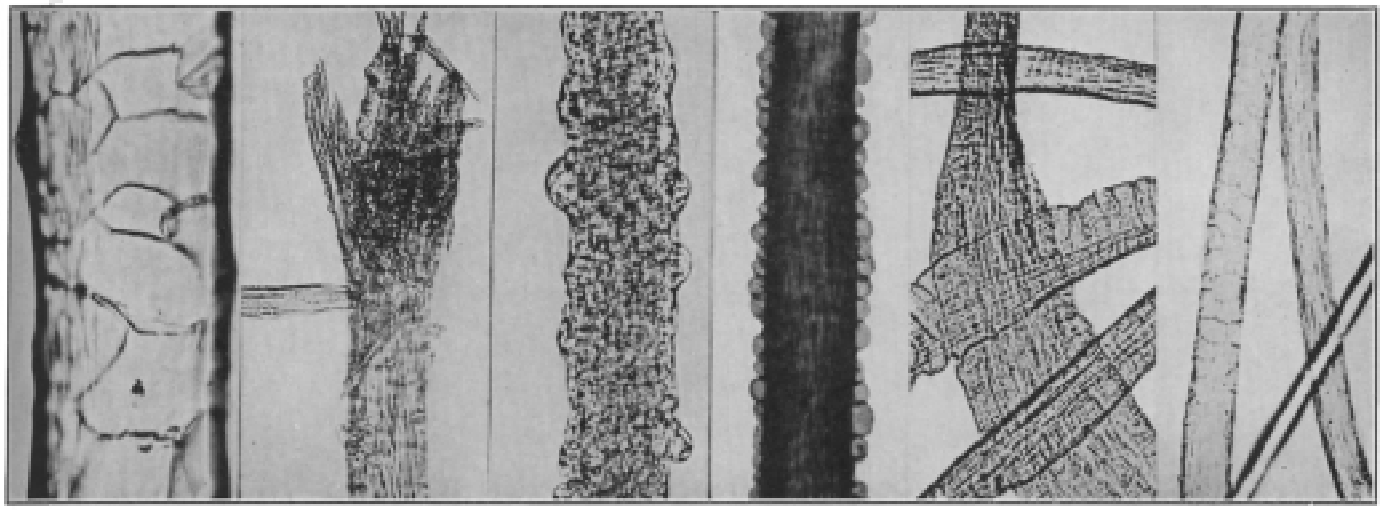
WOOL FIBER DAMAGE — PLATE V



PHYSICAL DEFORMITIES
(x 500) (x 250)

SUNLIGHT DAMAGE
Virginia Wool Ends Water (x 160)
AUSTRALIAN WOOL ENDS
Water (x 160)
N/10 NaOH (x 160)

Over-scoured Fiber showing holes in epidermis (x 500)



ALKALI
Over-scoured fiber—Folds in epidermis (x 500)

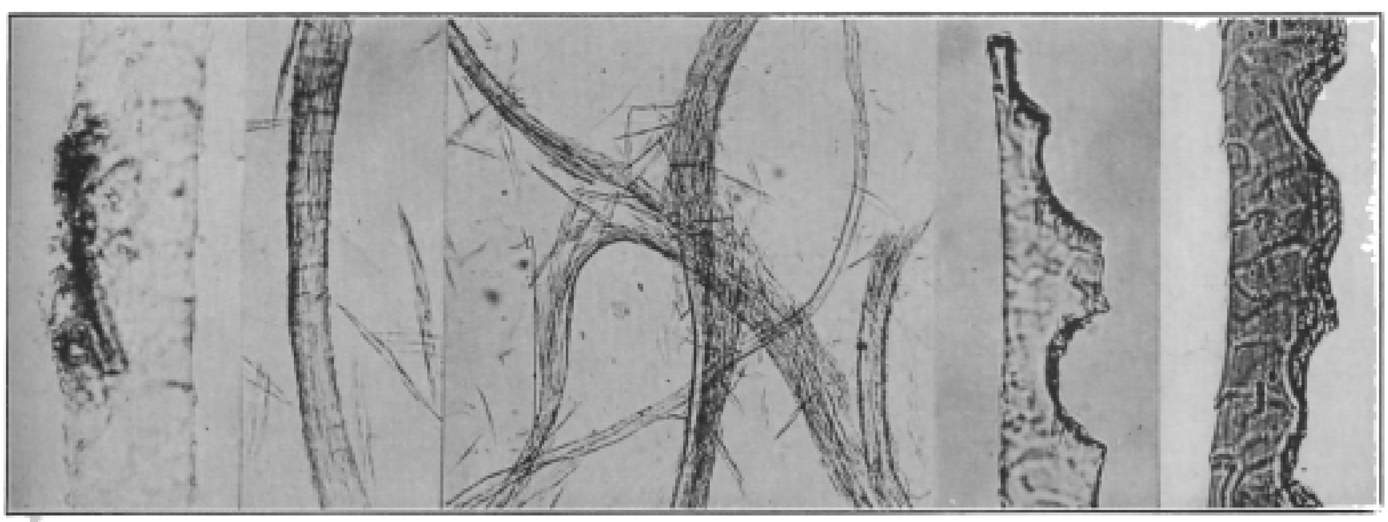
ACID
Typical Brush-end (x 500)

ACID
Krais-Viertel reaction on damaged fiber (x 500)

CHLORINE
Allworden reaction on normal fiber (x 240)

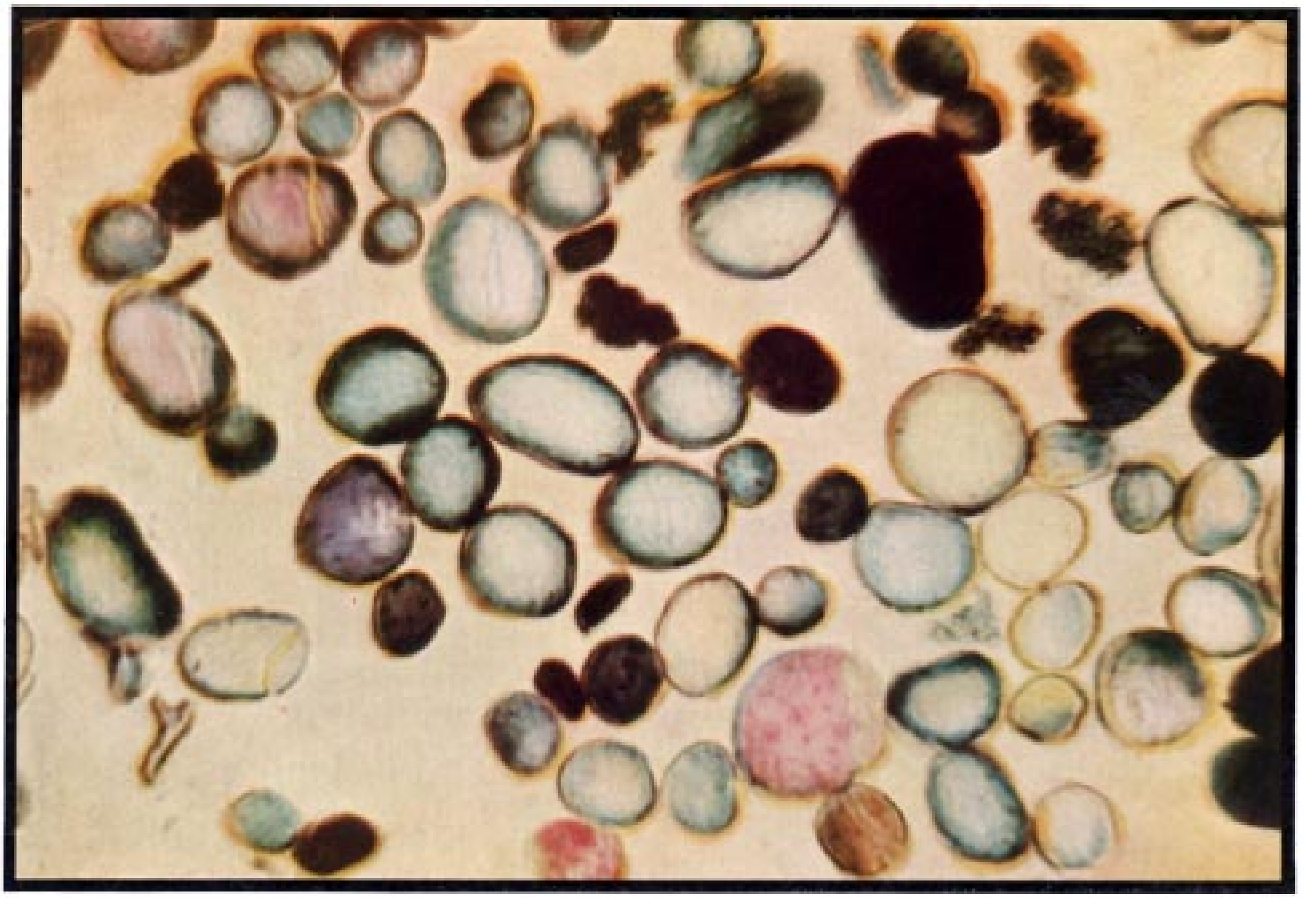
CHLORINE
Over-chlorinated fibers in N/10 NaOH (x 160)

BLEACHING
Over-bleached fibers showing removal of scales (x 160)



BACTERIA DAMAGE
Fiber showing beginning of damage (x 500)
Later stage of damage (x 230)
Final destruction of fibers (x 12[illegible])

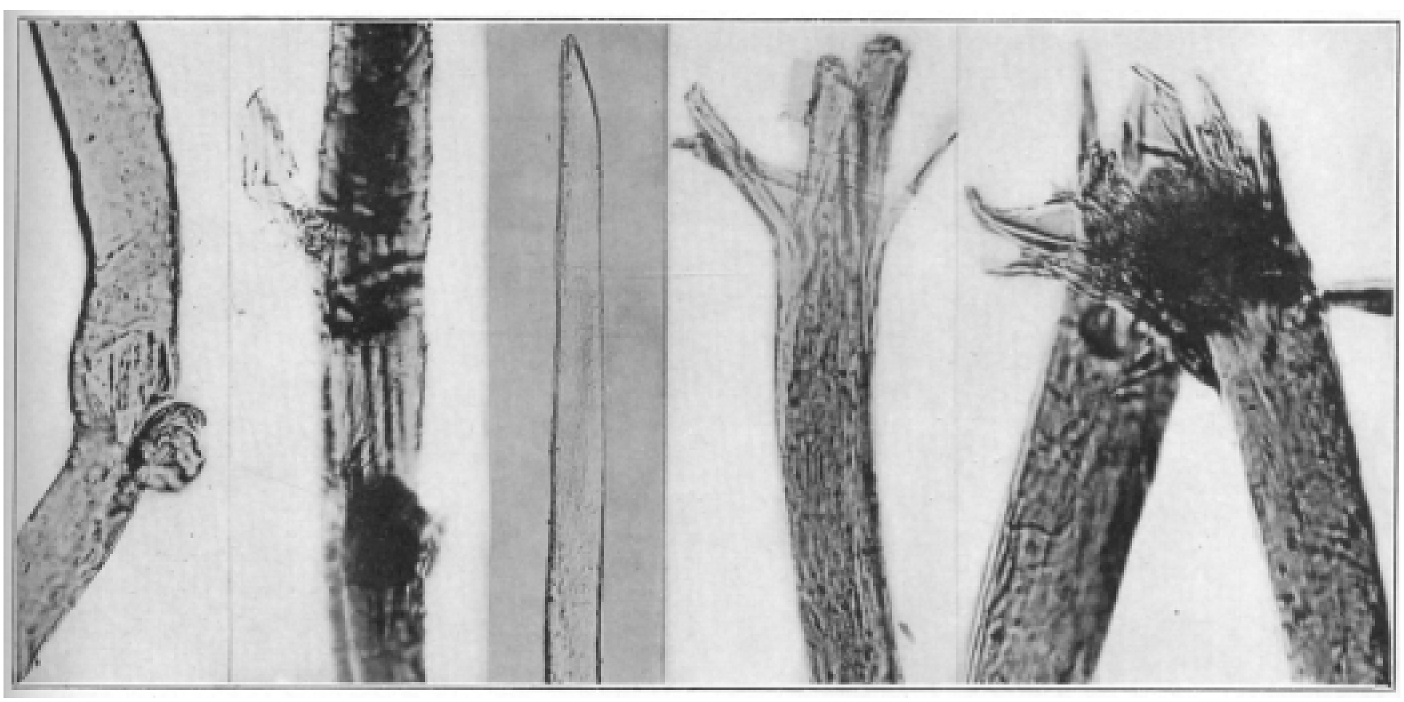
INSECT DAMAGE
Moth or carpet beetle damage on fibers (x 500)



KODACHROME CROSS-SECTION OF A YARN FROM A GREEN SKI SUIT
(x 650)

Fiber content:	Wool	84.6%	approximately 90% reused wool
	Viscose Rayon	8.0%	
	Cotton	7.2%	
	Jute	0.2%	

Courtesy G. Moro, Forstmann Woolen Co. Lab.



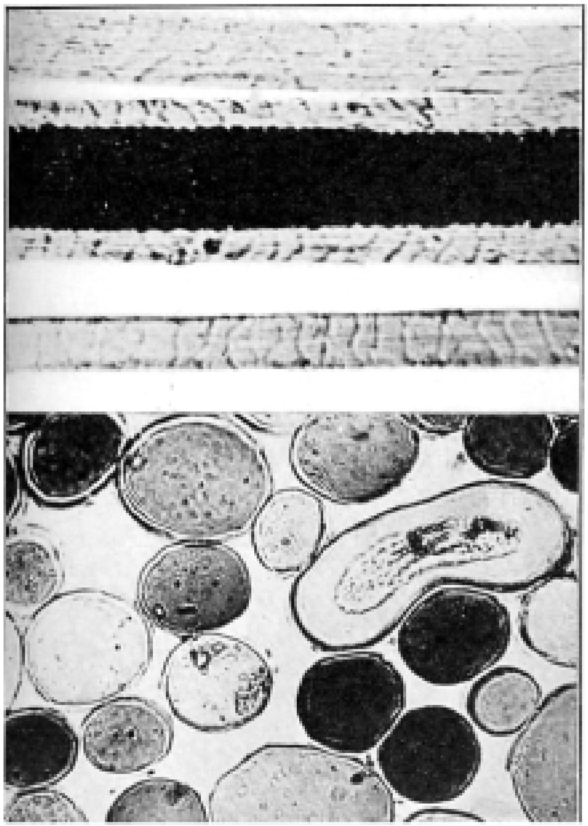
FIBERS TAKEN FROM REPROCESSED AND REUSED WOOLS

Mechanical damage caused during processing (x 500)

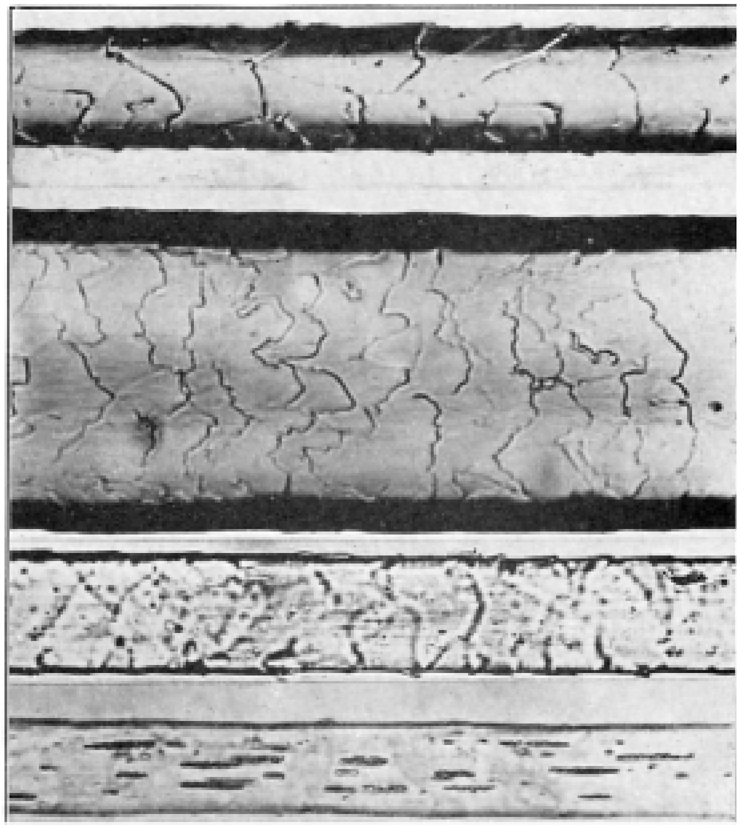
Worn fiber tip (x 230)

Breaks of fibers caused by wear (x 500)

SPECIALTY HAIR FIBERS — PLATE VII



MOHAIR: Top: Longit. view (X 240)
Bottom: Cross-section (X 500)



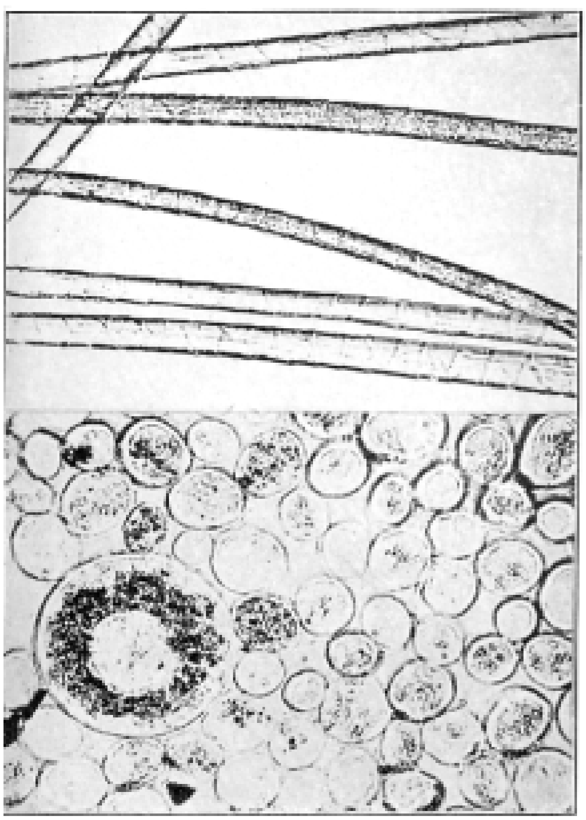
A

B

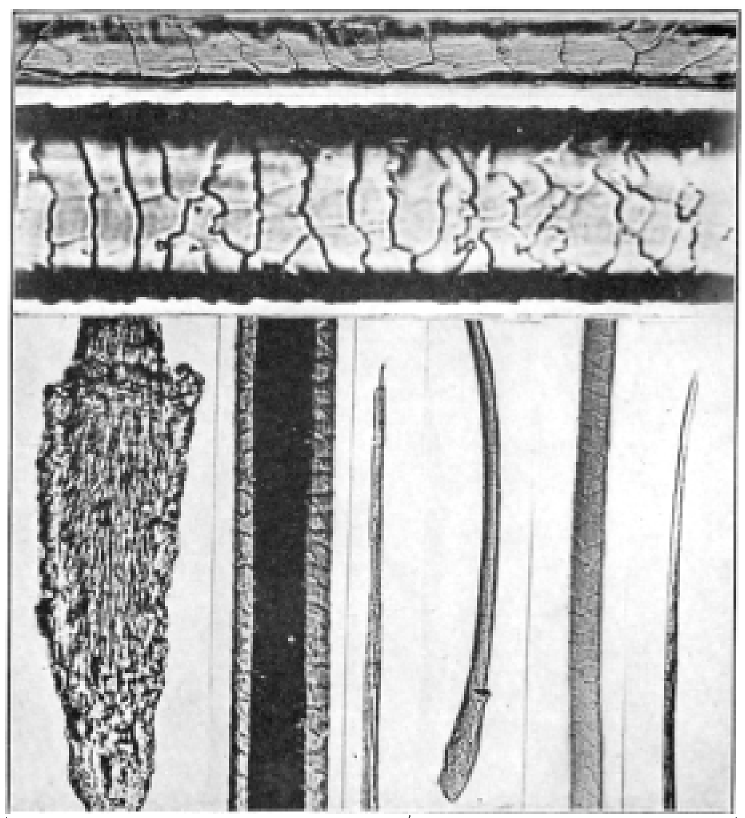
C

D

Epidermis: A—Woolhair. B—Beardhair.
C—Longit. view. D—Same with air-filled vacoules (X 500)



