VOL. 4 JUNE, 1929 NO. 5

HILGARDIA

A Journal of Agricultural Science

PUBLISHED BY THE

California Agricultural Experiment Station

CONTENTS

UNIVERSITY OF CALIFORNIA PRINTING OFFICE
BERKELEY, CALIFORNIA

HILGARDIA

A JOURNAL OF AGRICULTURAL SCIENCE

PUBLISHED BY THE

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

VOL. 4 JUNE, 1929 No. 5

THE MEDULLATED WOOL FIBER

J. F. WILSON*

CLASSIFICATION OF HAIR MEDULLAE

The classification of the various types of medullae found among all types of hairs has been described by Hausman.[1] Medulla types of infra-hominid hairs are shown as (*a*) absent; (*b*) discontinuous, in which the medullary substance is displayed at fairly regular intervals throughout the length of the shaft; (*c*) intermediate, in which the medullary cells are found so closely contiguous as to present a medulla unbroken but uneven in contour; (*d*) continuous, in which the cells of the central lumen are apparently completely anastomosed or so closely packed as to give a regular tubular appearance to the fiber; and (*e*) fragmental, in which the medulla is found only as an occasional fragment at irregular intervals. Medulla types of human head hairs are classified as (*a*) absent; (*b*) fractional, which is seemingly almost identical with the fragmental type among infra-hominid hairs; (*c*) broken, in which the medulla may be heavy but does not form a continuous canal; and (*d*) continuous. Hausman has shown that among the infra-hominid hairs the greatest hair-shaft diameters were found in those carrying the fragmental medullae, while in human head hair, the largest were associated with presence of the continuous medulla.

The writer's examination of medullated wool fibers from several breeds of sheep, but largely from the Lincoln and Romney, indicates that the medulla types found in wool follow more closely Hausman's classification for human head hair than that for infra-hominid hair, the coarsest fibers being associated with the continuous rather than with the fragmental medulla.

* Assistant Professor of Animal Husbandry and Associate Animal Husbandman in the Experiment Station.

Blyth[2] also classifies the medullae as continuous or discontinuous, depending upon whether or not the medulla persists throughout the length of the fiber or is interrupted at fairly long intervals. Fine medullae, much and irregularly interrupted, are called fragmentary, while those having a width of less than half that of the entire fiber shaft are termed rod-medullae. Practically all of the medulla types found by the writer among improved wools from the Lincoln and Romney breeds fall into the 'rod' classification.

The medulla in the wool fiber may be present to any degree between the fragmental and continuous classifications, along the entire length of the fiber, or along a portion of it only. The medullation may be at the proximal or distal extremities or at any point between them, although if present, it is usually found in the distal portion. Various types of medullae are often found in a single fiber. Occasionally a double medulla is to be observed (figs. 1, 2, 3).

DEFINITION OF MEDULLATED WOOL FIBER

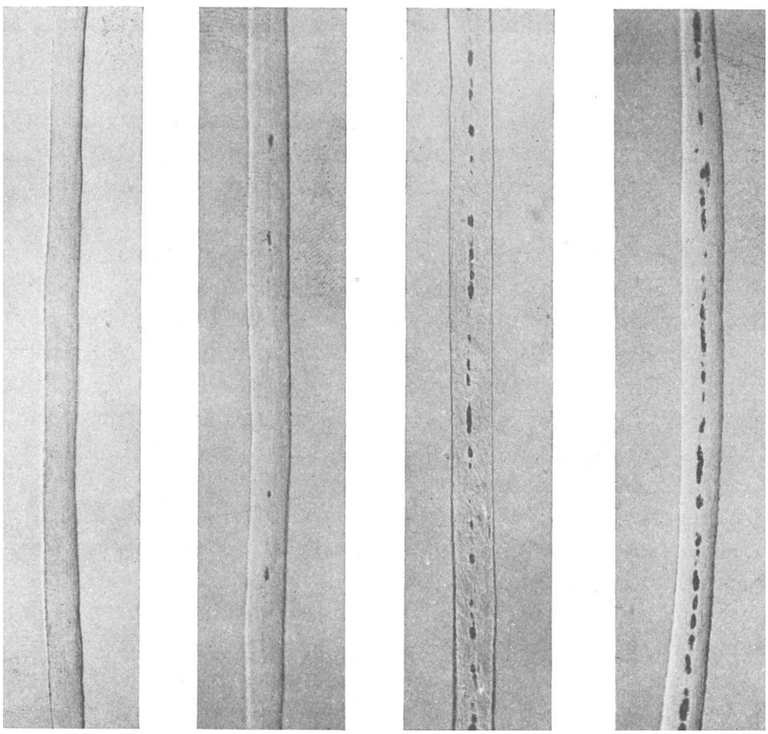
The literature discloses the need for making some differentiation between the medullated wool fiber and 'kemp' or 'kemps.' Bliss[3] points out that perhaps sufficient distinction is not drawn between true, short kemp and kempy or medullated wool.