CASHMERE: Top: Longit. view (X 240)
Bottom: Cross-section (X 500)



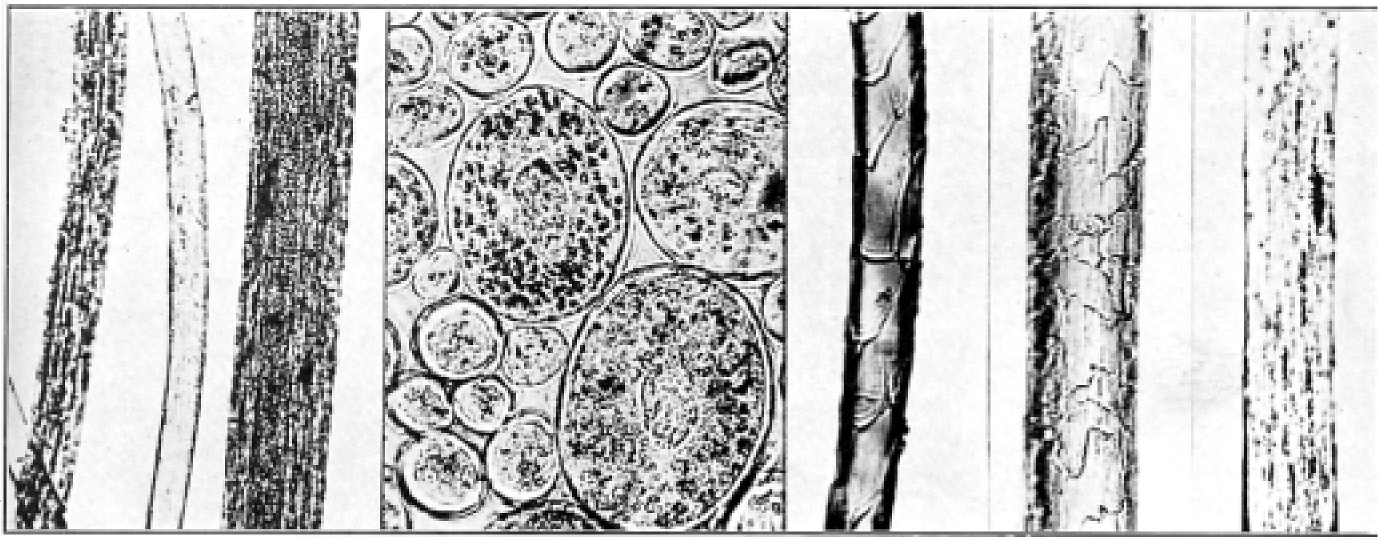
A

B

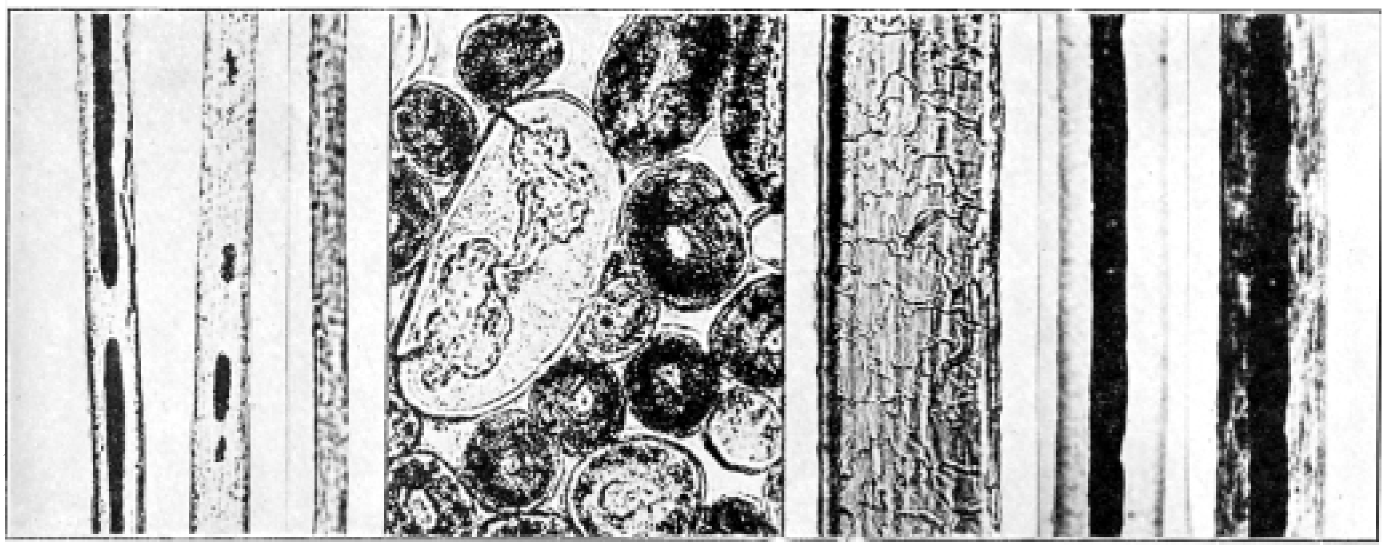
C D

Epidermis: A—Woolhair. B—Beardhair (X 500)
Root, Shaft, Tip: C—Beardhair. D—Woolhair (X 180)

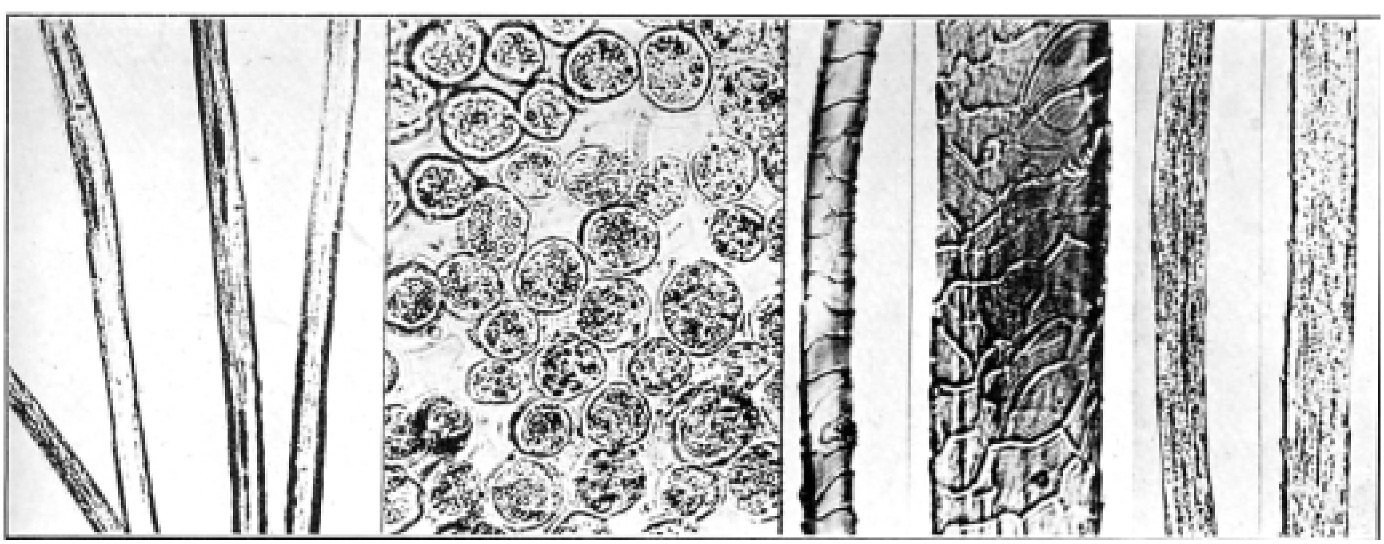
SPECIALTY HAIR FIBERS — PLATE VII



CAMELHAIR:
Longit. view (X 240) — Cross-section (X 500) — Surface structure of fine and medium wool hairs (X 500) — Longit. view (X 500)

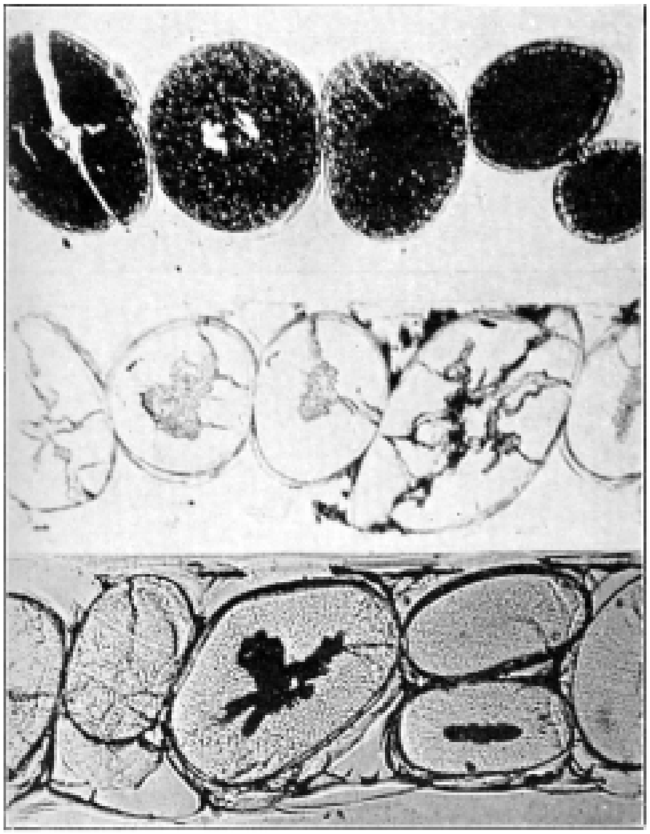


ALPACA: White Longit. view (X 240) — Fawn Cross-section (X 500) — Epidermis (X 500) — White Brown Longit. view (X 500)

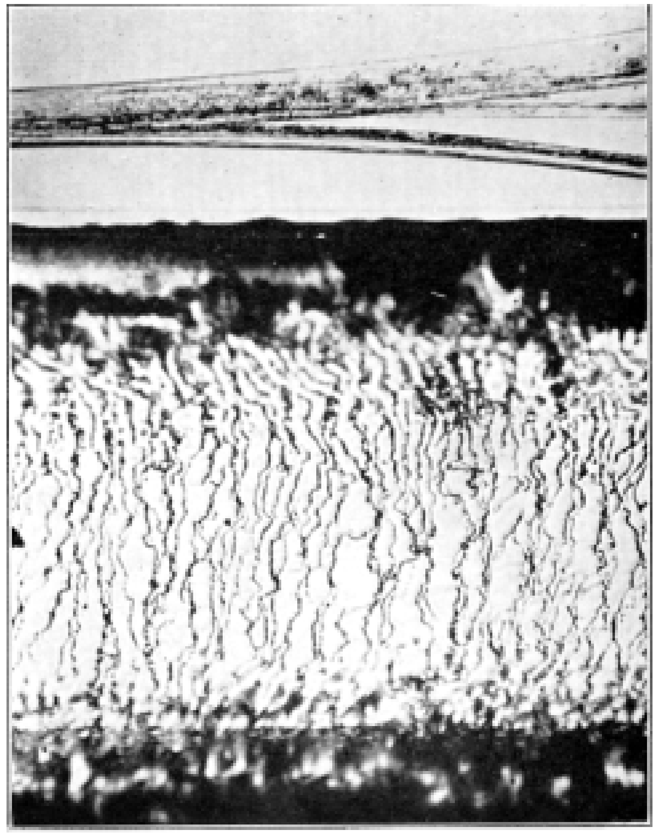


VICUNA:
Longit. view (X 240) — Cross-section (X 500) — Epidermis of wool and beardhair (X 500) — Longit. view of woolhairs (X 500)

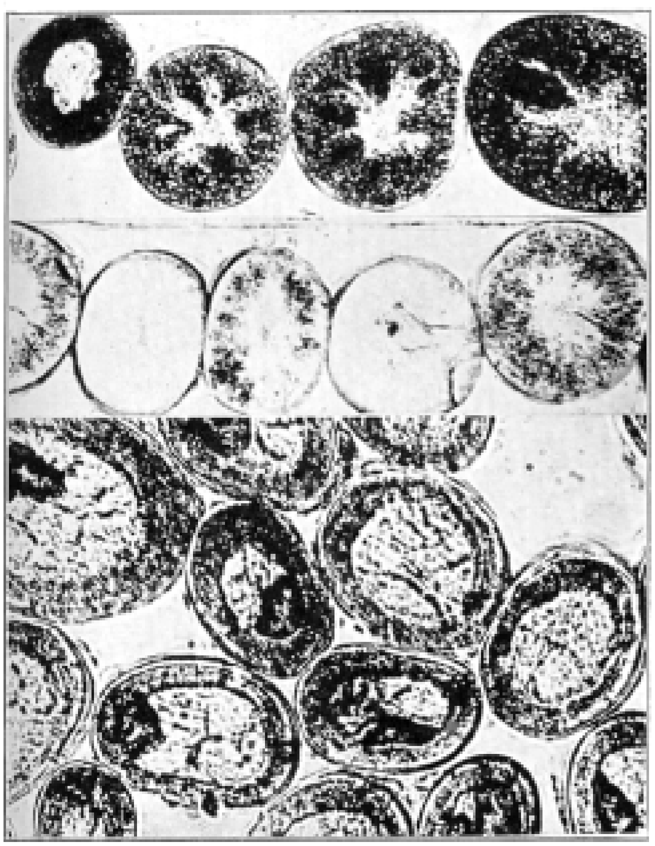
MINOR HAIR FIBERS — PLATE IX



HOG Top: Black Bristles, middle } Cross-
Center: White Bristles, near tip } Sections
Bottom: White Bristles, middle } (X 115)



Top: Flagged Tip (X 50)
Bottom: Epidermis (X 500)

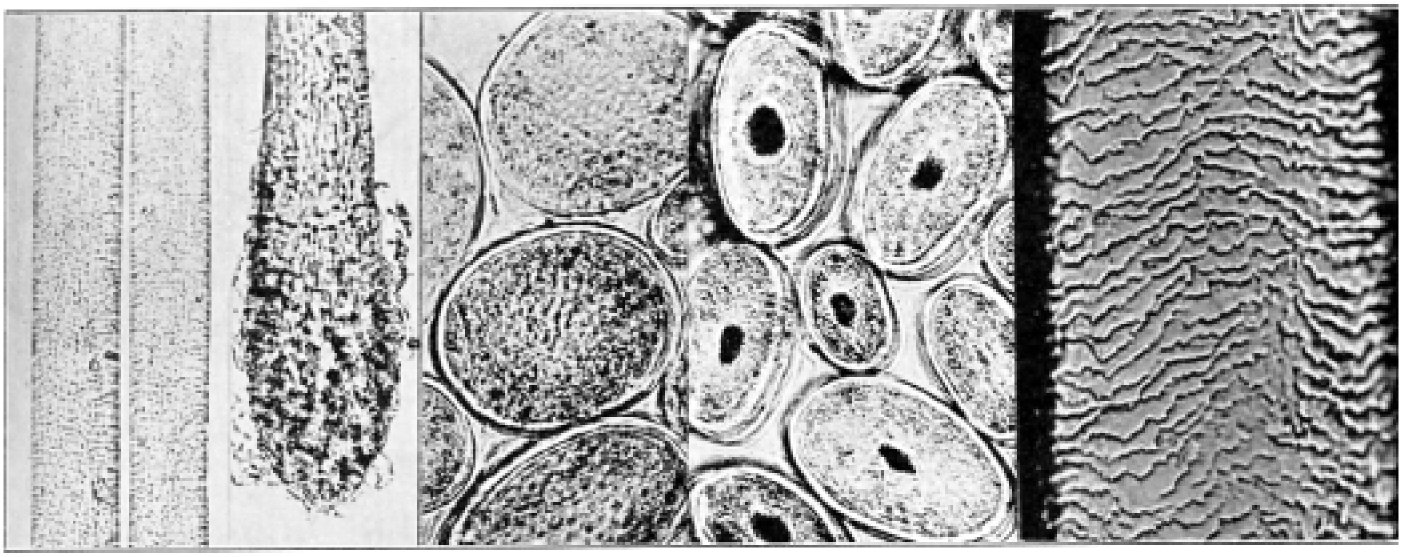


HORSE Top: Black Hair } Cross-
Center: White Hair } Sections (X 115)
Bottom: Pony Hair (X 500)

Top: Epidermis Pony (X 500)
Bottom: Epidermis Horse (X 500)

MINOR HAIR FIBERS

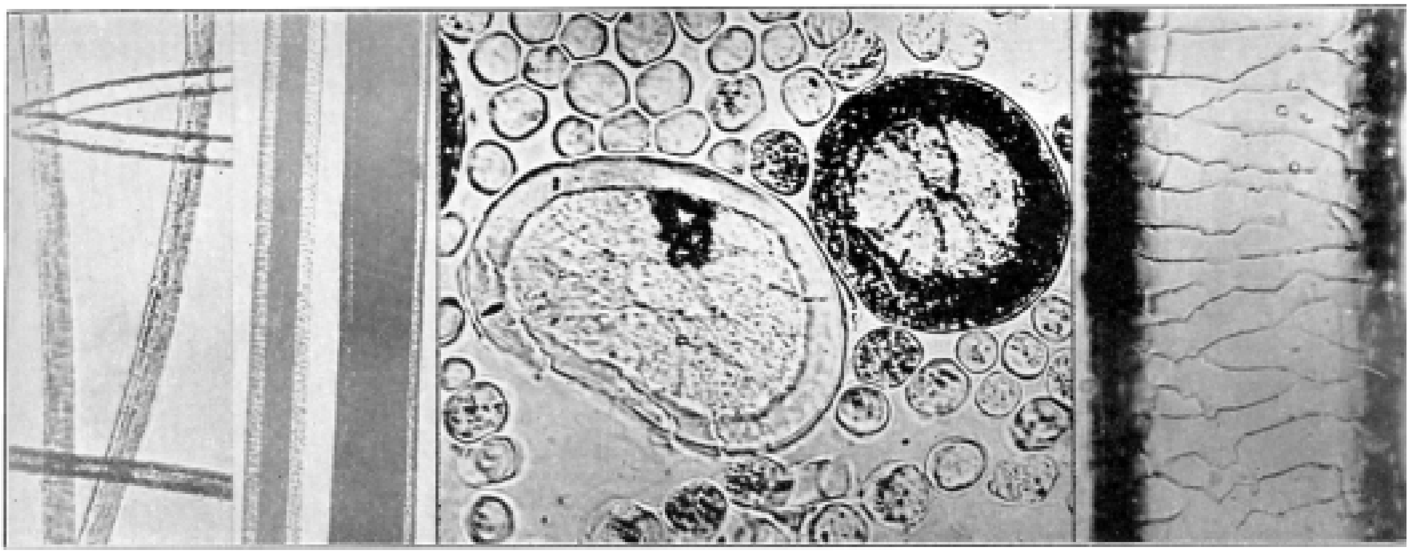
PLATE X



HUMAN
Shaft Root
(X 160)

CROSS-SECTIONS
Adult Infant
(X 500)

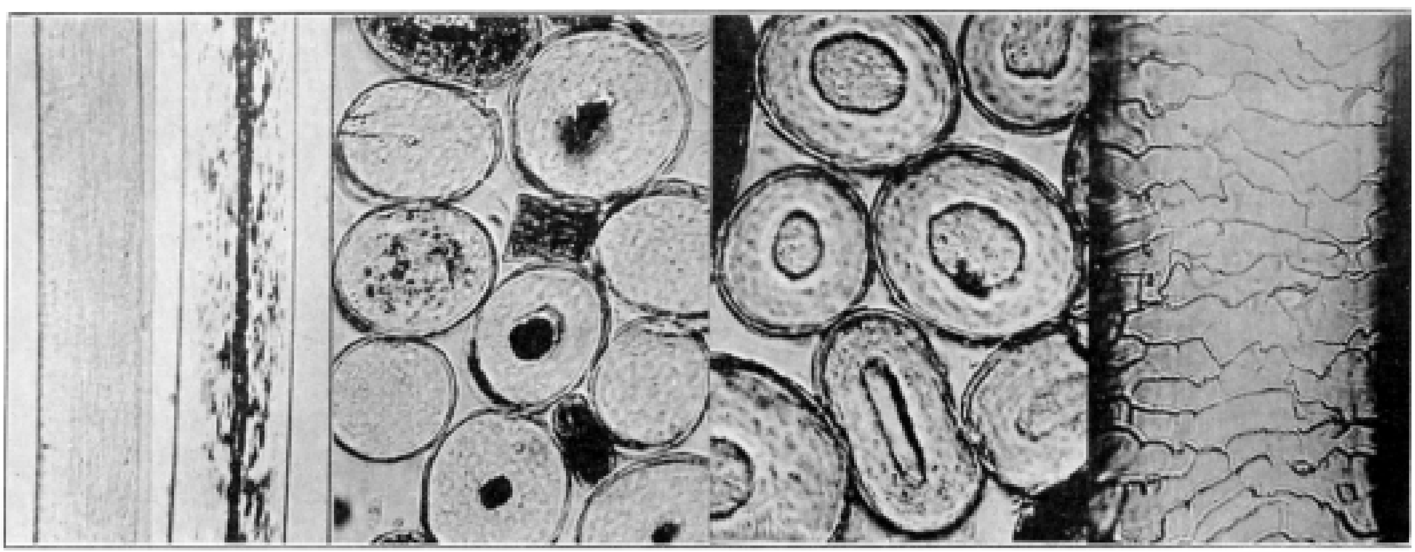
EPIDERMIS
(X 500)



GOAT
Wool Hair Beard Hair
(X 160)

CROSS-SECTIONS
Wool and Beard Hairs
(X 500)

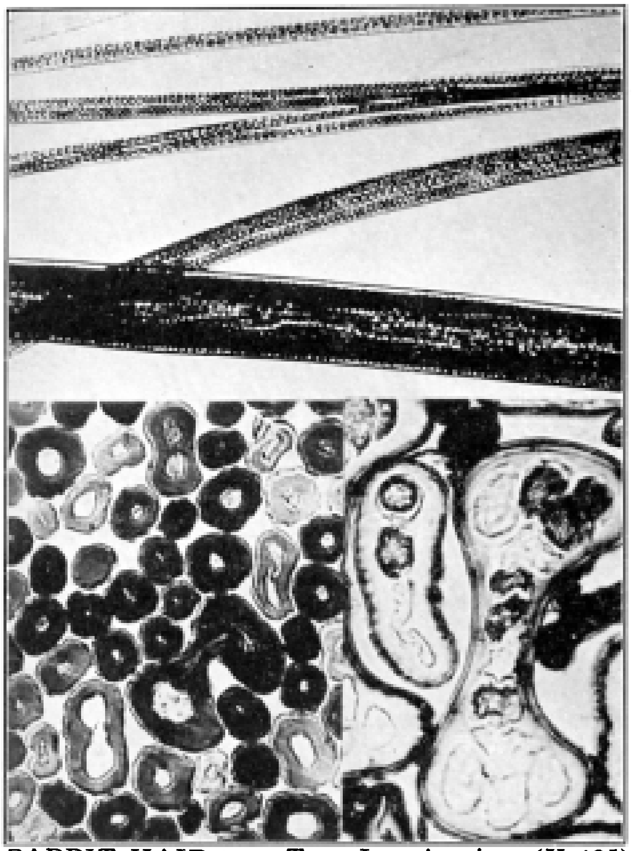
EPIDERMIS
(X 500)



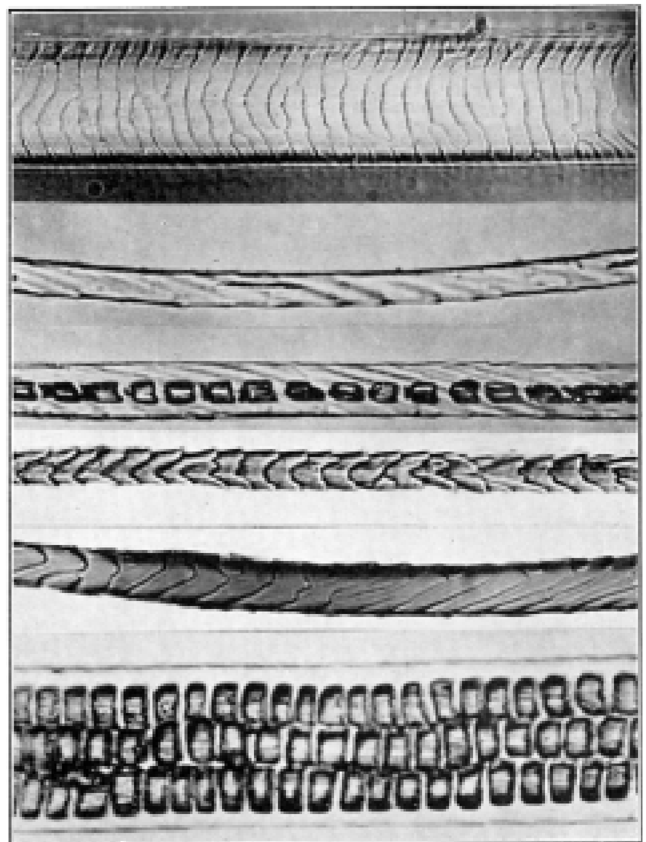
COW
Longitud. View
(X 115)

CROSS-SECTIONS
Cow (X 250) Calf (X 500)

EPIDERMIS
(X 500)

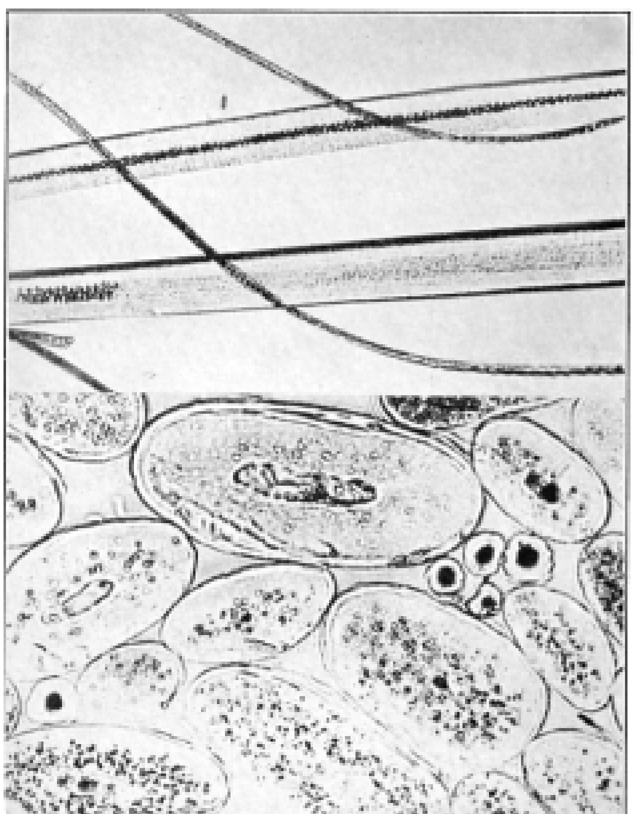


RABBIT HAIR Top: Longit. view (X 125)
Bottom: Cross-sect. (left) Furhairs
(right) Guardhairs (X 500)

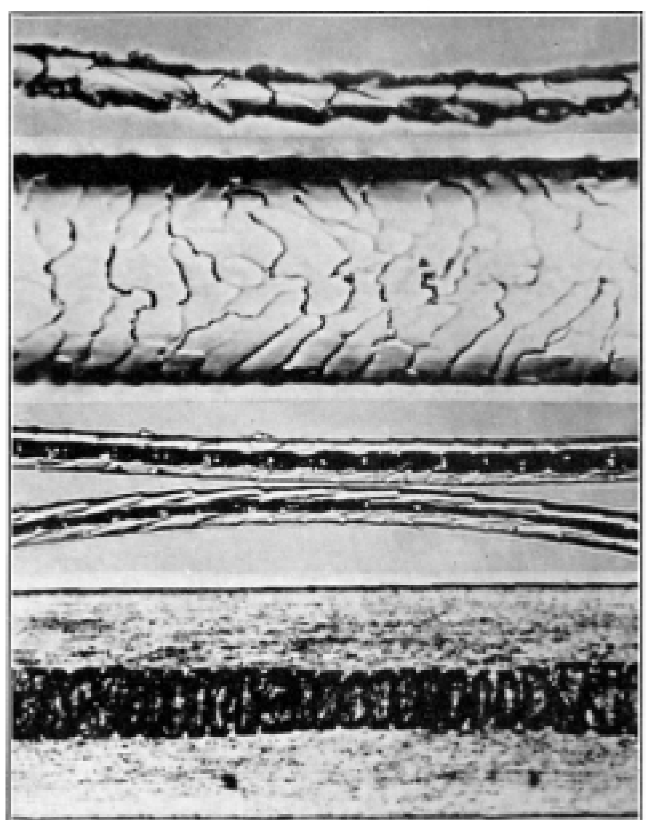


A B C D E F

A—Epidermis of Guardhair; B, C—Furhairs, longit. view; D, E—Epidermis of Furhairs; F—Guardhair, longit. view (all X 500)

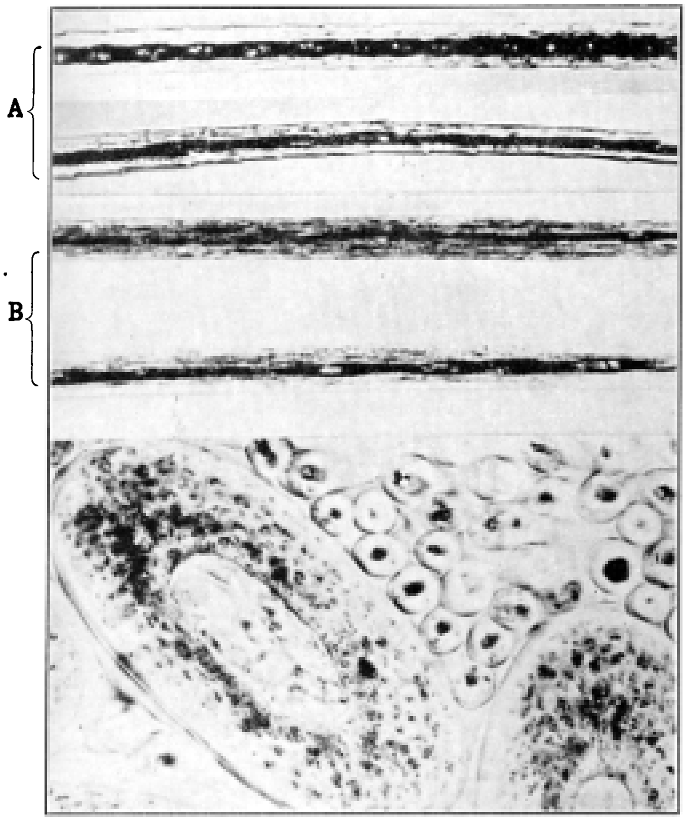


MUSKRAT: Guard- and Furhairs
Top: Longit. view (X 125)
Bottom: Cross-sect. (X 500)

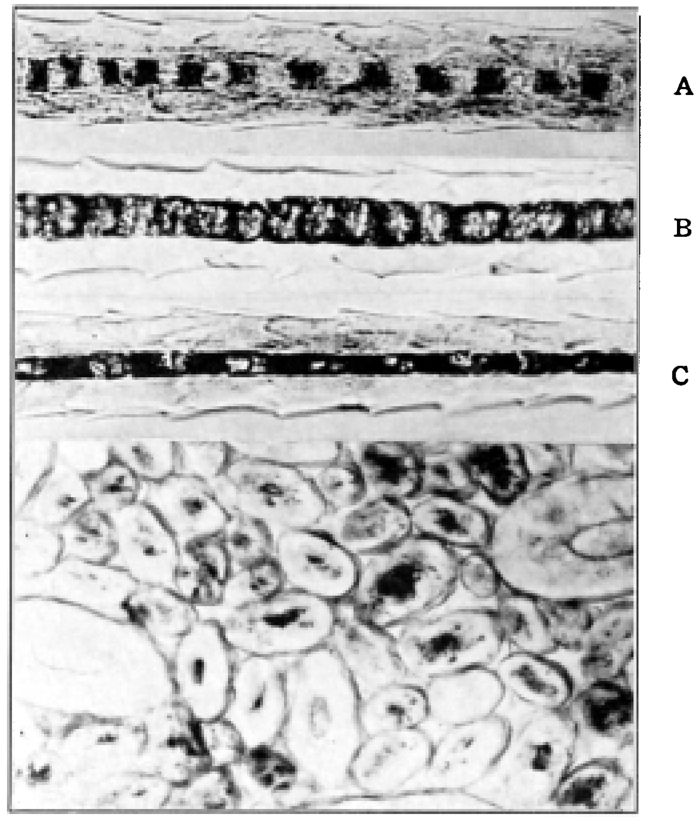


A B C D E

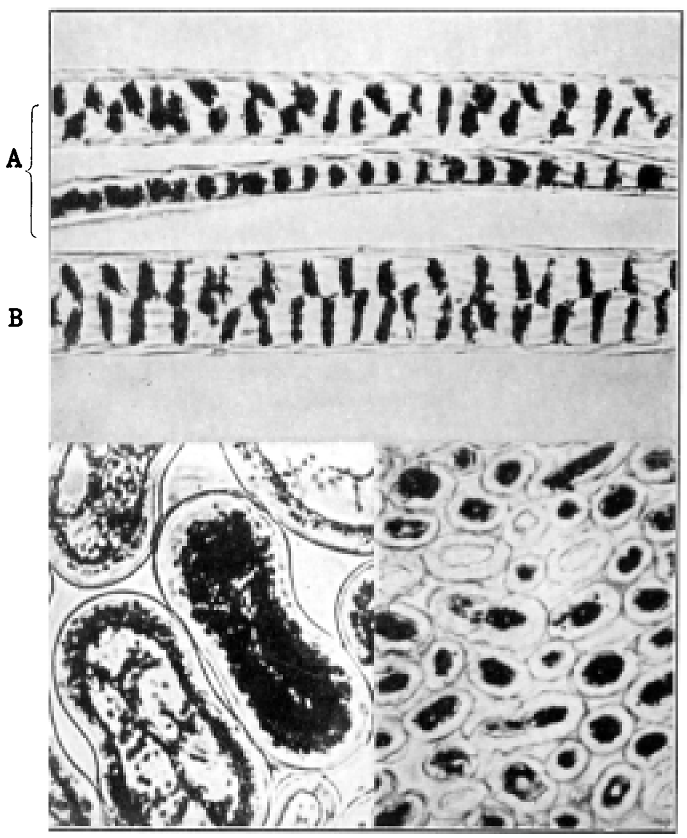
A—Epidermis of Furhair; B—Epidermis of Guardhair; C, D—Furhairs, longit. view; E—Guardhair, longit. view (all X 500)



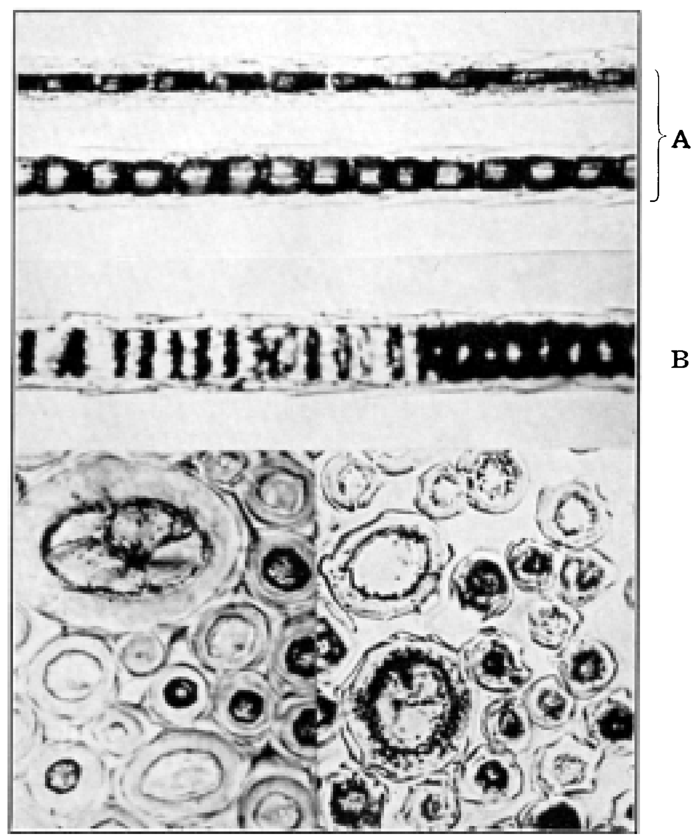
BEAVER Top: A—Furhairs near middle, B—Furhairs near tip
Bottom: Cross-sects. (all X 500)



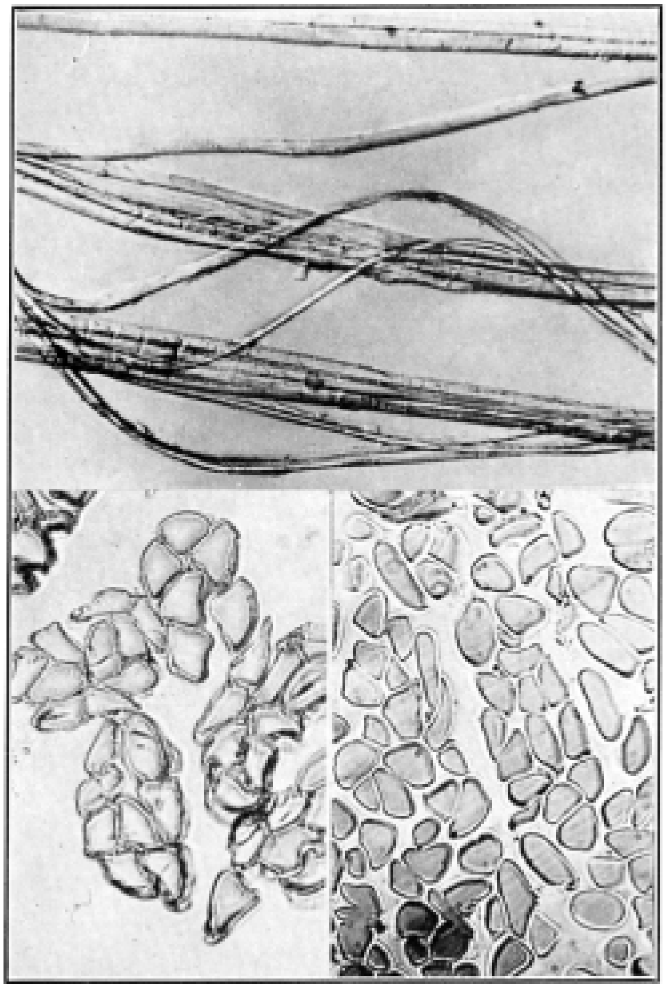
RACCOON Top: A—Medulla with air removed, B—Hair near base, C—Hair near tip
Bottom: Cross-sects. (all X 500)