The present paper makes no attempt to deal with true kemp as a medullated fiber, but is concerned rather with the intermediate type—the medullated wool fiber. The difference between the two kinds should be sharply defined, for kemp, in addition to being composed largely of the medulla, which is surrounded only by a thin wall of cortical and cuticular material, is usually shed in the fleece, whereas the medullated wool fiber is not. Kemp also has practically no tensile strength, is brittle and non-elastic, and presents a dead-white, opaque appearance. These characteristics are in sharp contrast to those of the medullated wool fiber.

THE SIGNIFICANCE OF THE MEDULLATED FIBER

Matthews[4] describes the wool fiber as consisting of "several distinct portions: [including] (*a*) a cellular marrow, or medulla, which frequently contains more or less pigment matter . . . ." He presents illustrations showing "wool fibers deficient in medullary cells," although he states in the text that the medulla is very frequently absent.

Woolman and McGowan[5] speak of the medulla as if it were a normal constituent of the wool fiber and describe it as composed of cells, generally rounded in form. "The medullary canal may be broad and plainly visible; it may appear as a continuous or broken line, or it may not be seen at all in some fine, transparent wools. Granular fragments and often pigment matter may appear in the contents. Hair fibers commonly show the medulla, wool fibers often do not."



A *B* *C* *D*

Fig. 1. Types of medullae found in wool (× 90). *A,* absent; *B,* fragmental; *C,* fragmental; *D,* broken.

Hawkesworth[6] considers absence of the medulla a defect, and states that inspection of the wool fiber reveals a central, or medullary part resembling marrow. To quote, "It has been noticed that in some fibers the central cells are wanting, and the fibers are, therefore, not perfect, which has much to do with many of the malformations we see in wool."

Bowman[7] intimates that the medulla is perhaps a mark of differentiation between hair and wool and says that a wool fiber differs from a hair in having much less frequently a development of the central cells. The fallacy of differentiating between wool and hair on the basis of the presence or absence of the medulla is forcibly brought out by Lewis and Stöhr,[8] who state that in man a medulla is lacking in many hairs, and that when present, in the thicker hairs, it does not extend their whole length.

Microscopic examination by the present writer of human head hairs, in balsam mounts, reveals that the medulla is often absent even in very coarse hair. Work at the California station indicates that in well-bred sheep of some of the long-wool breeds which are most subject to medullated fiber, the medulla is more often absent than present, although a great variation exists among individual animals within breeds.

Manufacturers of wool goods in England apparently have views at complete variance with those of Hawkesworth,[6] and consider the medulla a serious defect. The matter was first brought to the attention of Romney sheep breeders in New Zealand by F. A. Aykroyd, a prominent English manufacturer, who suggested that New Zealand 'cross-breds' (wools of the medium and coarser grades not produced by the Merino) were deteriorating and at present left much to be desired from the manufacturer's viewpoint.† The criticism attracted the attention of breeders and elicited both favorable and unfavorable comment. In one of the trade journals[9] a correspondent says in agreement with the criticism, ". . . . I have frequently pointed out the absurdity of allowing sheep to live when they produce a mongrel fiber—a fiber that shows normal features for one-third of its growth from the base, while from that point to the tip of the staple, the fiber is only tubular." Answering a specific question put by the writer, Aldred F. Barker, Professor of Textile Industries in the University of Leeds, England, replied, "Medullation is considered to indicate a hair and consequently is anathema to the British manufacturer."

That the presence of the medulla affects the dyeing properties of wool has been indicated by King,[10] who states that the presence of 'kempy' fibers in wool is of much concern to the trade, because the

† Mr. Aykroyd caused samples of wool to be prepared, illustrating his criticism. These samples consisted of small locks of Romney wool, from which a few "strong" or hairy fibers had been removed and mounted separately on the same background. The samples were sent to a New Zealand breeder of Romneys who in turn forwarded them to a Romney breeder in the United States. Through the latter, the writer was privileged to examine the samples. All of the so-called "strong" fibers to which Mr. Aykroyd took exception proved to be medullated.

inclusion of air gives them a different lustre and makes them appear to dye a lighter shade than normal fibers.

In a lecture before the Bradford Textile Industry, Sir James Parr,[11] High Commissioner for New Zealand, said, "During the past few years Bradford spinners have been insistent that our 44–48's wool is deteriorating, being characterized by too large a proportion of hair-like fibers and fibers which have a much greater diameter thickness at their tip than at their base, accompanied by reduction in luster and a lack of elasticity."