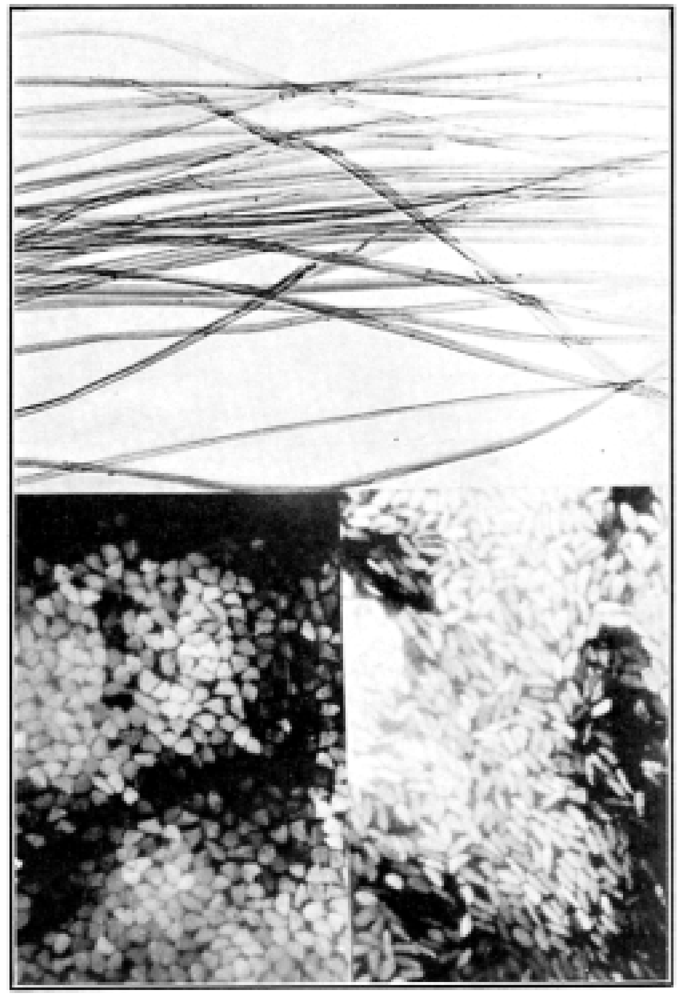
SQUIRREL Top: A—Furhairs, B—Guardhair (air removed); Bottom: Cross-sects. (left) Guardhairs, (right) Furhairs (all X 500)



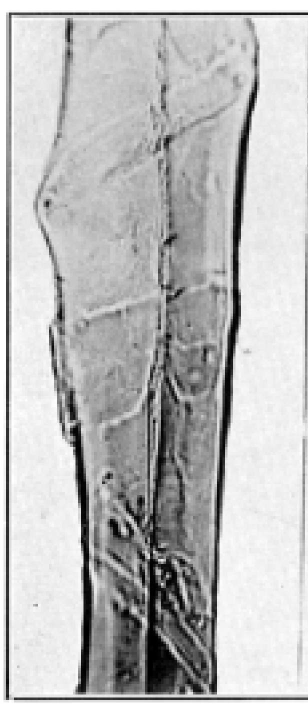
FOX Top: A—Furhairs, B—Guardhair
Bottom: Cross-sections of (left) Silver Fox, (right) Red Fox (all X 500)



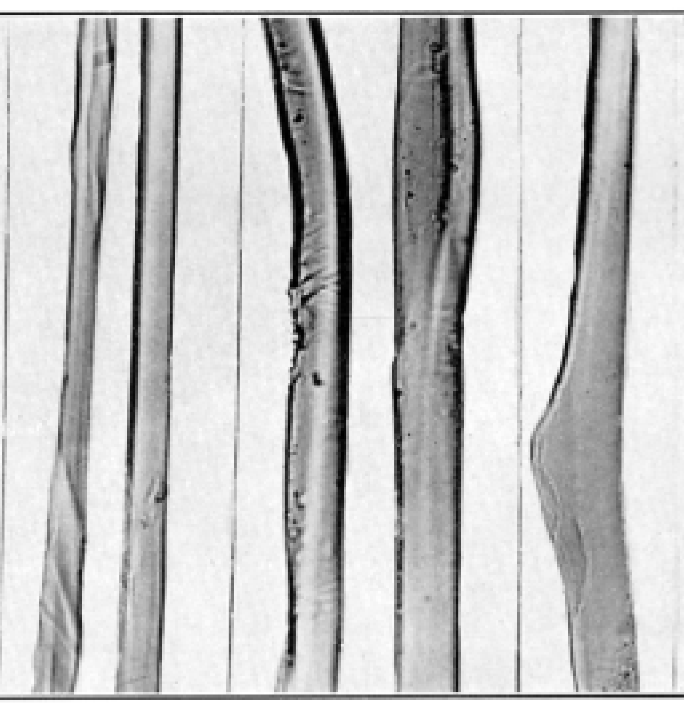
Top: RAW SILK Oblique Light (X 115)
Bottom: Cross-sections (X 500)
Raw Silk Degummed Silk



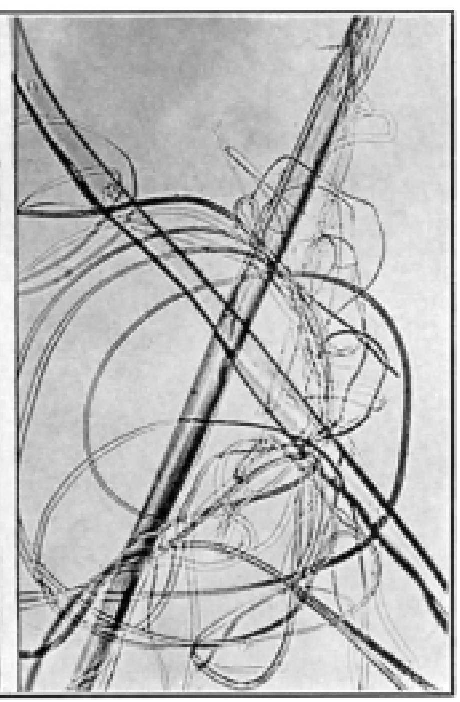
Top: DEGUMMED SILK (X 115)
Bottom: Variations in Cross-sections (X 165)
Diameter ratio, 0.610 Diameter ratio 0.398



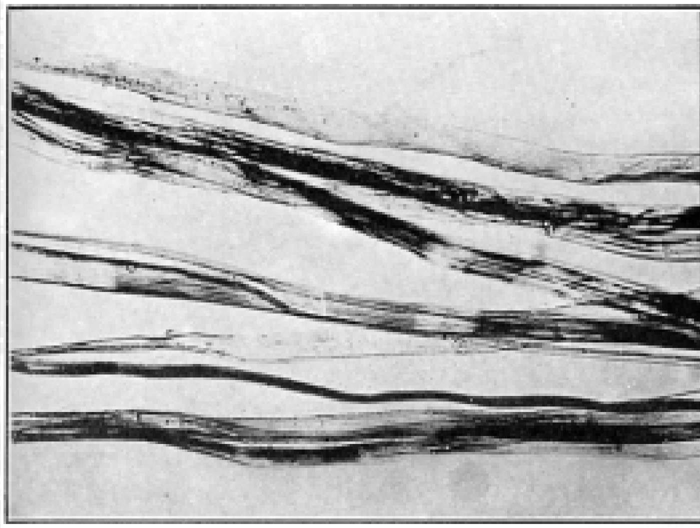
RAW SILK
showing Gum
(Sericin) (X 500)

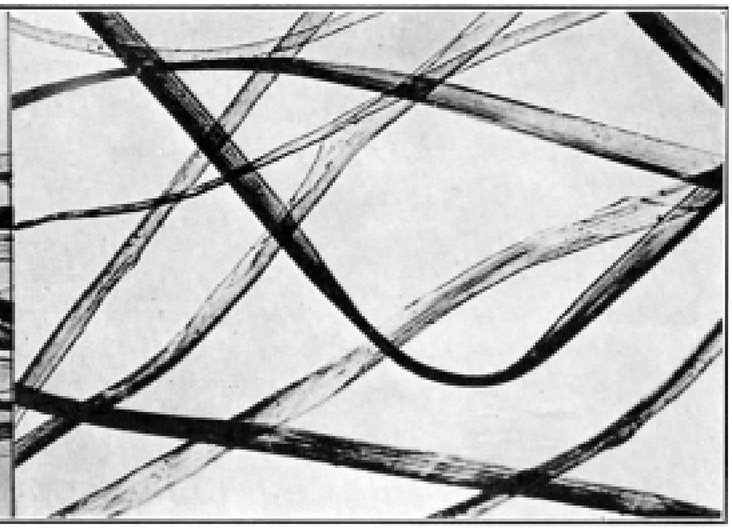


DEGUMMED SILK FIBERS
of three different Diameters (X 500)



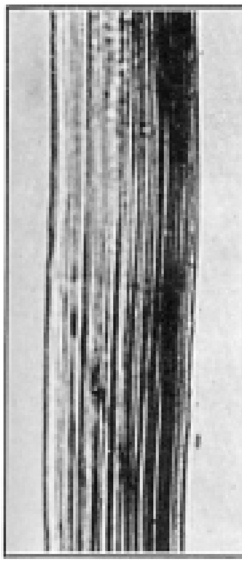
LOUSY SILK
(X 250)

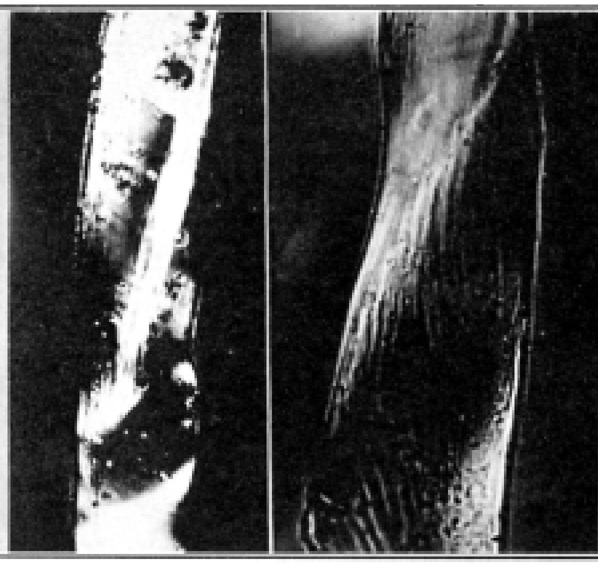


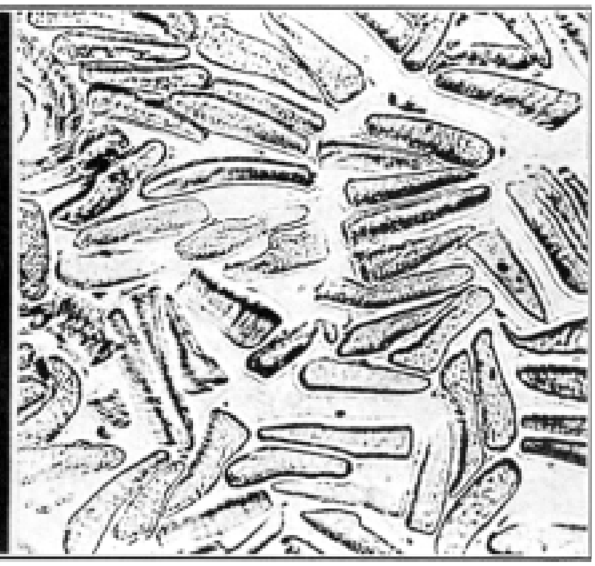


TUSSAH SILK
Raw Fibers (X 115)

Degummed Fibers (X 115)



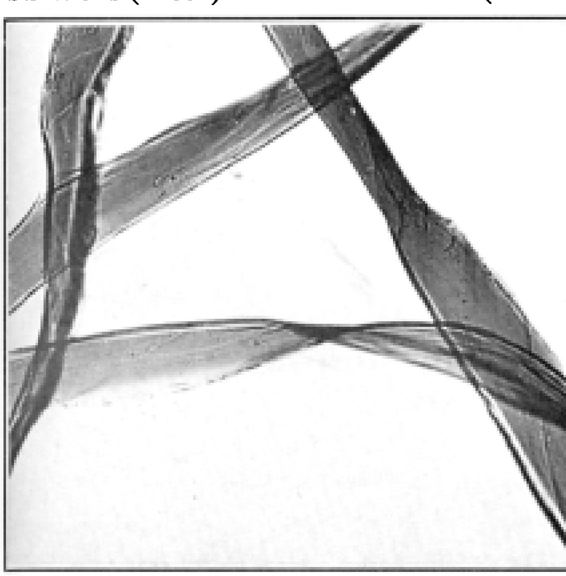


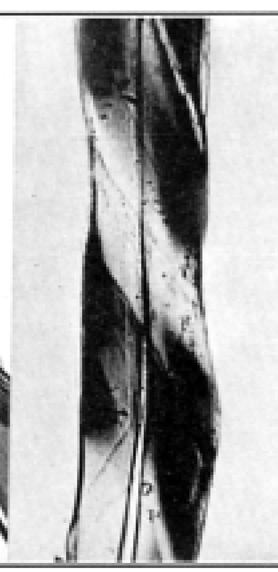


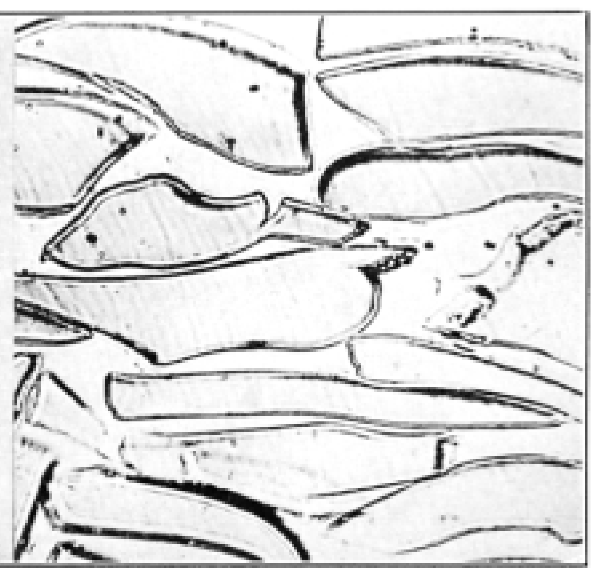
Tussah Fiber
showing
Striations (X 500)

Two Fibers in Polarized Light
showing Surface Conditions
(X 500)

Cross-section
(X 500)



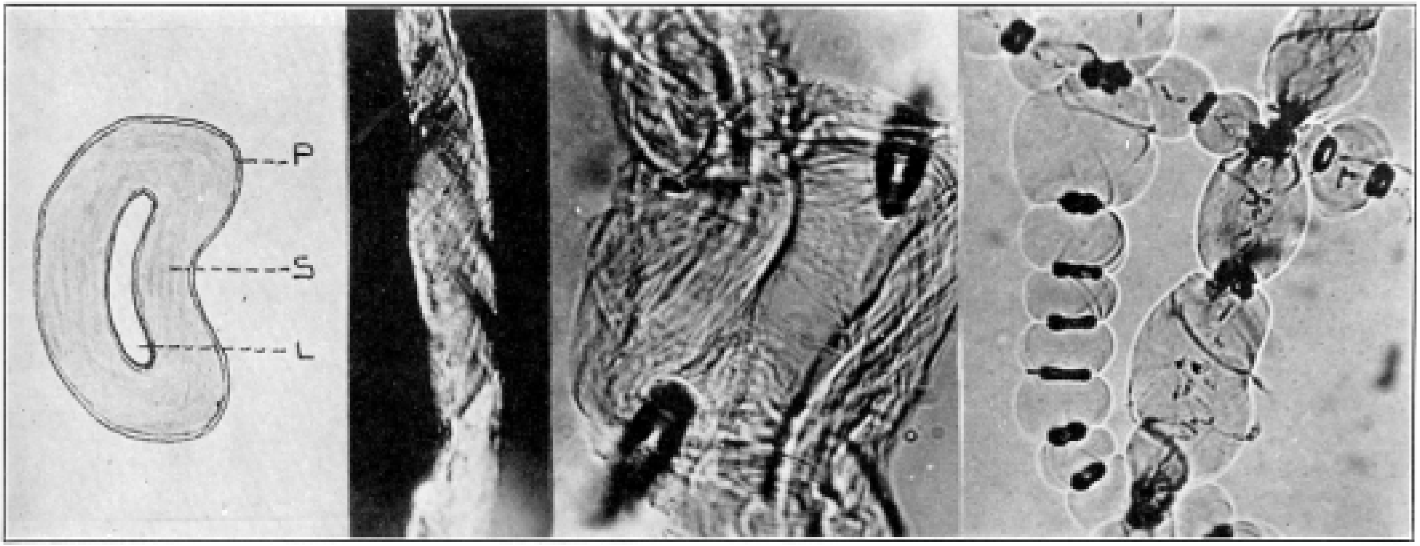




KURIWATA SILK
Longitudinal View (X 115)

2 Filaments (X 115)
Oblique Illumination

Cross-section
(X 500)



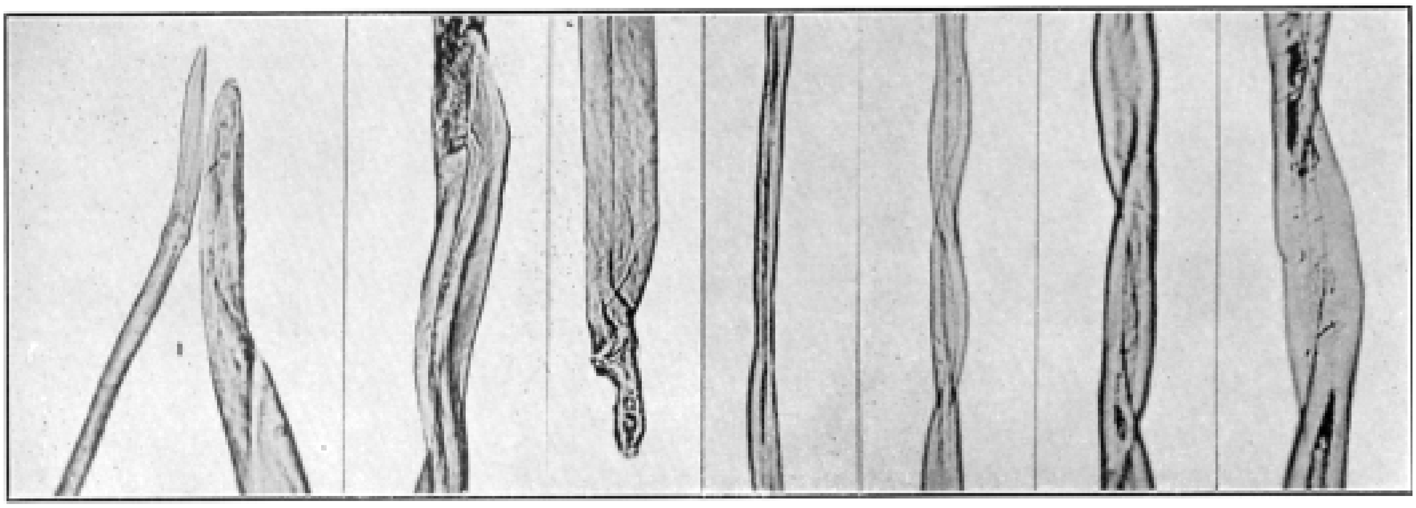
Schematic Drawing of Cross-section.
P = Primary wall and cuticle.
S = Secondary cellulose.
L = Lumen.