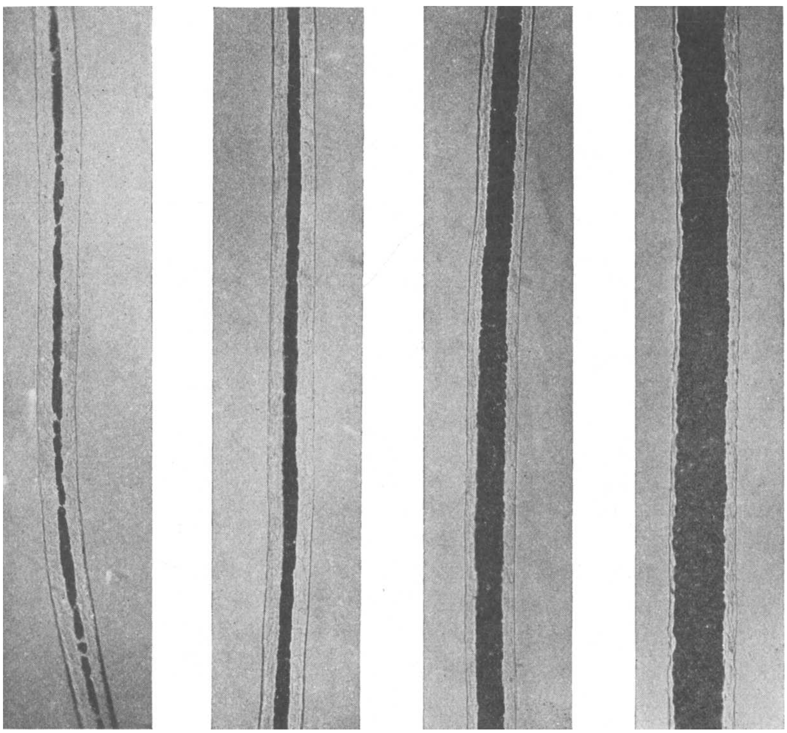


Fig. 2. Types of medullae found in wool (× 90). *E,* broken; *F,* continuous; *G,* continuous; *H,* continuous.

CONTENT OF THE MEDULLA

Nathusius[12] was the first to suggest that the medulla contained air. This view is now widely accepted. Hausman[13] describes the medulla as being built up of many superimposed cells or chambers and containing air spaces and sometimes small masses of pigment material. Barker and King,[14] measuring the fiber diameters and medulla diameters of 120 fibers from the Scottish Blackface breed, found the medulla to occupy 50 to 60 per cent of the total fiber volume. They also found the medulla to be composed of about 90 per cent air space by volume, so that the actual medulla substance occupies only 10 per cent of the medulla core.

King[10] in calculating the sulfur content of medullated fibers, by comparison with those which are non-medullated, states that the medullary material is practically devoid of sulfur, whereas the sulfur content of various wools is shown to range from 3.10 per cent in the Lincoln to 4.00 per cent in the Cape Merino.

ORIGIN OF THE MEDULLA

Duerden[15] describes the medulla in kemp fibers as arising from a special group of cells located in the middle of the shaft and derived from the basal layer of the epidermis. In the case of the cuticle and cortex, keratinization is complete, and the cells become solid, while in the medulla the cells walls only are thickened with minute spinous projections, the cavity that remains in each cell filling with air as the cytoplasm disappears. He suggests that any fiber containing air should be classed as kemp, or kempy. Blyth[2] states that in the formation of the medulla the cell walls always become keratinized and that the cell contents disappear before reaching the mouth of the follicle, possibly on account of a lack of nourishment caused by impermeability of the cell walls. King[10] cites the fact that the medulla is sulfur-free, as being in consonance with the hypothesis that the medulla is an upward protrusion of the basal layer of the epidermis, which is almost sulfur-free. Thus the chemical aspects of medulla formation are at least compatible with the histological.

THE CAUSE OF THE FORMATION OF THE MEDULLA

King[10] propounds an interesting speculative hypothesis relative to the cause of medulla formation. The fact that the medulla is sulfur-free is cited as an indication that it may possibly be caused by a diet deficient in sulfur. That the defect has been considered as extra-hereditary by others was shown by Sir James Parr: "In the past it has been thought that harshness, accompanied by hair and thickened tip, was rather a reflection of environmental than of genetic factors. . . . . It is, however, being quite clearly shown that such is not the case. . . . ."

Duerden[15] in discussing the origin of kemp attributes the presence of 'kempy' fibers to the failure of the original outer protective coat of hair wholly to disappear in the process of evolution. He recalls the fact that in their natural state nearly all mammals have two types of hair, an outer coat of long, coarse fibers and an under coat of fine, short fibers. The presence of kempy fibers in the improved breeds is caused by the persistence of a portion of the outer or hairy coat.

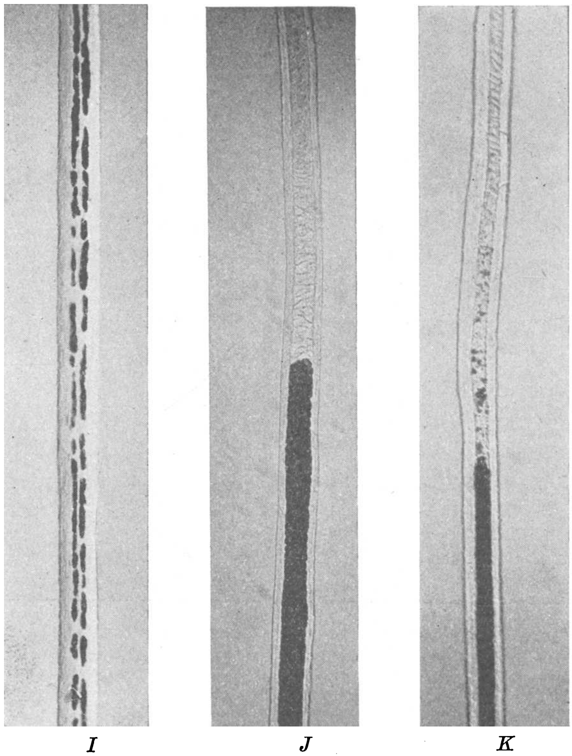


Fig. 3. Types of medullae found in wool (× 90). *I*, double broken medulla; *J*, continuous medulla with air inclusions (black portion) and without air inclusions (light portion); *K*, continuous medulla showing, in the lower portion, complete air inclusions, and in the central portion, a few medullary cells containing air.