Fiber in polarized light showing spiral structure. (X 500)

Depectinized Fiber swollen and dissected showing fibrills. (X 500)

Fibers swollen in cuprammonium hydroxide showing balloons and cuticle (collars). (X 120)

(Courtesy Hock and Harris)



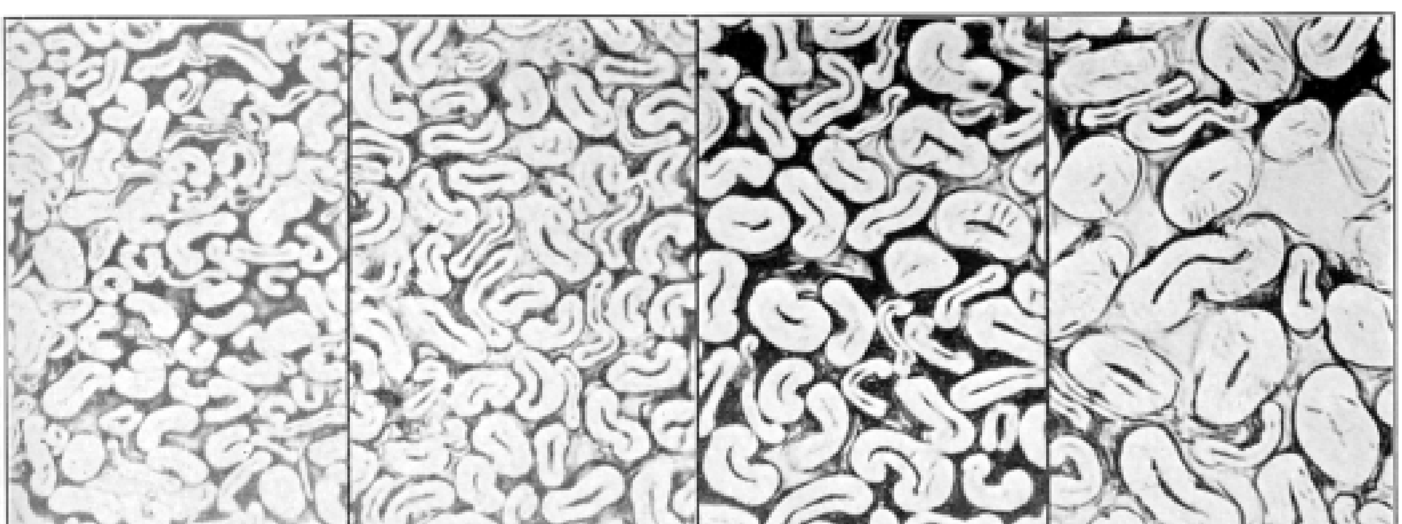
Fibertip (X 500)

Stem (X 500)

Base (X 500)

Mature Fibers of different diameters (American Upland) (X 300)

(Courtesy U. S. Department of Agriculture)



Sakellarides

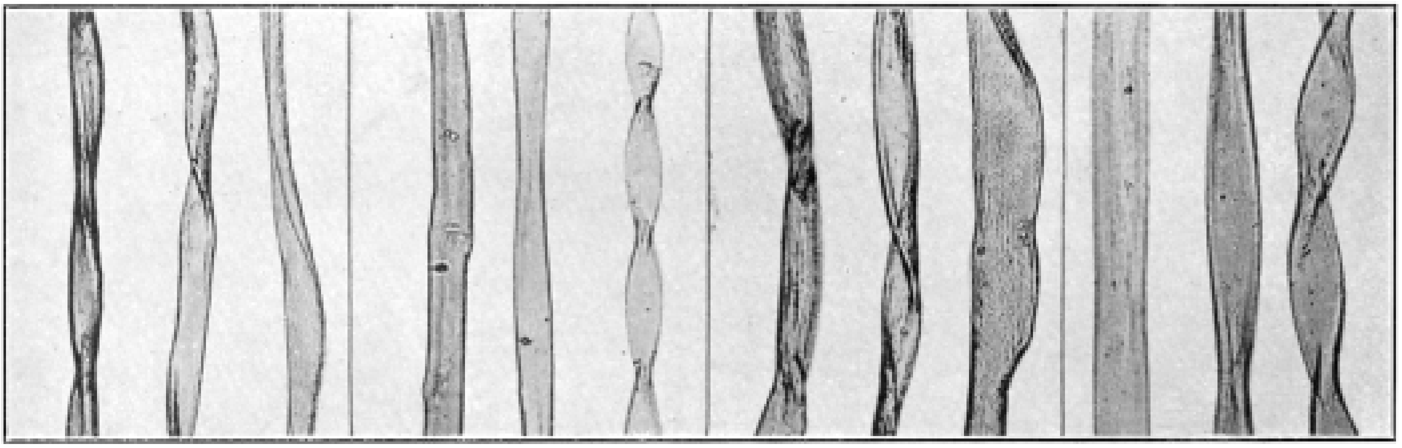
American Upland

Asiatic

Cross-sections (X 500)

(Courtesy U. S. Department of Agriculture)

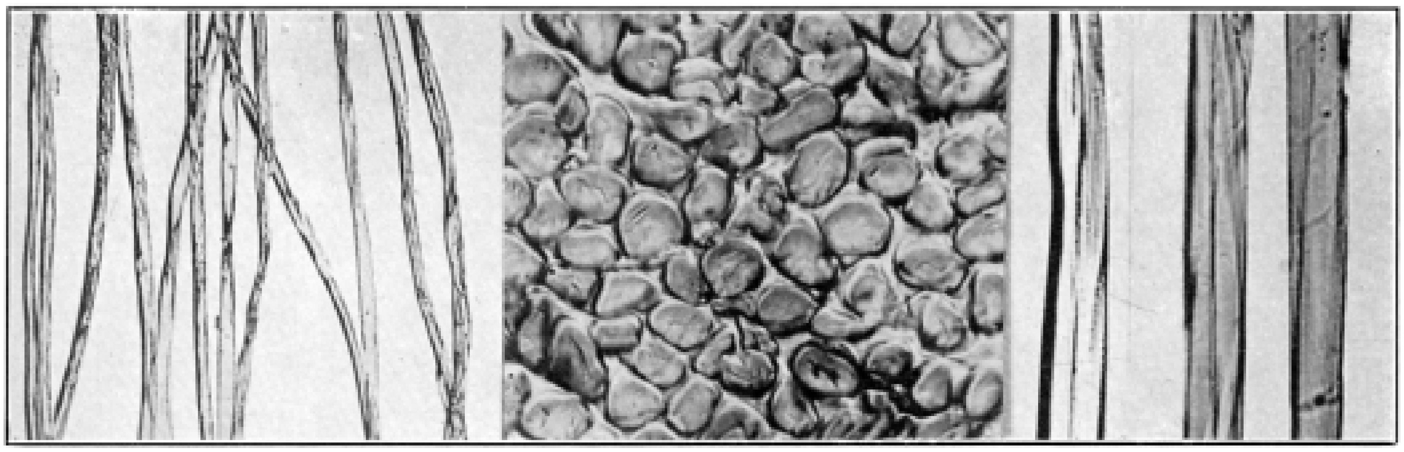
COTTON AND MINOR SEED HAIRS — PLATE XVI



MATURITY TEST
Untreated — Swollen

Coarse Fibers
Untreated — Swollen

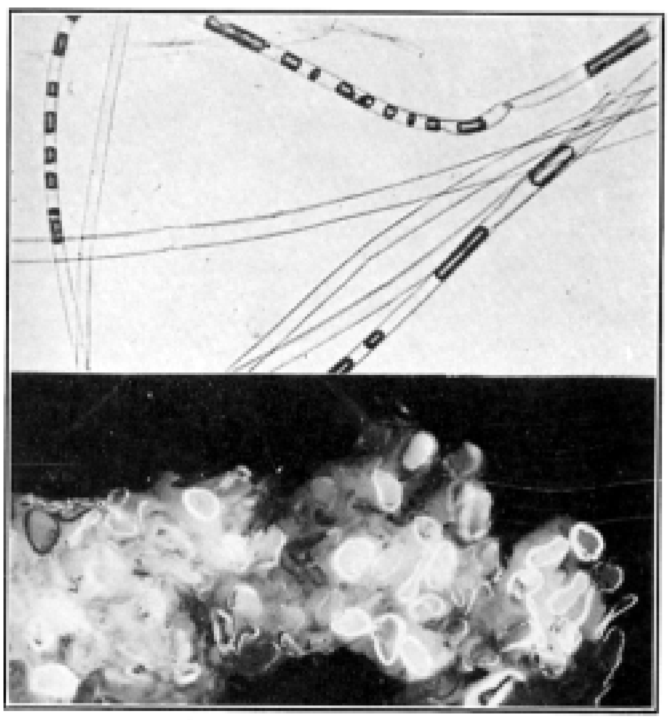
(Courtesy U. S. Department of Agriculture)



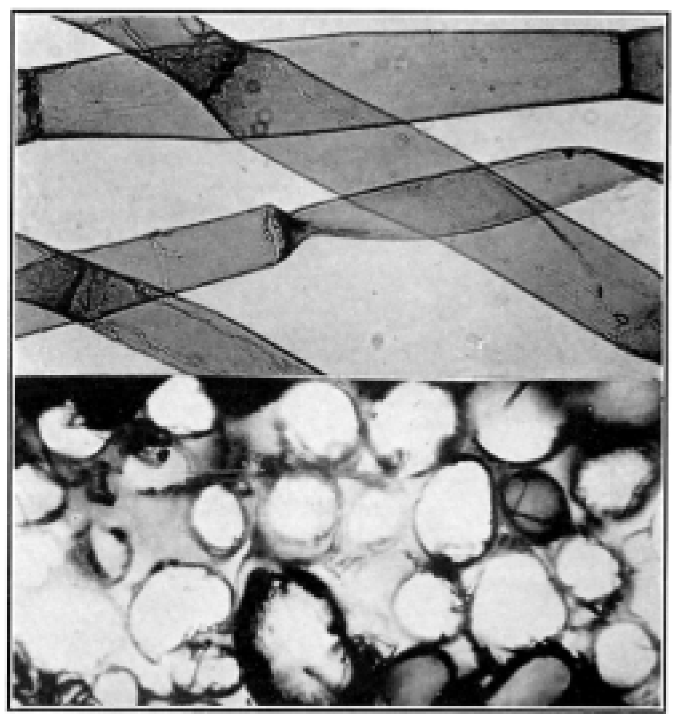
MERCERIZED COTTON:
Longit. view (X 115)

Cross-section (X 500)

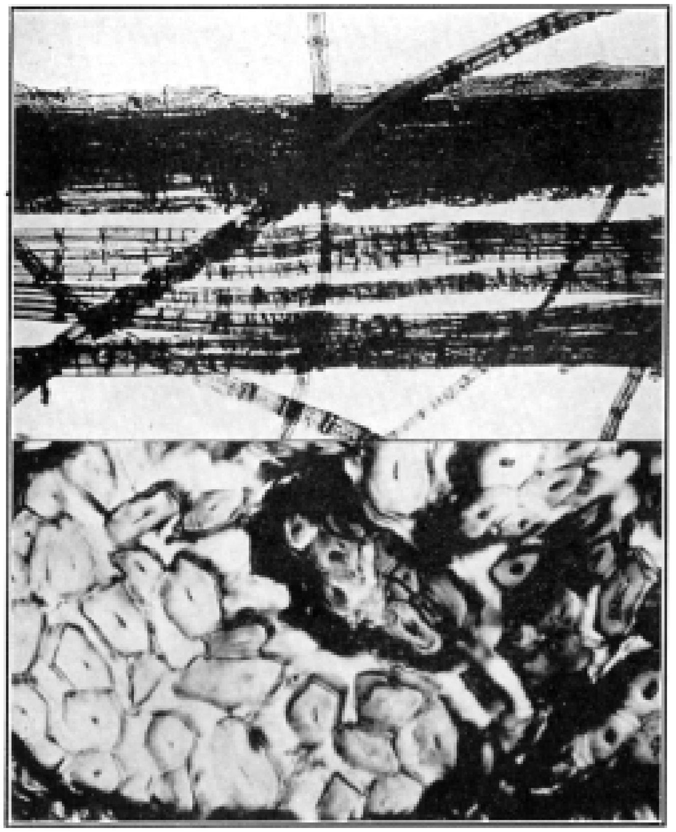
Well mercerized Fibers
(X 500)

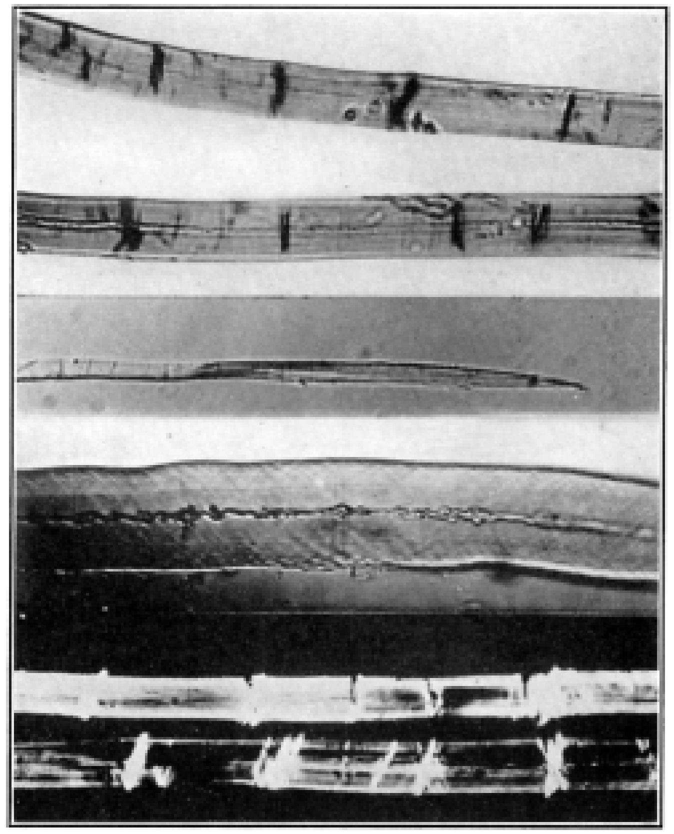


KAPOK: Longit. view (X 115)
Cross-section (X 230)



PULU: Longit. view (X 115)
Cross-section (X 230)





A

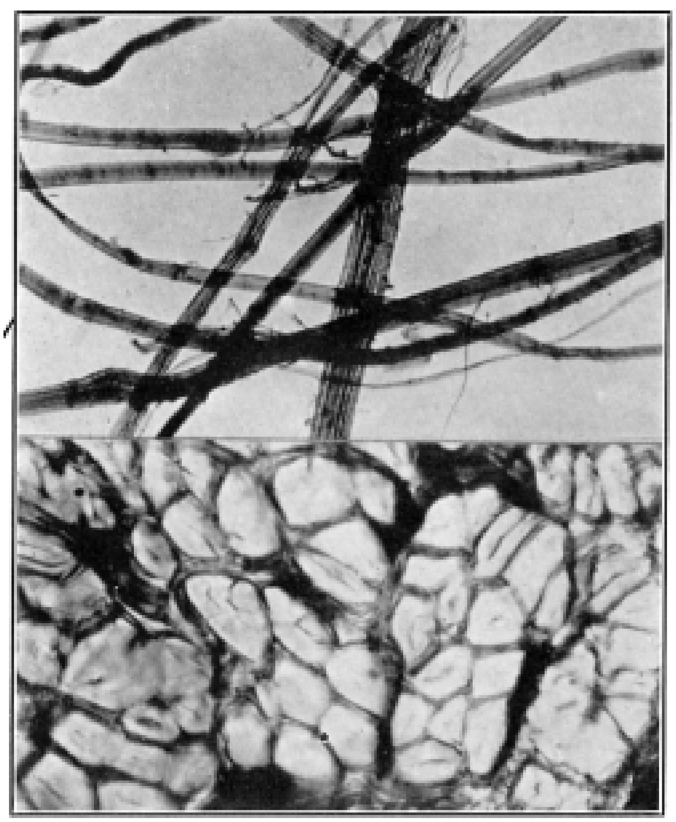
B

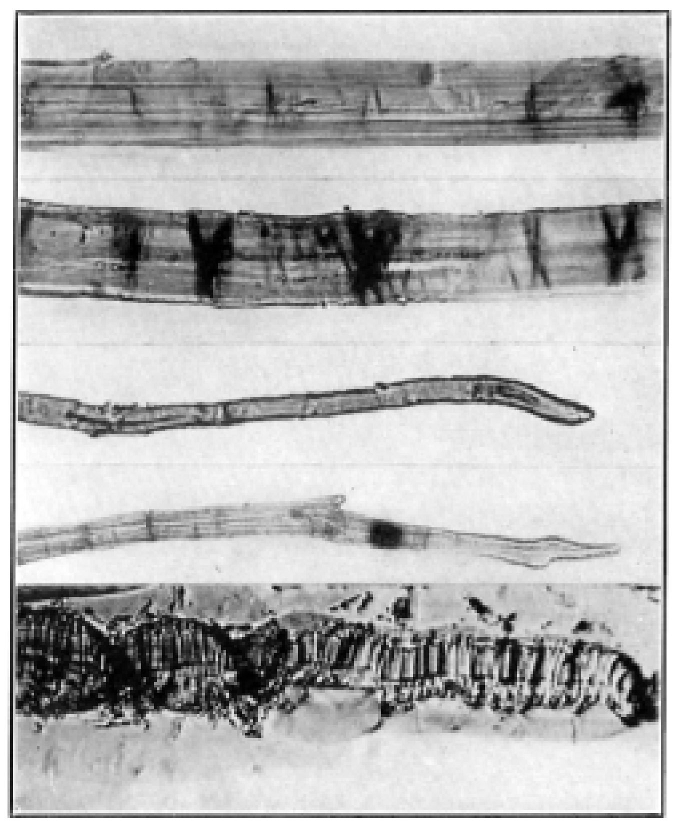
C

D

FLAX
Top: Raw Flax fibers stained (X 115)
Bottom: Cross-section (X 500)

A—Two stained fibers showing lumen and nodes (X 500); B—Typical fiber end (X 500); C—Fiber in cuprammonium hydroxide (X 230); D—Two fibers in polarized light (X 500).





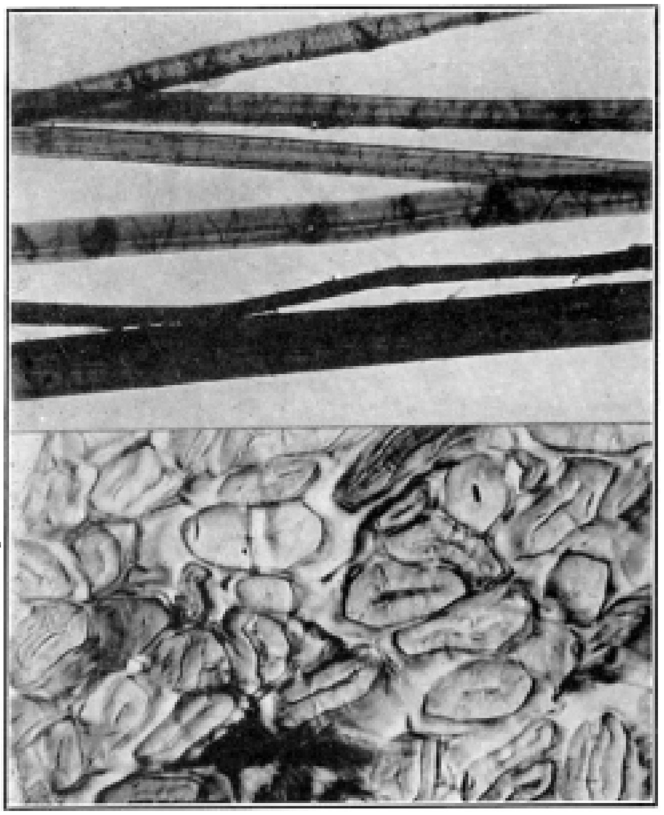
A

B

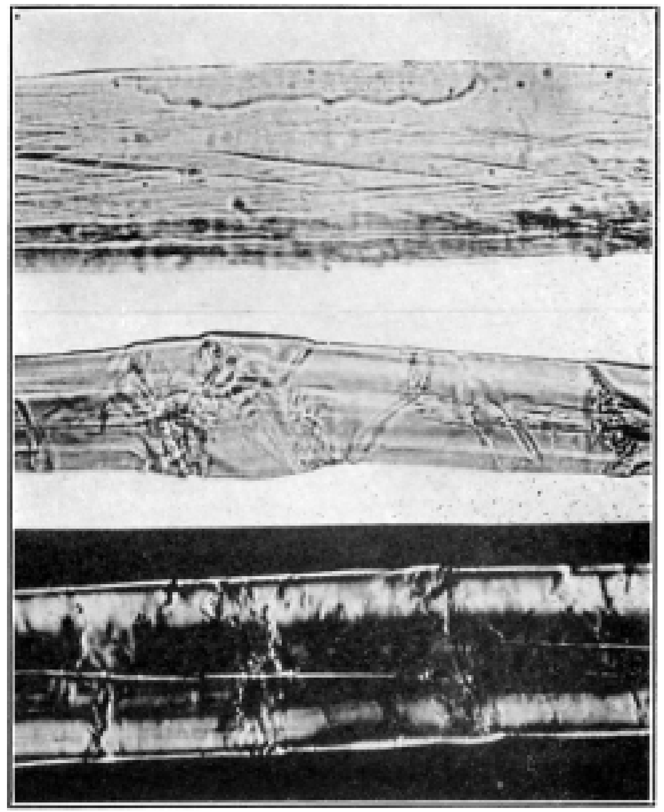
C

HEMP
Top: Raw fibers stained (X 115)
Bottom: Cross-section (X 500)

A—Two hemp fibers, top unstained, bottom stained (X 500); B—Fiber tips showing rounded and forked ends (X 500); C—Fiber in cup. hydroxide (X 230).



RAMIE
Top: Longit. view of stained fibers (X 115)
Bottom: Cross-section (X 500)

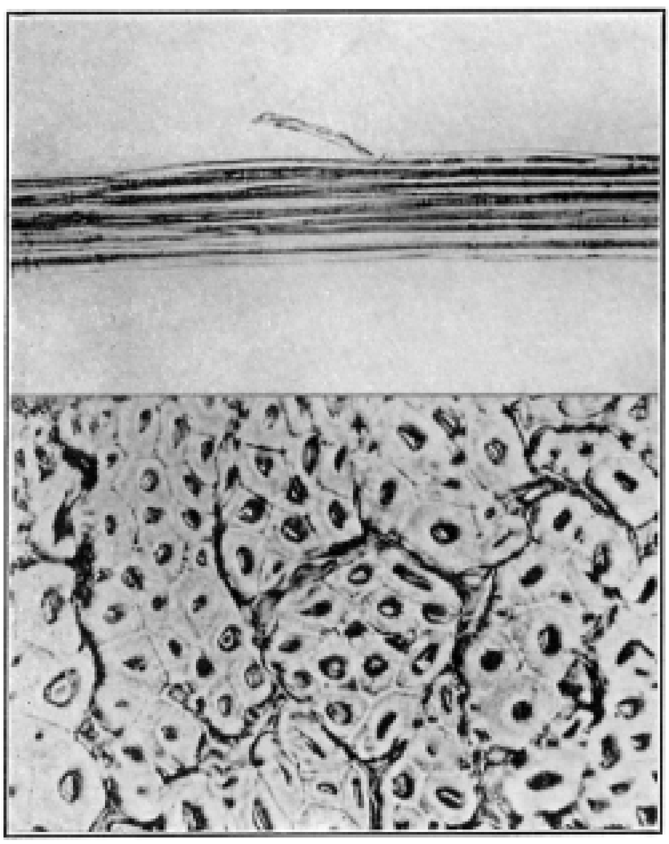


A

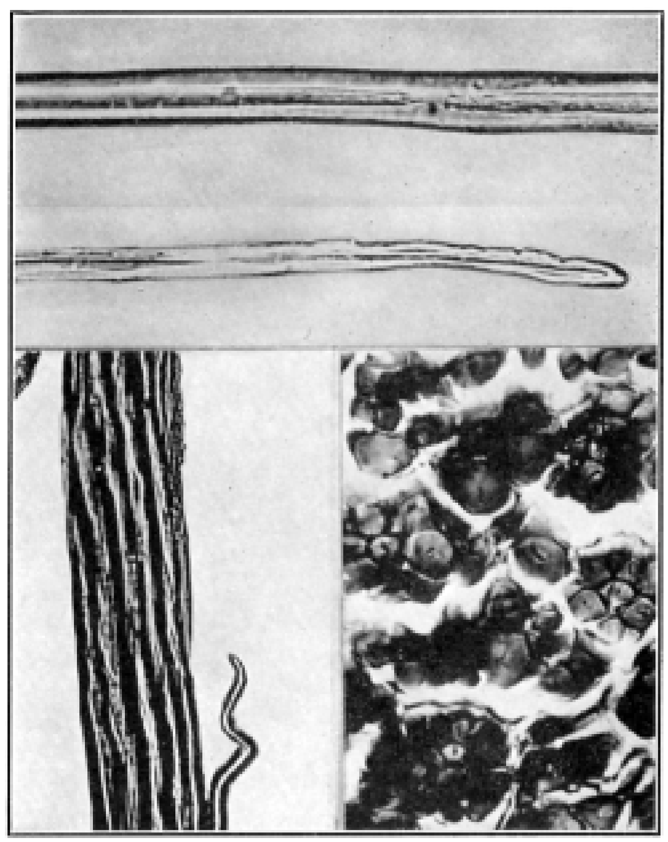
B

C

A—Ramie fiber showing diagonal cracks (X 500); B—Fiber with typical thickenings and fissures (X 500); C—Fiber under polarized light (X 500).



JUTE
Top: Longit. view of fiber bundle (X 230)
Bottom: Cross-section (X 500)

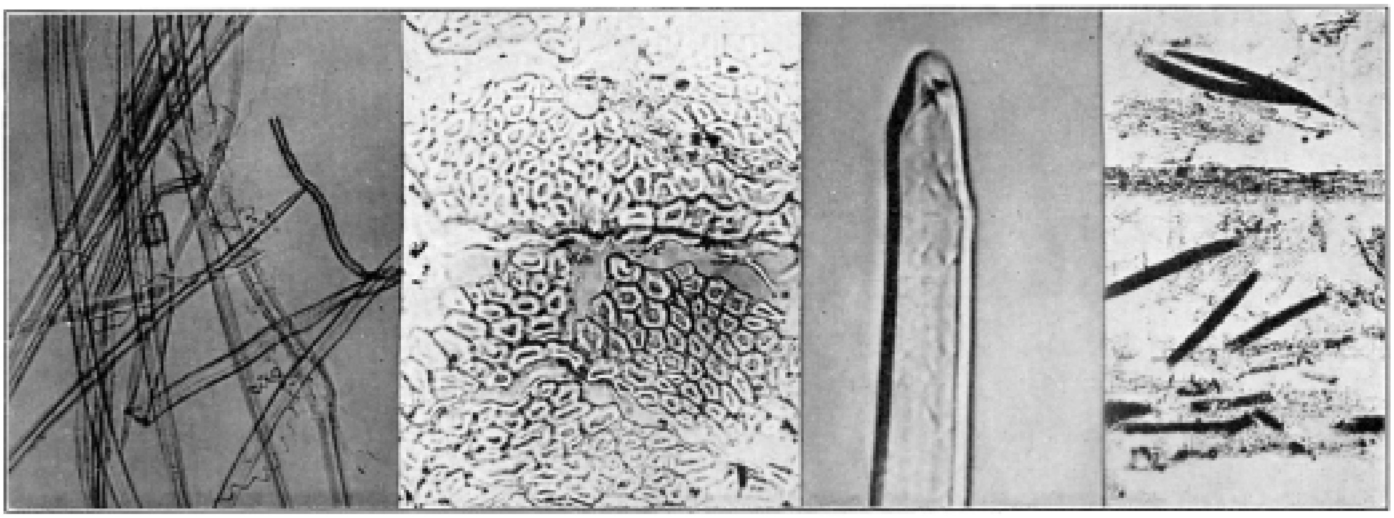


A

B

C

A—Jute fiber showing contraction of lumen (X 500); B—Cell end (X 500); C—Treated jute (Lanatin), Longit. view (X 230), Cross-section (X 500).

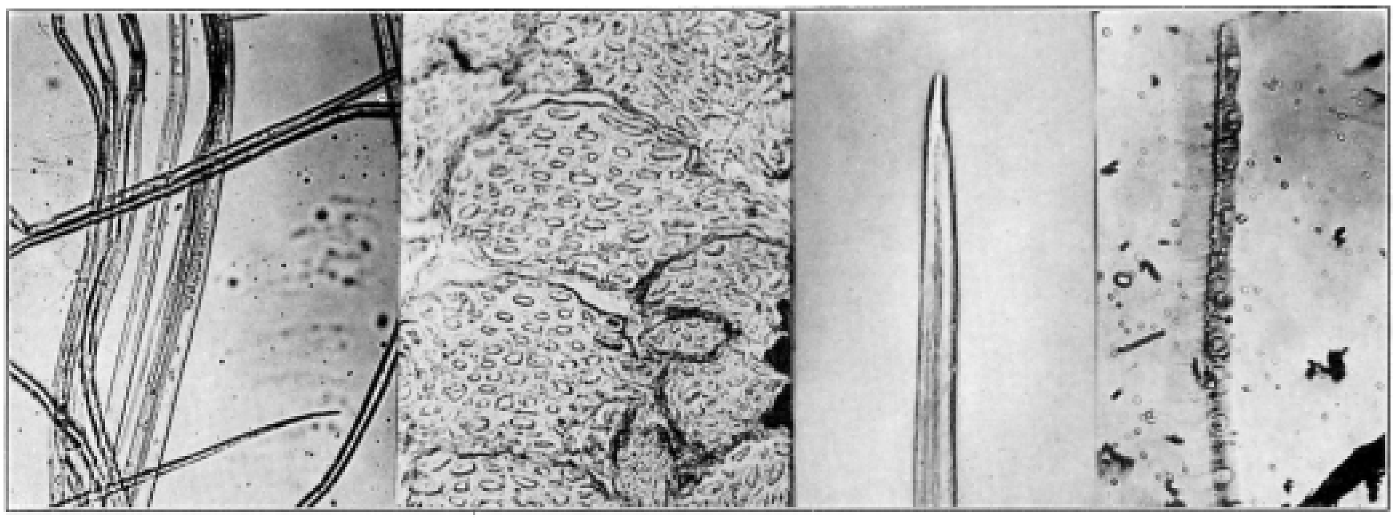


SISAL (Agave sisalana)
Longit. view showing fibers and spiral tissue (X 115)

Cross-section of fiber bundles (X 230)

Fiber end (X 500)

Black crystals of calcium oxalate in ash (X 115)

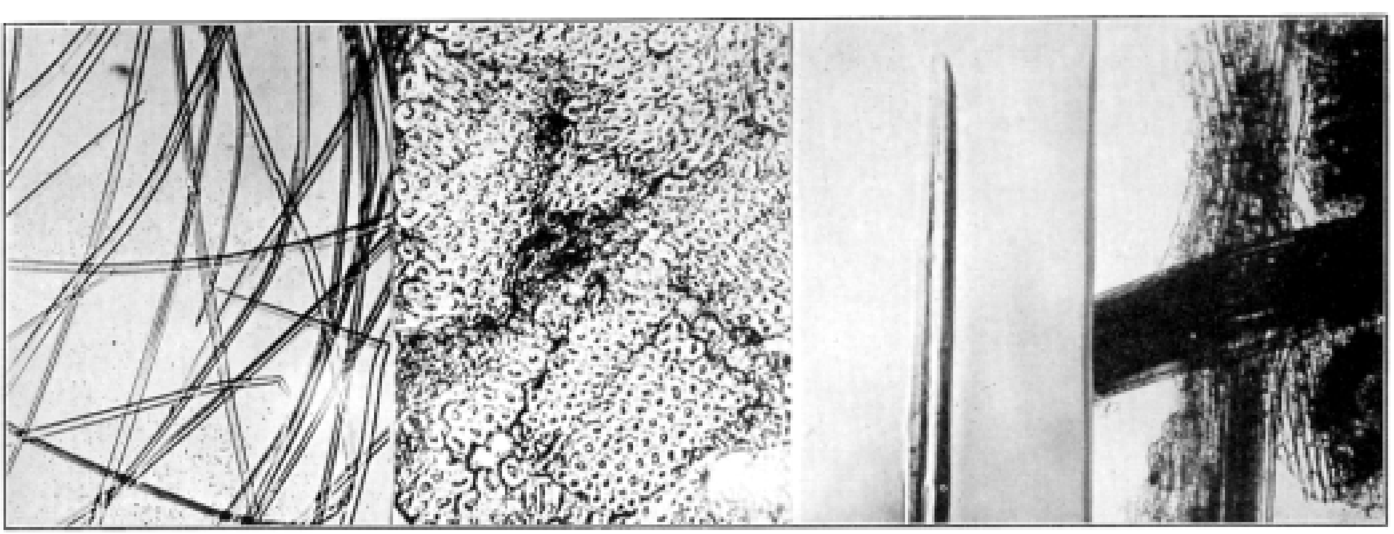


MANILA (Musa textilis)
Longit. view (X 115)

Cross-section of fiber bundles (X 230)

Fiber end (X 500)

Plate like stegmata found in ash (X 230)

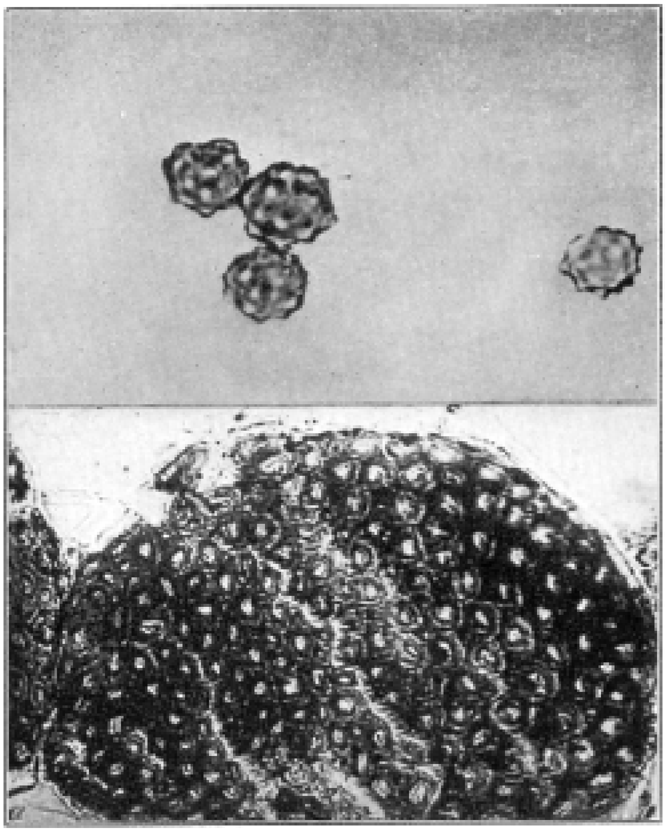


NEW ZEALAND FLAX (Phormium tenax)
Longit. view (X 115)

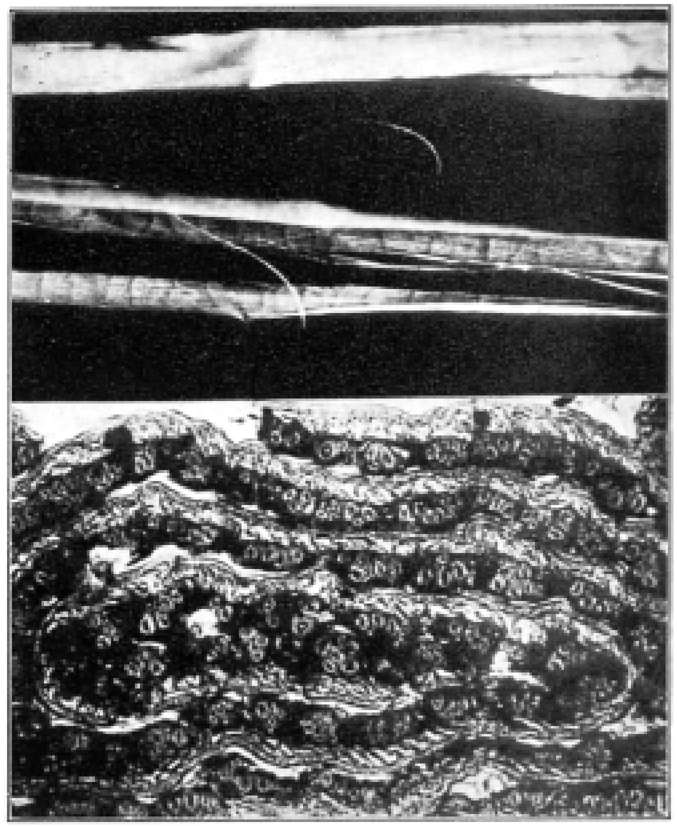
Cross-section of fiber bundles (X 230)

Fiber end (X 500)

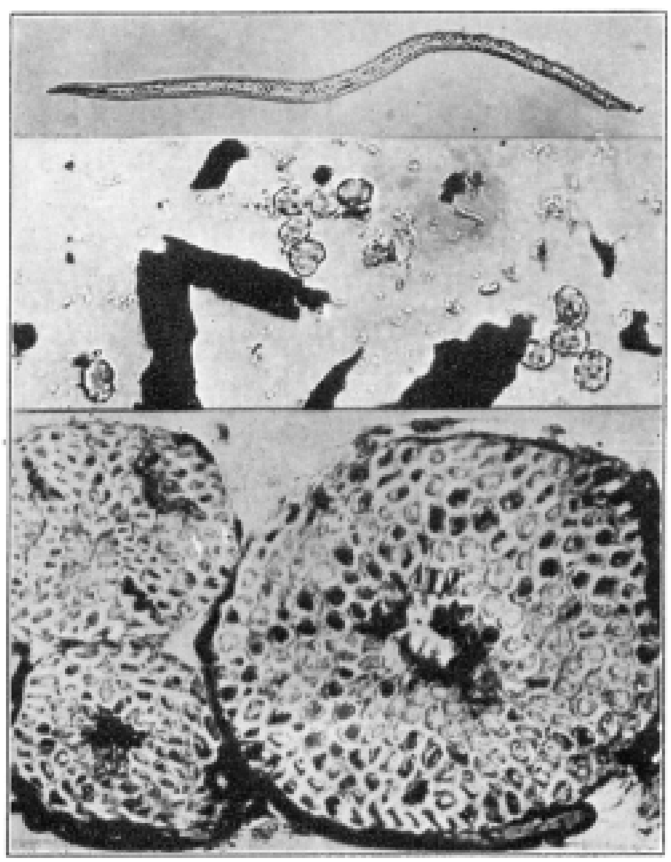
Fragments of parenchyma frequently found (X 115)