Confirmation of this theory is evidenced by the coat of the new-born Merino lamb, the entire body of which at birth is provided with long, straight, kempy hairs, each with a medulla and air inclusions. Such hairs are shed very early in the life of the lamb. Duerden evidently considers the problem of elimination of the medullated fibers as lying wholly outside the field of nutrition, for he states, ". . . . complete elimination should be possible by continued selection in breeding."

That nutrition is not involved in the formation of the medullated fiber has been partially verified by the writer. Sections through the epidermis of the thigh region were obtained from several Romney embryos taken late in gestation. The presence of medullated fibers was clearly shown, indicating that the medulla is formed before nutritional or environmental factors have had opportunity to become causative, unless the possibility of foetal malnutrition is given credence.

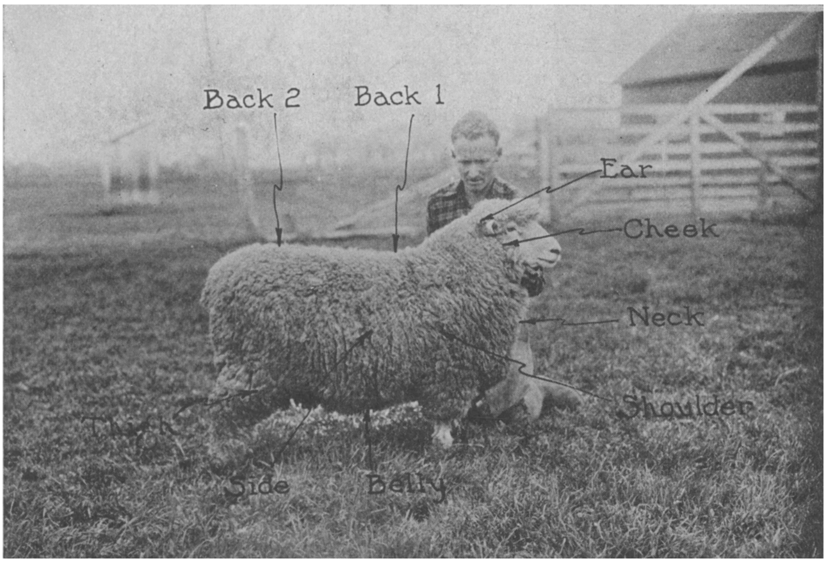


Fig. 4. The samples used in the study of the distribution of the medullated fiber within the fleece were obtained at the points indicated. (From *Hilgardia*, Vol. 3, No. 19.)

DISTRIBUTION OF MEDULLATED FIBERS

Hausman[13] has shown that medullation is common in the hair covering of most animals. Duerden[15] has found the defect in the Merino, which produces the finest wool known among improved breeds, and since a positive correlation exists between hair-shaft diameter and presence of the medulla (the coarser wools tending towards medullation) it seems logical to assume that medullation in the Merino fiber is indicative of its presence to some extent, at least, among all the breeds of sheep. Blyth[2] has shown the presence of 'kemps' in four of the mountain long-wool breeds, six of the luster-wool breeds, and five of the Down breeds. Duerden and Spencer[16] found medullated or heterotype fibers in the fleece of the Angora goat.

The writer,[17] studying the distribution of medullated fibers in the fleeces of four Romney rams, found the forward portions of the fleece—the wool from the neck, shoulder, sides, and withers—to be much more nearly free from the defect than the rear portions from the thigh, the belly, and over the hips. There was, however, a great variation among the four individuals as to the proportions of medullated and non-medullated fibers and also as to the extent of the defect in certain parts of the fleece. Since this work was done, another test has been carried on with three purebred Romney wether lambs and with one registered Lincoln ewe. The lambs and ewe were kept together for a period of six months on a daily ration of 2.5 pounds of alfalfa hay and 0.75 of a pound of rolled barley. Thus any differences observed could hardly be attributed to the plane of nutrition unless there is considered the remote possibility of failure properly to metabolize the nutrients afforded. Samples were taken from each of the animals from nine different parts of the fleece (fig. 4). The fibers tested for medullation were taken at random by holding a staple and drawing from its side, one at a time, the 100 fibers nearest the right. Thus there was no tendency on the part of the operator to select the coarser fibers by virtue of their being more easily seen. No attempt was made to determine the sizes of the medullae microscopically or to classify them. Those fibers listed as "partly medullated" have discontinuous or fragmental types. The method of detection is described later.

The results in tabular form are given in table 1.