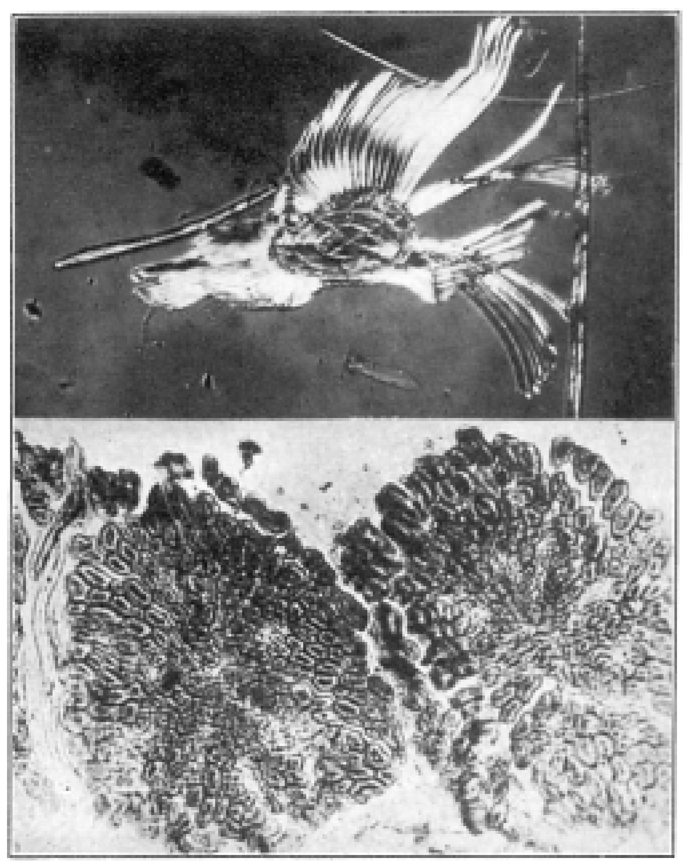
PIASSAVA (Attalea funifera)
Top: Star shaped silicous enclosures after treating fibers in chromic acid (X 500)
Bottom: Cross-section of one fiber bundle (X 230)



RAPHIA (Raphia ruffia)
Top: Raphia bast under low power microscope (X 7.5)
Bottom: Cross-section of several layers of bast (X 230)

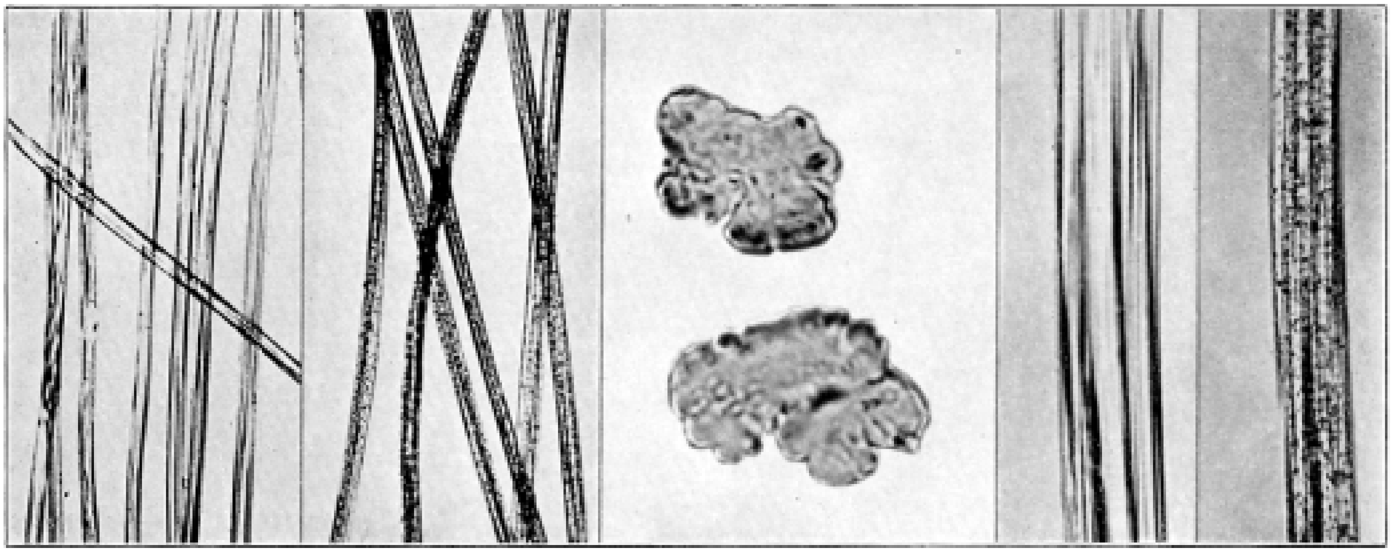


COIR (Cocos nucifera)
Top: Single cell showing spiral structure (X 115)
Middle: Silicous remains in ash (X 500)
Bottom: Cross-section of fiber bundle with hollow

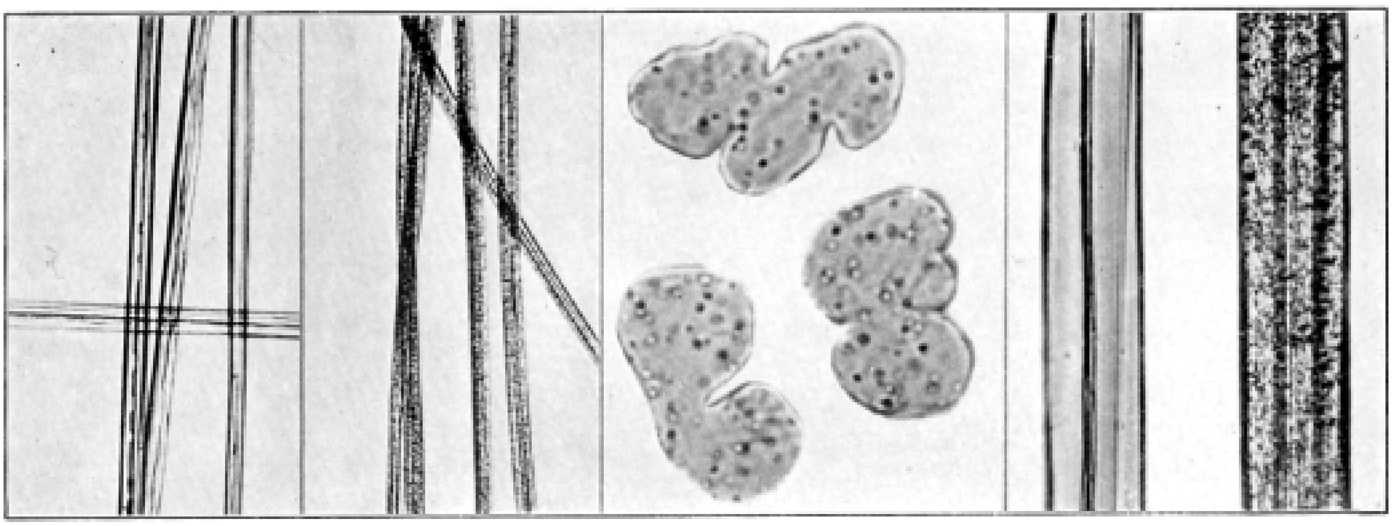


SPANISH MOSS (Tillandsia usneoides)
Top: Scale from outer surface of fibers (Polarized light) (X 85)

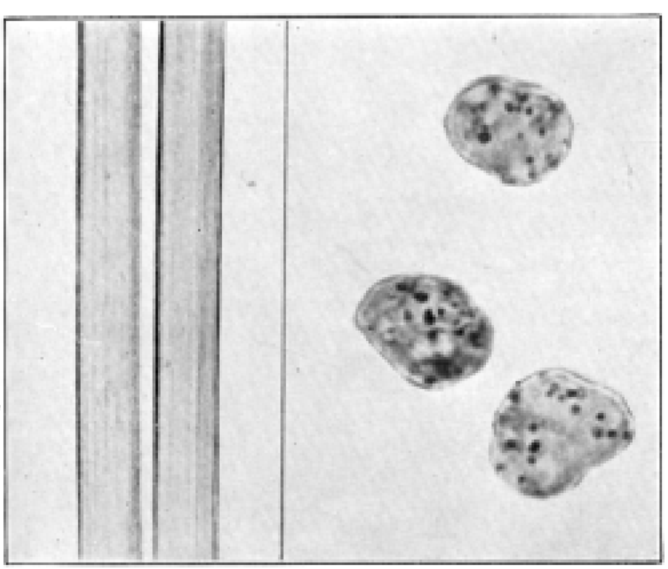
CONTINUOUS FILAMENT RAYON — PLATE XXI



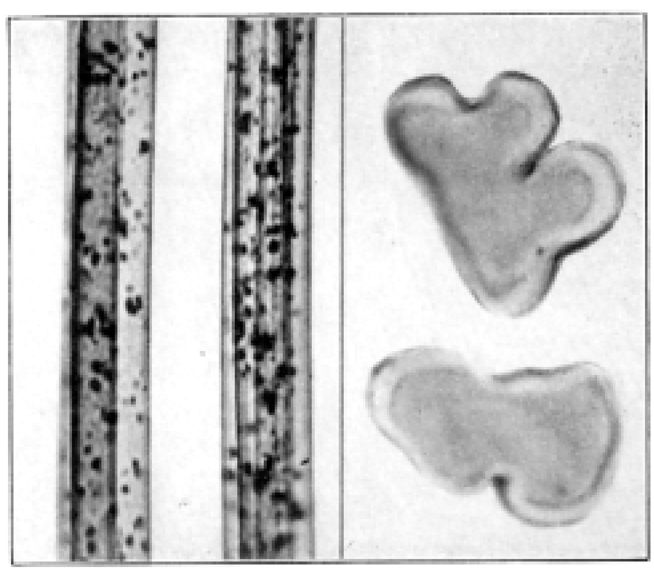
VISCOSE RAYON
Bright filaments (X 115) — Dull filaments (X 115) — Cross-sections Bright (X 1000) — Bright / Dull Filaments showing striations (X 500)



ACETATE RAYON
Bright filaments (X 115) — Dull filaments (X 115) — Cross-sections Dull (X 1000) — Bright / Dull Filaments showing striations (X 500)

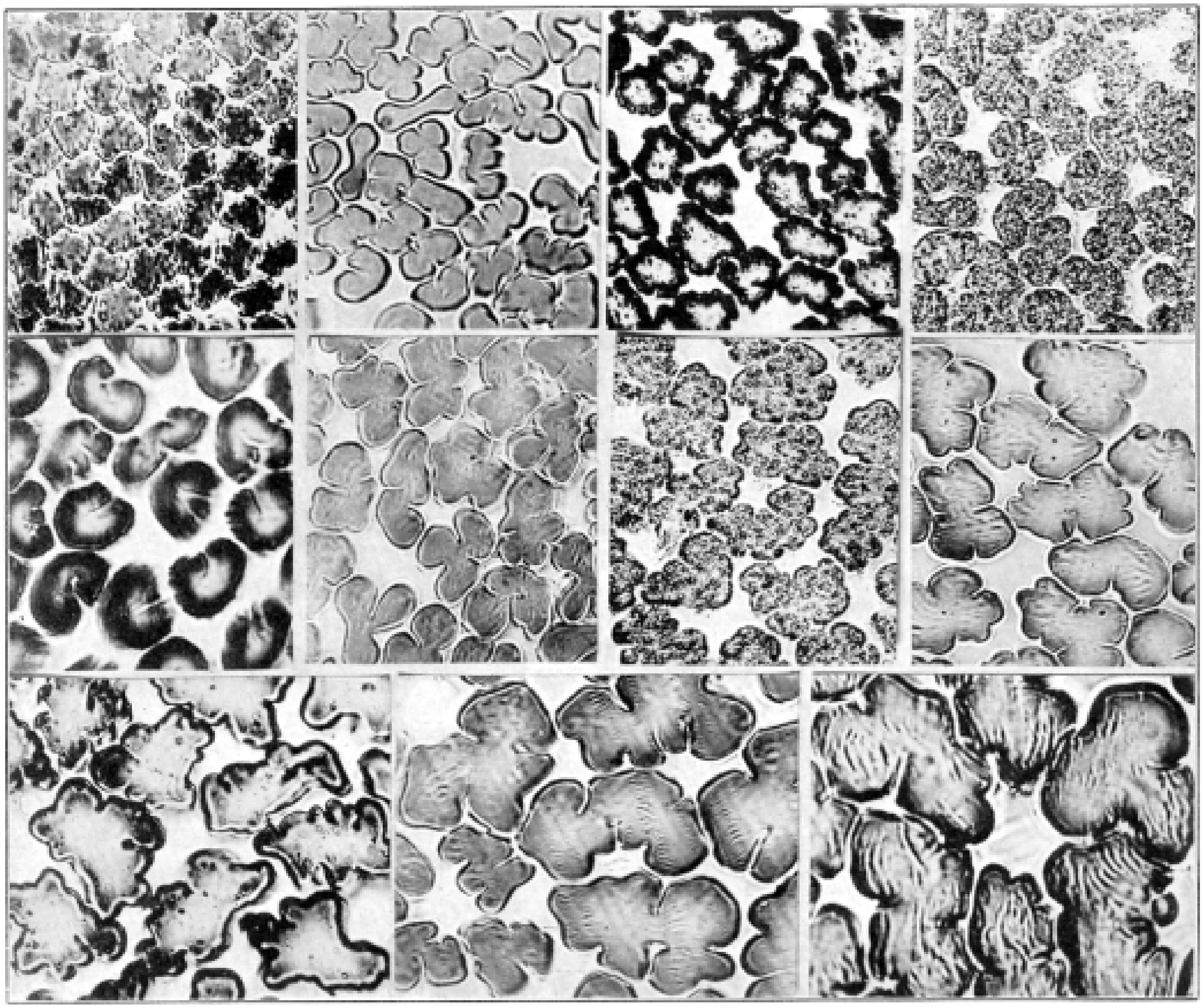


CUPRAMMONIUM RAYON
Bright filaments (X 500) — Cross-sections dull (X 1000)



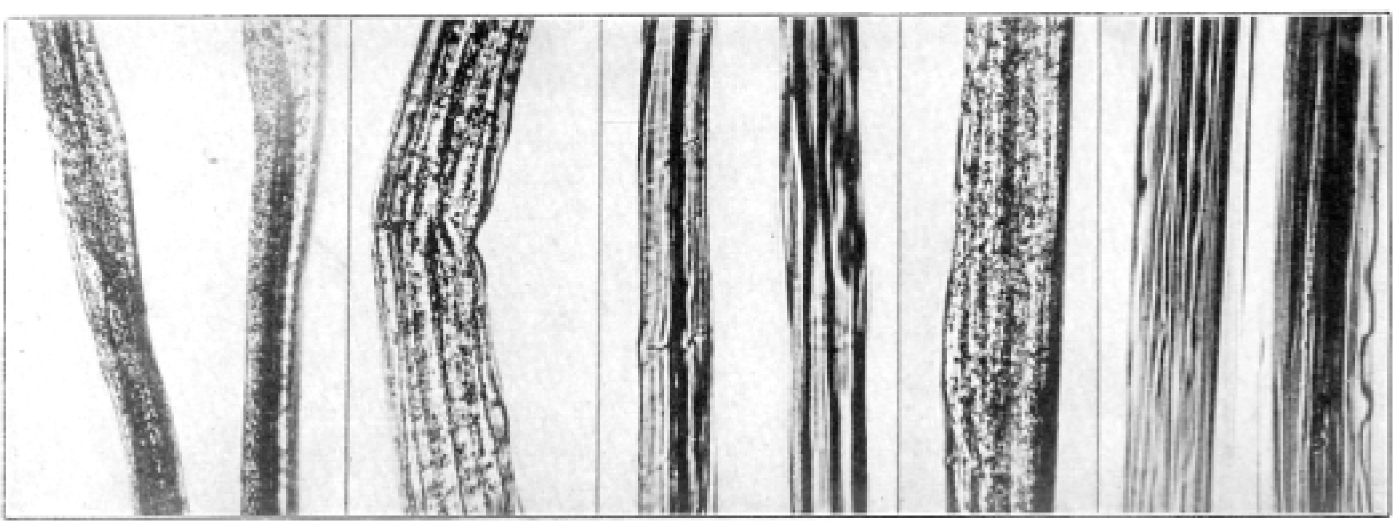
NITROCELLULOSE RAYON
Dull filaments (X 500) — Cross-sections Bright (X 1000)

RAYON STAPLE FIBERS — PLATE XXII



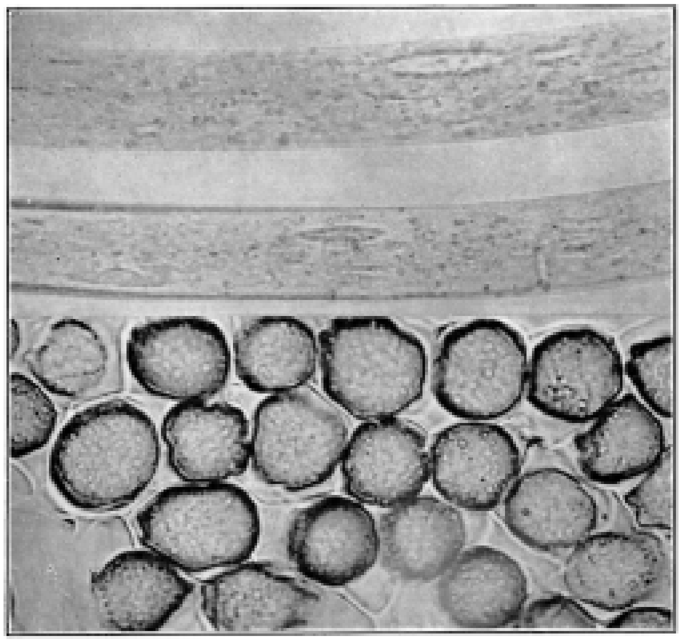
CROSS-SECTIONS OF VARIOUS STAPLE FIBERS (X 500)

Upper Row: Fibro, 1.5 den. Bri.—Celanese, 2 den. Bri.—Fibro, 3 den. Dull—Teca, 3 den. Dull.
Middle Row: Sylph, 4.5 den. Bri.—Celanese, 5 den. Bri.—Acele, 5.5 den. Dull—Teca, 8 den. Bri.
Bottom Row: Fibro, 10 den. Bri.—Celanese, 12 den. Bri.—Teca, 20 den. Bri.