TABLE 1

DISTRIBUTION OF MEDULLATED FIBERS IN VARIOUS PARTS OF THE FLEECE

Breed and name	Ear	Cheek	Neck	Shoulder	Side	Thigh	Back 1	Back 2	Belly	Scrotum	Total
*Lincoln ewe 304**											
Non-medullated	100	100	89	97	93	66	98	91	93	....	827
Partly medullated	0	0	11	3	7	28	2	9	7	....	67
Medullated	0	0	0	0	0	6	0	0	0	....	6
*Romney wether lamb 1147**											
Non-medullated	100	100	70	77	67	51	100	87	92	100	844
Partly medullated	0	0	30	23	33	33	0	13	8	0	140
Medullated	0	0	0	0	0	16	0	0	0	0	16
*Romney wether lamb 1151**											
Non-medullated	100	100	100	97	80	62	100	100	94	96	929
Partly medullated	0	0	0	3	20	30	0	0	6	4	63
Medullated	0	0	0	0	0	8	0	0	0	0	8
*Romney wether lamb 1152**											
Non-medullated	100	100	100	100	100	100	100	100	100	100	1000
Partly medulated	0	0	0	0	0	0	0	0	0	0	0
Medullated	0	0	0	0	0	0	0	0	0	0	0

* Number refers to the University flock record.

The data presented in table 1 give partial support to the evidence obtained in the previous test. The largest proportion of defective fibers was found in thigh samples, although two of the present fleeces showed substantial numbers of partly medullated fibers on the forward portions.

The fact that wether lamb 1152 disclosed no medullated fiber is important. It proves that sheep of the long-wool types may produce fleeces without the defect.

BREAKING STRESS OF MEDULLATED AND NON-MEDULLATED FIBERS

A comparison of the breaking stress and extension at break of medullated and non-medullated Cotswold fibers was made by Speakman,[18] who showed a mean percentage extension at break of 70.2 and a mean breaking stress of 1.51×10^6 grams per square centimeter for non-medullated fibers, while the corresponding figures for medullated fibers were 71.4 per cent and 1.20×10^6 grams per square centimeter, respectively. The variability in his results was high, but the data indicated that the medullated fibers were more elastic and less strong than the non-medullated ones. On the latter point he says, "From first principles, in view of the air spaces within the medullary cells of medullated fibers, it is to be expected that they will be weaker than non-medullated fibers. . . . . Finally, the strength of medullated and non-medullated fibers is directly proportional to their cross-sectional area, although the former are weaker than the latter, as was to be expected."

A similar test of medullated and non-medullated fibers was conducted by the writer. Several hundred fibers of each kind were separated by the method later described, and then segregated into groups according to diameter at the midsection. All of the fibers used were taken from a single fleece of a Lincoln ewe. While no study was made of the various types of medullae present in the medullated group, it is certain that each would fall into either the "intermediate" or the "continuous" class described by Hausman.[1] No fibers showing the slightest defect were chosen for the non-medullated group, and no fibers failing to exhibit clearly the characteristic phenomenon presented by the truly medullated fiber were chosen. All of the "partly medullated" fibers were discarded.

The tests were carried on with a McKenzie fiber-testing machine. Atmospheric conditions were not controlled, although the testing of the various groups was conducted in such a manner that fluctuations in humidity were impartial. The rate of loading likewise was not accurately controlled, but a serious attempt was made by the operator to turn at a uniform rate the screw device which applies the load in an apparatus of the type mentioned. Precautions were taken to insure a uniform tension on each fiber before it was secured between the clamps of the fiber-testing machine.

The data are here given in tabular form (table 2). The cross-sections of the fibers, exclusive of the cross-sections of the medullae, were not considered; the comparisons, therefore, are direct on the basis of outside diameters of the fibers at the midsection of each.

TABLE 2

BREAKING STRESS OF MEDULLATED AND NON-MEDULLATED WOOL FIBERS FROM LINCOLN EWE

Distance between jaws of fiber tester (length of fiber), 2 inches

Midsection diameter of fiber	Mean breaking stress			
	Medullated fibers	Number of medullated fibers	Non-medullated fibers	Number of non-medullated fibers
Inches	*Decigrams*		*Decigrams*	
Under 0.0012	....	....	231.50±26.72	96
.0012	....	....	267.39±29.53	112
.0013	....	....	301.75±32.30	106
.0014	380.78±46.37	14	349.04±36.61	104
.0015	357.29±39.66	21	344.10±43.23	123
.0016	415.93±47.69	58	409.77±44.97	130
.0017	428.24±35.50	62	426.99±39.37	67
.0018	465.15±62.81	46	455.79±46.18	34
.0019	501.13±63.71	48	492.00±28.53	23
.0020	506.07±59.60	88	581.67±36.65	9
.0021	507.19±58.99	43		
.0022	532.12±59.77	74		
.0023	526.84±63.45	64		
.0024	560.49±62.49	55		
Over 0.0024	573.97±72.74	31		
Mean of fibers from 0.0014 to 0.0020 inch diameter, incl..........	455.47	....	392.96	....
Number of fibers from 0.0014 to 0.0020 inch diameter, incl..........	....	337	....	490

The relative humidity of the room in which these tests were conducted varied from 33 per cent to 66 per cent during the course of the experiment.