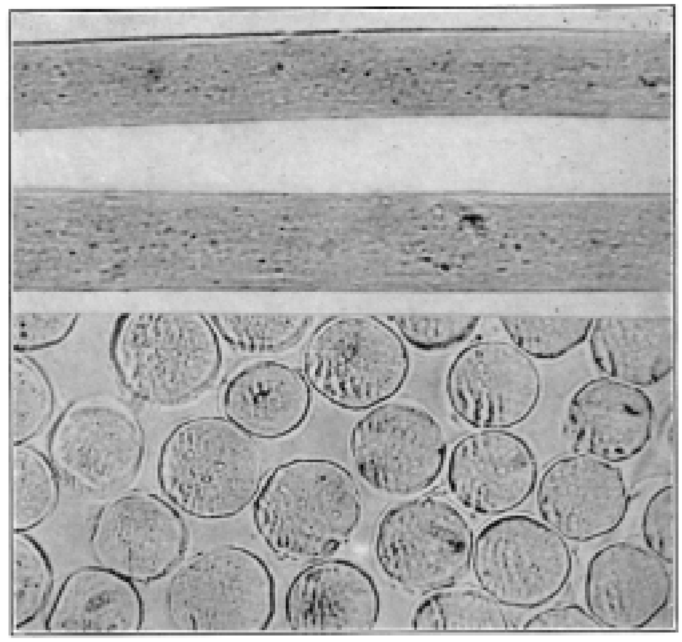


Teca—3 den. Dull Acetate — Fibro—5 den. Dull Viscose — Sylph—4.5 den. Bri. Viscose — Du Pont 5.5 den. Dull Viscose — Celanese—5 den. Bri. Acetate

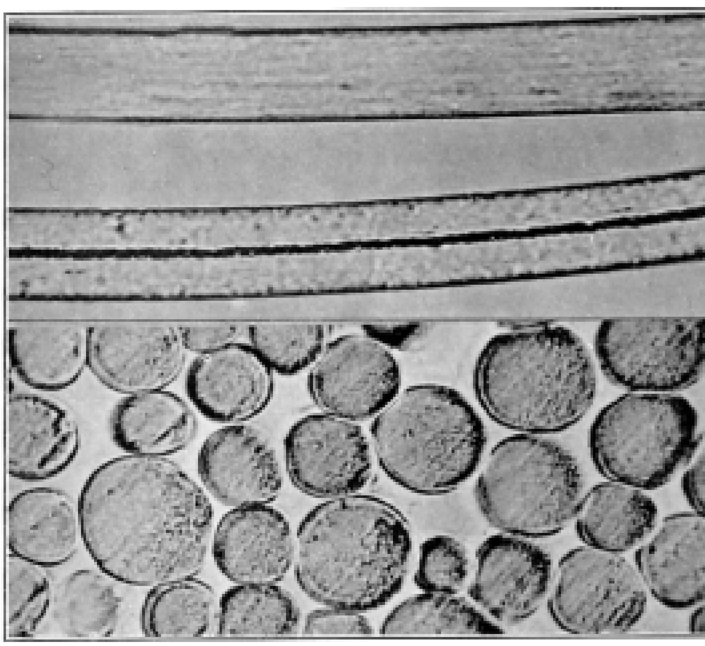
LONGITUDINAL VIEWS (X 500)



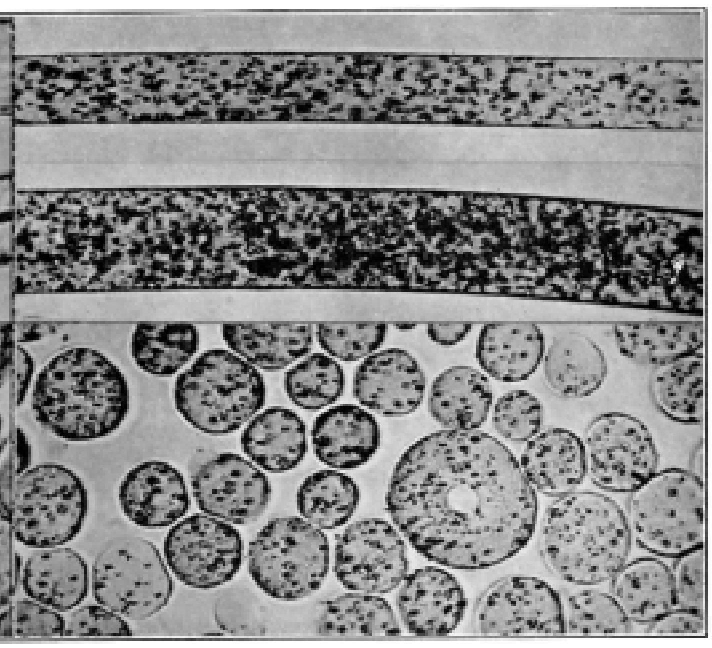
LANITAL
Top: Longit. View (X 500)
Bottom: Cross-section of dyed fibers (X 500)



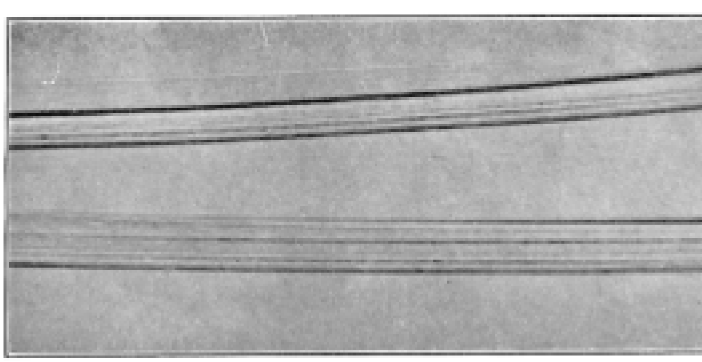
SOYA BEAN FIBERS
Top: Longit. view (X 500)
Bottom: Cross-section (X 500)



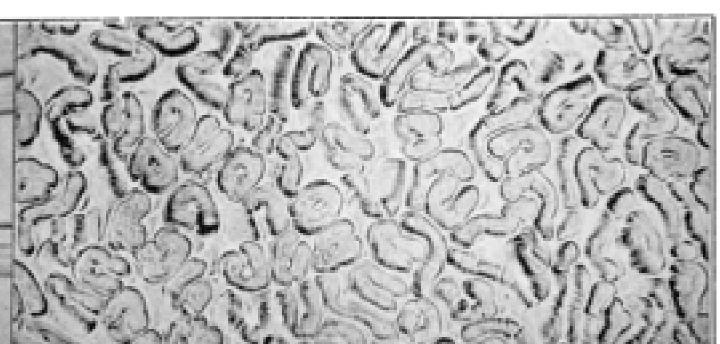
ARALAC (U. S. Casein Fiber): Bright
Top: Longit. view (X 500) Note inner air-filled channel
Bottom: Cross-section (X 500)



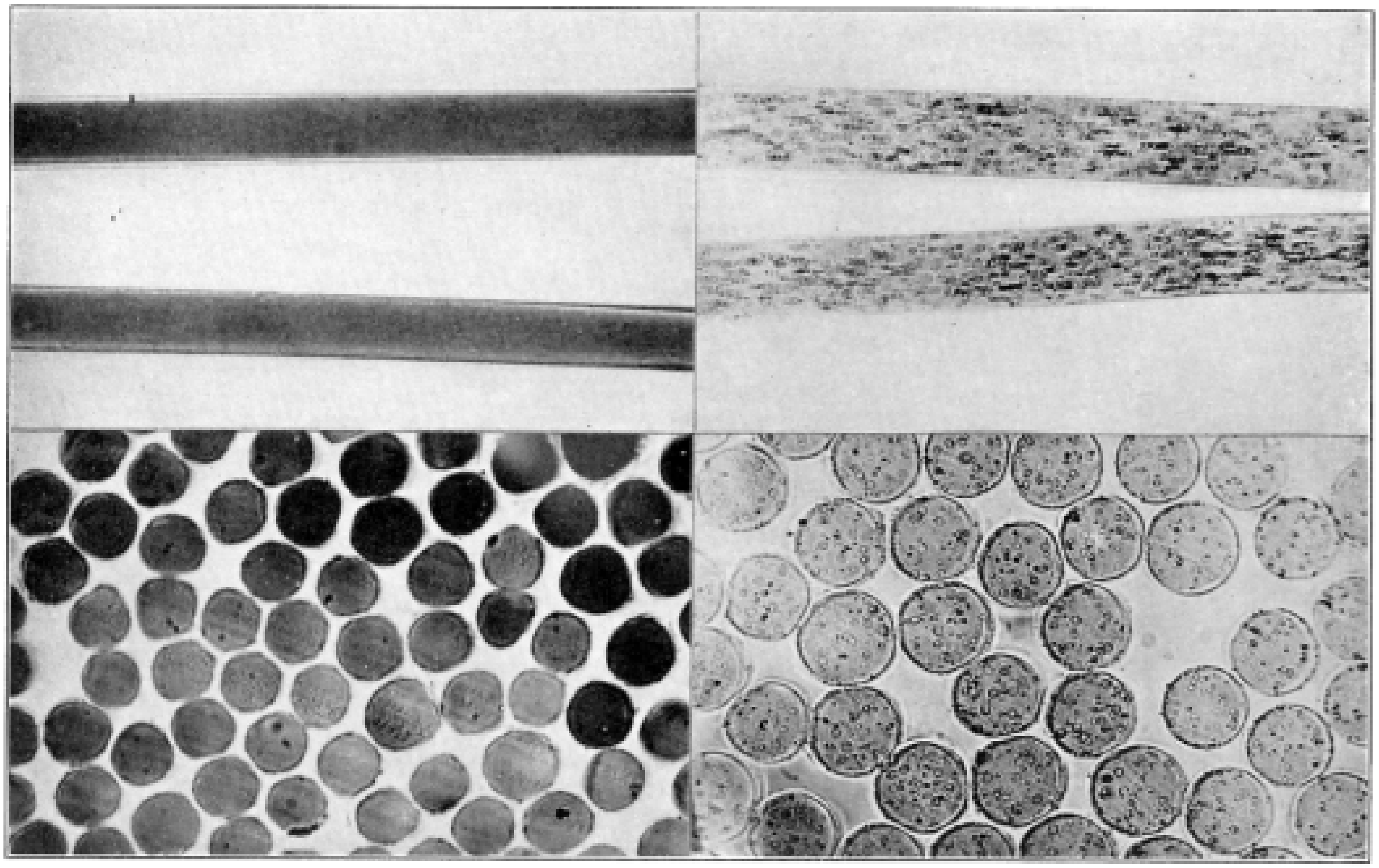
Dull
Top: Longit. view (X 500)
Bottom: Cross-section (X 500) One fiber with inner channel



REGENERATED SILK: Longit. view (X 500)

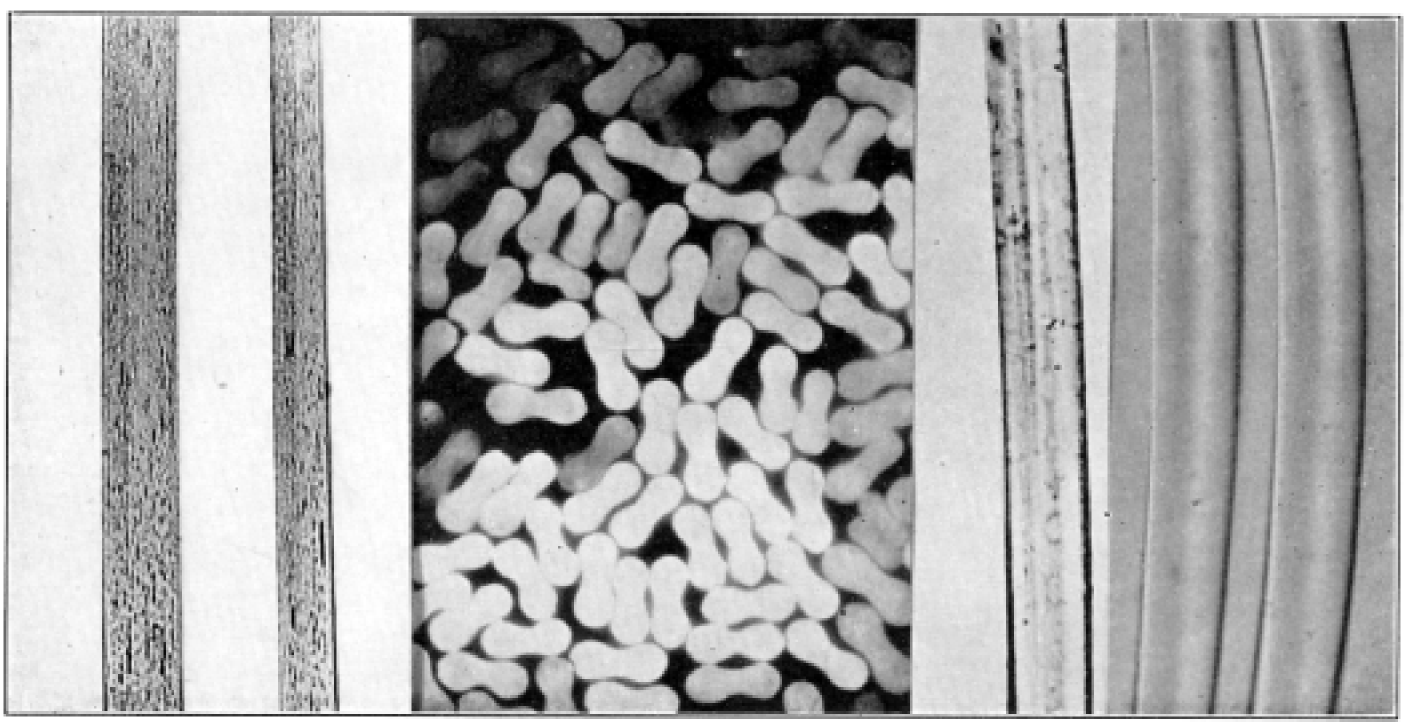


Cross-section (X 500)



NYLON Bright (dyed)
Top: Longit. view (X 500)
Bottom: Cross-section (X 500)

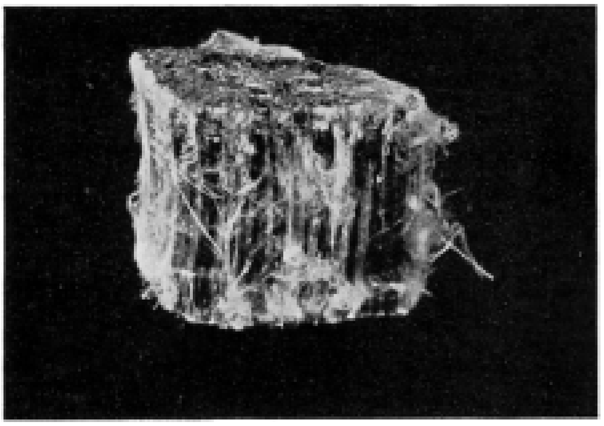
Dull
Top: Longit. view (X 500)
Bottom: Cross-section (X 500)

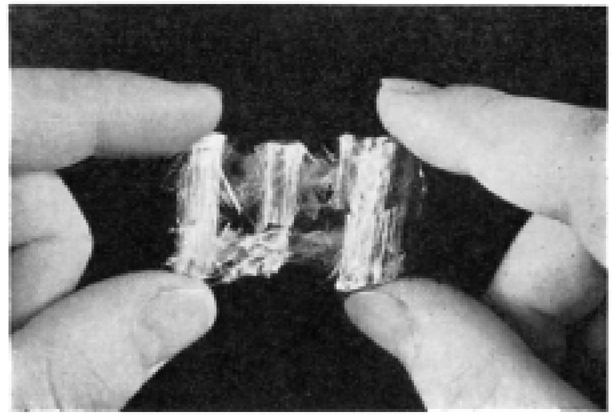


VINYON Dull
Longit. view (X 500)

Cross-section (X 500)

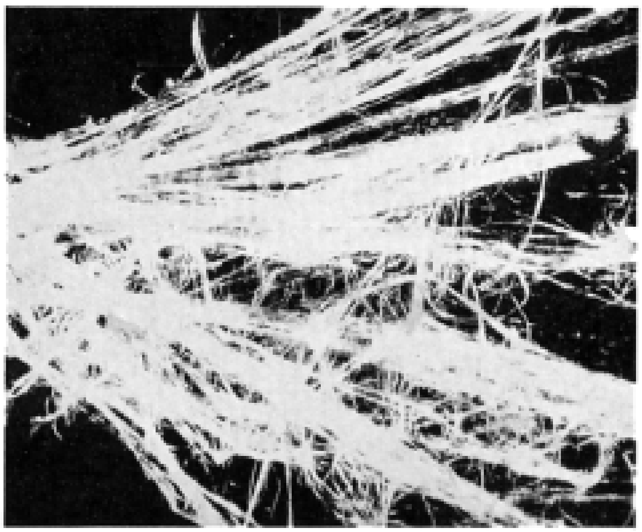
Bright
Longit. views (X 500)
Oblique Illumination

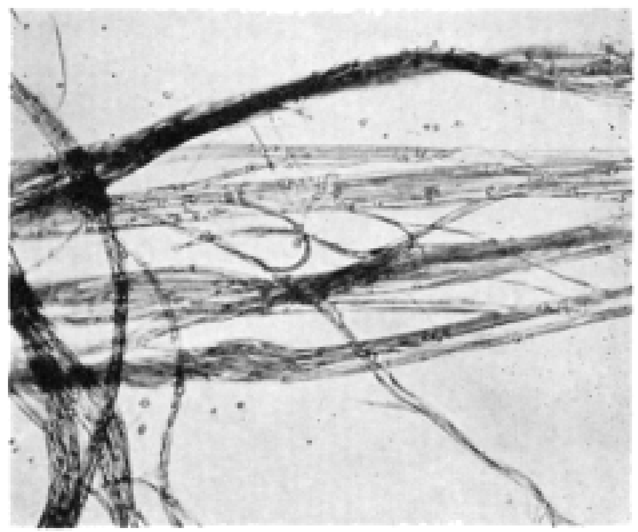




ASBESTOS
Actual size

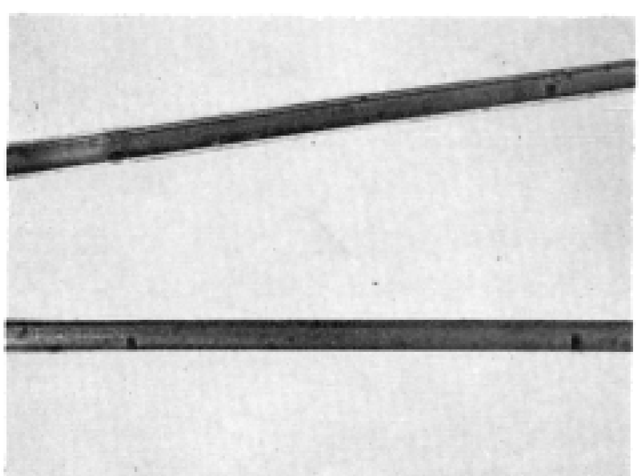
Actual Size

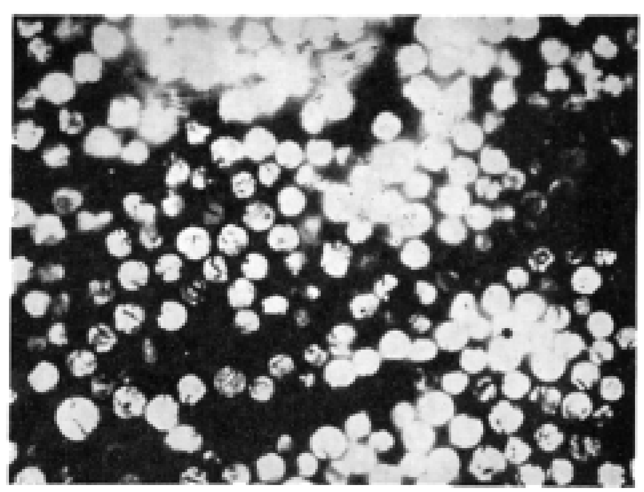




ASBESTOS
(X 8)

(X 500)





GLASS
Longitudinal view (X 500)

Cross-section (X 500)

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