These data seem to be at variance with those obtained by Speakman.(18) While the probable errors are admittedly high, the fairly large numbers of fibers involved in each group tested, and the consistently higher breaking stress with each increase in fiber diameter, are indications of accuracy and point to the greater strength of the medullated fiber, regardless of the presence of the medulla.

In an attempt to prove the reliability of the results obtained, a number of 'partly medullated' fibers were broken in the apparatus. These fibers were carefully examined microscopically, and each was known to possess a discontinuous or broken medulla. Following the breaking of the fibers, the two fragments were again mounted and studied under the microscope. In each instance, it was found that the *break had occurred in the non-medullated portion* of the fiber. The results, therefore, support the data presented in table 2 and afford further evidence of the greater breaking stress of the medullated fiber.

EXTENSION AT BREAK OF MEDULLATED AND NON-MEDULLATED FIBERS

The observations on the extension at break of the same fibers studied in table 1 are recorded in table 3.

TABLE 3

EXTENSION AT BREAK OF MEDULLATED AND NON-MEDULLATED WOOL FIBERS FROM LINCOLN EWE

Distance between jaws of fiber tester (length of fiber), 2 inches

Midsection diameter of fiber	Mean extensibility at break			
	Medullated fibers	Number of medullated fibers	Non-medullated fibers	Number of non-medullated fibers
*Inches**	*Millimeters*		*Millimeters*	
Under 0.0012	....	....	26.47±1.85	96
.0012	....	....	25.88±2.15	112
.0013	....	....	27.08±1.98	106
.0014	23.57±4.62	14	26.78±1.75	104
.0015	25.67±2.52	21	26.34±1.72	123
.0016	23.29±3.12	58	25.30±1.83	130
.0017	21.05±3.63	62	25.61±1.45	67
.0018	22.30±4.87	46	26.62±1.40	34
.0019	24.06±4.02	48	26.83±1.08	23
.0020	24.07±3.65	88	27.44±1.28	9
.0021	22.98±3.90	43		
.0022	22.03±4.90	74		
.0023	22.44±3.72	64		
.0024	21.85±4.90	55		
Over 0.0024	18.80±4.78	31		
Mean of fibers from 0.0014 to 0.0020 inch diameter, incl..........	23.22	....	26.12	....
Number of fibers from 0.0014 to 0.0020 inch diameter, incl..........	....	337	....	490

The humidity of the room in which these tests were conducted varied from 33 per cent to 66 per cent during the course of the experiment.

* The units are in inches because the machinist's micrometer used to measure the diameters of the fibers was constructed to read in inches. The McKenzie fiber-testing machine records the stretch in millimeters.

Here also the data are not in accord with those obtained by Speakman.[18] The higher probable errors obtained with medullated fibers are perhaps due to disregarding the medulla diameters, and while these errors are sufficiently high to make inadvisable the drawing of any definite conclusions, again attention must be called to the consistency of the results and to the numbers of fibers tested.

THE EFFECT OF THE PRESENCE OF THE MEDULLATED FIBER UPON THE UNIFORMITY OF THE FLEECE

Hausman[1] has shown that the presence of the medulla is associated with increased hair-shaft diameter, both in infra-hominid and human head hairs. In the data given by Speakman,[18] if it may be assumed that the fibers used were of common origin, the coarsest non-medullated fiber tested was practically of the same diameter as the finest medullated fiber. Blyth[2] found in the heterotypic fibers that where the fiber diameter was greatest, the medulla was most likely to be found. She states, in the description of the mountain long-wools, that the medulla occurred more frequently in the coarse samples than in the fine. That the presence of the medulla tends toward the production of a coarse fiber is strikingly borne out by the fiber diameters given in table 2. It will be observed that no medullated fibers were found in the particular fleece under consideration, which were less than 0.0014 of an inch in diameter, whereas hundreds of non-medullated fibers of a diameter less than 0.0014 of an inch were readily available. Similarly no non-medullated fibers were found of a diameter greater than 0.0020 of an inch, while in the same sample medullated fibers up to 0.0024 of an inch were found in great numbers. Regardless, then, of whether or not medullation adversely affects the dyeing affinity, tensile strength, elasticity, softness, or any other attribute of the fleece, its presence is highy undesirable if it lends toward greater variability in the diameter of fiber. Until the medullated fiber is eliminated, it would seem impossible to produce the level, even fleeces so desired by the spinner.

THE DETECTION OF THE MEDULLATED FIBER

The medulla is easily detected under the microscope by preparing the fiber in a balsam or glycerin mount. Detection is sometimes difficult in a water mount and is often impossible when the fiber is mounted dry.

Realization of the desirability of having a macroscopic method for accurate detection of the medulla led the writer to the discovery of a method described in a previous paper.[19] Since that time, however, certain changes in technique have been adopted, and a new description, although necessitating partial repetition, seems warranted.

A square or rectangular piece of glass about 5 inches by 8 inches (a discarded photographic plate is excellent) is placed horizontally over a black or dark blue background. Melted paraffin is then slowly poured on the glass in such a manner as to form a wall about one-quarter to three-eighths of an inch high and in the form of a pair of parentheses with ends completely joined. At the top of the 'parentheses' the wall of paraffin is of full height, but at the bottom, which is placed almost at the lower edge of the glass plate, the wall is depressed to a height of about one-eighth of an inch. The 'parentheses' should be about six inches in the longest dimension and about three inches across at the point of greatest width.

Into the area surrounded by the paraffin wall a quantity of clear glycerin sufficient to fill the 'parentheses' is poured.

Fibers are examined in a room lighted only by a dim red light, such as is used for photographic dark rooms. This light is suspended about twelve inches above the shallow lake of glycerin and sufficiently far forward to allow the operator to make close observation of the fibers without coming in contact with the lamp. The sample to be tested is cleaned in benzene, and fibers are subjected to treatment one at a time.

The distal end of the fiber is held with a pair of fine tweezers, the proximal end with the fingers. The fiber is then submerged in the glycerin, the end held between the fingers being allowed to pass over the paraffin wall at the lower end of the 'parentheses,' the end nearest the operator. For examination of every part of the fiber, the ends may be reversed.

If the fiber is non-medullated, it cannot usually be seen with the naked eye when submerged in the glycerin under the subdued light. Very coarse non-medullated fibers, such as are to be found in the Lincoln and Cotswold breeds, can sometimes be seen, but their appearance offers slight contrast with that of the glycerin. If the fibers are medullated, the medulla, if it contains air inclusions, persists as a fine, white line which can readily be seen.

In some fibers, a clearly defined medullary substance, which exhibits no air inclusions, may be found. These fibers, which as yet have been observed in only one fleece, are not detectable by the method described. It is probable, however, that they are so few in number as not seriously to affect the efficiency of the method.

Tests of the efficacy of this method of detection have shown that it is quite satisfactory. At first the operator should check results with the microscope, but experience has shown that proficiency in detection may be acquired to a point where subsequent proof is superfluous. A fiber with intermittent or fragmentary medulla is easily detected, the medullated areas being revealed as tiny white spots. Accuracy in detection seems, after reasonable practice, to be regulated only by the eyesight of the operator.

For less exacting work, the operation may be carried on in natural light, subdued to such a point that reading would be difficult. The advantage of the artificial light apparently lies only in its uniform intensity.

THE ELIMINATION OF THE MEDULLATED FIBER

While it is conceivable that factors extraneous to heredity are partially responsible for the formation of the medulla, the evidence thus far points strongly to the field of genetics. If, then, it is a genetic problem, the elimination of the medullated fiber lies wholly in the hands of the breeder. If the problem is to be solved the breeder should adopt a test for the presence of medullated fibers in the fleeces of stud animals, especially in the fleeces of stud rams. The results of such a test should be used as a partial index of the desirability of the animal for breeding purposes.

The glycerin test herein described affords an ideal method for the husbandman's use. It requires no technical training and no expensive equipment. Furthermore, it yields the information needed by the breeder—whether or not the fiber is medullated and contains air inclusions.

The results of the study on the distribution of the medullated fiber within the fleece, presented in table 1, indicate that it is possible to produce sheep of the long-wool breeds which carry fleeces without the defect.

SUMMARY

A sharp differentiation should be made between the medullated fiber and kemp.

The medullated wool fiber is thought to be responsible for serious difficulties encountered in wool manufacturing.

The medullated fiber is found among many kinds of animals, probably among all of the breeds of sheep, and is common among those breeds producing the coarser grades of wool. It is likely to be found in any part of the fleece, but is most apt to occur in the rear portions notably on the lower thigh. Some sheep are entirely free from the defect.

Breaking stress data reported in this paper show medullated fibers to be stronger than non-medullated fibers of the same diameter at the midsection.

Tests on the extension at break indicate that non-medullated fibers may be more elastic than medullated fibers of equivalent midsection diameter.

The medullated fiber is partially responsible for wide deviations from the mean diameter of fiber of the fleeces in which it occurs.

The medullated fiber may be detected microscopically by the use of several mounting media. It may be detected accurately by a macroscopic method described in the text. The macroscopic method of detection is simple and inexpensive, and may be used, with practice, by the breeder.

The elimination of the defect is probably within the field of genetics. The fact that some animals of the long-wool breeds are free from the defect, indicates that the problem of elimination is possible of solution.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. E. E. Brownell for his assistance and kindly interest, and to Mr. William R. Hosselkus, whose cooperation made possible the procuring of the Romney embryos. Mrs. A. Alexander, technician in the wool laboratory, also gave valuable service in connection with obtaining the data on the breaking stress and the extension at break of the wool studied.

LITERATURE CITED

[1] HAUSMAN, LEON AUGUSTUS

1925. The relationships of the microscopic structural characters of human head hair. Amer. Jour. Phys. Anthrop. **8**:173–177.

[2] BLYTH, JANET S. S.

1926. Studies on the fleece fibers of British breeds of sheep. Zeitschrift für Tierzuchtüng und Züchtungsbiologie **7**:383–417.

[3] BLISS, H. J. W.

1926. Kemp (Part I). Jour. Text. Inst. **17**:T264–T267.

[4] MATTHEWS, J. MERRITT

1924. The textile fibers. 4th ed., 1–1053. John Wiley & Sons., Inc., New York.

[5] WOOLMAN, MARY SCHENCK, and ELLEN BEERS MCGOWAN

1921. Textiles. 1–428. The Macmillan Company, New York.

[6] HAWKESWORTH, ALFRED.

1920. Australasian sheep and wool. 1–594. Wm. Brooks and Co., Ltd., Sydney.

[7] BOWMAN, F. H.

1908. Structure of the wool fiber. 1–475. Macmillan & Co., Ltd., London.

[8] LEWIS, FREDERICK T., and PHILLIPP STÖHR

1913. A textbook of histology. 2d ed., 1–539. P. Blackiston's Sons & Co., Philadephia.

[9] ANONYMOUS

1925. Wool Record and Textile World **31**:424.

[10] KING, A. T.

1927. Some chemical aspects of wool research. Jour. Text. Inst. **18**:T361–T368.

[11] PARR, SIR JAMES

1929. New Zealand sheep and wool. Wool Rec. and Textile World, **35**:157–160.

[12] NATHUSIUS, W.

1866. Das Wollhaar des Schafs in histologischer und technischer Beziehung mit vergleichender Berücksichtigung andererück Haare und der Haut. xvi + 1–200. Weigant und Hempel, Berlin.

[13] HAUSMAN, LEON AUGUSTUS

1920. The hair of mammals. Amer. Nat. **54**:496–523.

[14] BARKER, S. G., and A. T. KING
1926. A comparison of measurements of diameters of wool fibers with the micro-balance and the projecting microscope, with applications to the determinations of density and medulla (kemp) composition. Jour. Text. Sci. **17**:T68–T74.

[15] DUERDEN, J. E.
1926. Kemp fibers in the Merino. Jour. Text. Inst. **17**:T268–T273.

[16] DUERDEN, J. E., and M. ROSS SPENCER
1927. The coat of the Angora. S. Afr. Jour. Sci. **24**:418–420.

[17] WILSON, J. F.
1929. A macroscopical analysis of the fleeces of four Romney rams. Hilgardia **3**:583–594.

[18] SPEAKMAN, JOHN B.
1926. The gel structure of the wool fiber. Jour. Text. Inst. **17**:T457–T471.

[19] WILSON, J. F.
1928. Macroscopical detection of the medullated wool fiber. Science **67**:512–513.

5*m*-6,'29

The titles of the Technical Papers of the California Agricultural Experiment Station, Nos. 1 to 20, which HILGARDIA replaces, and copies of which may be had on application to the Publication Secretary, Agricultural Experiment Station, Berkeley, are as follows:

1. The Removal of Sodium Carbonate from Soils, by Walter P. Kelley and Edward E. Thomas. January, 1923.
4. Effect of Sodium Chlorid and Calcium Chlorid upon the Growth and Composition of Young Orange Trees, by H. S. Reed and A. R. C. Haas. April, 1923.
5. Citrus Blast and Black Pit, by H. S. Fawcett, W. T. Horne, and A. F. Camp. May, 1923.
6. A Study of Deciduous Fruit Tree Rootstocks with Special Reference to Their Identification, by Myer J. Heppner. June, 1923.
7. A Study of the Darkening of Apple Tissue, by E. L. Overholser and W. V. Cruess. June, 1923.
8. Effect of Salts on the Intake of Inorganic Elements and on the Buffer System of the Plant, by D. R. Hoagland and J. C. Martin. July, 1923.
9. Experiments on the Reclamation of Alkali Soils by Leaching with Water and Gypsum, by P. L. Hibbard. August, 1923.
10. The Seasonal Variation of the Soil Moisture in a Walnut Grove in Relation to Hygroscopic Coefficient, by L. D. Batchelor and H. S. Reed. September, 1923.
11. Studies on the Effects of Sodium, Potassium, and Calcium on Young Orange Trees, by H. S. Reed and A. R. C. Haas. October, 1923.
12. The Effect of the Plant on the Reaction of the Culture Solution, by D. R. Hoagland. November, 1923.
13. Some Mutual Effects on Soil and Plant Induced by Added Solutes, by John S. Burd and J. C. Martin. December, 1923.
14. The Respiration of Potato Tubers in Relation to the Occurrence of Blackheart, by J. P. Bennett and E. T. Bartholomew. January, 1924.
15. Replaceable Bases in Soils, by Walter P. Kelley and S. Melvin Brown. February, 1924.
16. The Moisture Equivalent as Influenced by the Amount of Soil Used in its Determination, by F. J. Veihmeyer, O. W. Israelsen and J. P. Conrad. September, 1924.
17. Nutrient and Toxic Effects of Certain Ions on Citrus and Walnut Trees with Especial Reference to the Concentration and Ph of the Medium, by H. S. Reed and A. R. C. Haas. October, 1924.
18. Factors Influencing the Rate of Germination of Seed of Asparagus officinalis, by H. A. Borthwick. March, 1925.
19. The Relation of the Subcutaneous Administration of Living Bacterium abortum to the Immunity and Carrier Problem of Bovine Infectious Abortion, by George H. Hart and Jacob Traum. April, 1925.
20. A Study of the Conductive Tissues in Shoots of the Bartlett Pear and the Relationship of Food Movement to Dominance of the Apical Buds, by Frank E. Gardner. April, 1925.