B: NATURAL FIBRES OF ANIMAL ORIGIN

Introduction

Animal fibres make up less than 7 per cent of the total weight of textile fibres produced annually. In quantity, therefore, they represent a minor part of the world's fibre resources. But animal fibres play a much more important role in the textile trade than their limited production indicates. They are all fibres of character; each one has unique properties which ensure it a position of special significance as a textile fibre.

Wool and Hair Fibres

Whenever fur-bearing animals form part of the domestic economy of a country, the fibrous materials of their coat are put to good use in one way or another. Wool, the fibrous covering of the sheep, is by far the most important of these fibres, and sheep-farming is now an extremely important activity in many parts of the world. Wool forms more than 90 per cent of the total world production of animal fibres.

Although wool plays such a dominant role in the animal fibre industry, a number of other animal fibres are of considerable commercial importance. In the textile industry, it is usual to describe all animal-covering fibres other than wool as hair fibres. The term wool is restricted to the covering of the sheep. This terminology can lead to some confusion, as the two terms 'hair' and 'wool' are often used to differentiate between the two types of fibre commonly forming the covering of animals. The long, coarse fibres forming the outer coat are called hair, and the short, fine fibres of the undercoat are called wool. It is preferable, therefore, to qualify the term wool by the name of the animal when it refers to anything other than sheep's wool.

Hair fibres are all related to wool in their chemical structure; they are all keratin. But they all differ from wool, and from each other, in their physical characteristics; they are of different length and fineness, and have different shapes and internal structures.

Many hair fibres are used in high-quality applications in the textile trade. Others have specialized non-textile uses; horse-hair, for example, is a padding or filling material; camel hair and pig's bristles are made into brushes; rabbit fur is used for producing felts.

Silk

This fibre, spun by the silkworm as it makes its cocoon, is the only natural fibre of importance which is in the form of a continuous filament. The quantity of silk produced is so small as to amount to only about 0·25 per cent of the total fibre production. But silk has always held a special position as a quality fibre, and sustains a high price by comparison with other fibres.

WOOL

Though vegetable fibres were probably the first to be used for spinning and weaving into cloth, animal fibres in the form of skins and furs were undoubtedly the earliest form of clothing used by primitive man. But at what stage did he discover that the hairs on a sheepskin could be cut off, twisted into yarn and then woven into cloth?

Nobody knows. What we do know is that by the seventh century B.C. the Phoenicians were buying woollen homespuns from the Israelites and shipping them to England to barter for tin and raw wool.

Britain, therefore, first comes into the story of wool as producer of the raw material which was exported to other lands for manufacture into cloth. The small, wild sheep with black faces and long horns that supplied the wool were probably indigenous to Britain. They carried an undercoat of short, fine wool together with a long hairy outer coat.

Domesticated sheep came to Britain with the Celtic tribes who invaded the country during the sixth and seventh centuries B.C. By the time Caesar arrived in 55 B.C. a woollen industry was already flourishing in Britain. Wool was being produced, spun into yarn and woven into cloth.

The Romans built a weaving factory at Winchester, from which they sent home 'wool so fine it was comparable to a spider's web'. The industry developed under Roman rule, but the coming of the Saxons in the fourth and fifth centuries A.D. put an end to the woollen trade by scattering the flocks and destroying the factories.

Then in 1066, William the Conqueror brought fresh supplies of sheep with him from the Continent, and Britain's wool industry re-established itself. The first guild of weavers was established in 1080. This time the industry became centred on Bristol and Exeter; and in 1111, Henry I built up a woollen industry at the mouth of the Tweed. The characteristic heavy woollen cloths that were produced still carry the name today.

By the thirteenth century, another famous name had become familiar in the wool industry. This was the town of Worstead near Norwich – whence came the cloth we now know as 'worsted'. But by this time, the centre of the wool trade had moved to Flanders; Flemish craftsmen were acknowledged experts in the arts of wool weaving and finishing. It was said that 'all Europe is clothed with English wool bought in Flanders'. Raw wool was being shipped to Flanders, made up into cloth and reshipped to England for retail sale.

In 1331, Edward III – at the suggestion of his wife Philippa, a Netherlands woman – invited the Flemish weavers to Britain. Many of these expert craftsmen came and settled in the Norwich area. From that time on, the British wool trade developed and eventually became the leader in the industry – a position it still holds today.

The Woolsack

So important did wool become as a part of Britain's economy that in 1350, Edward III decreed that the Lord Chancellor must sit on a woolsack so that he would remember the importance of the industry during his deliberations. The woolsack is still there.

Further encouragement to the wool-growing industry came from the Black Death that swept over Europe during the fourteenth century. Faced with a severe shortage of labourers – one-third of Britain's population had died – the farmers could no longer plough and cultivate the soil, and they turned increasingly to sheep-raising as being more economical of labour. Britain's sheep population increased until production of wool became our most important industry. In 1454, Parliament declared that 'the making of cloth within all parts of this realm is the greatest occupation and living of the poor commons of this land'.

During Elizabeth's reign, 80 per cent of Britain's exports were wool goods. Every effort was made to encourage the use of wool in the home market. The knitted stocking began to replace the old cloth stockings sewn up from woven material. It was decreed that everyone over seven years of age must wear a wool cap when out of doors; the fine for offenders was 3*s* 4*d* – about half a week's wages for a skilled workman.

In his efforts to encourage the use of wool, Charles II carried on where Elizabeth left off. Not content with making his subjects wear their wool caps, he insisted that all women must wear flannel next to the skin. Another decree proclaimed that all corpses should be buried in wool shrouds. This law remained in force until the eighteenth century. And the export of sheep from Britain remained an offence punishable by death until just over a hundred years ago.

This persistent and determined effort to establish the British wool industry was accompanied by a corresponding interest in sheep breeding. Robert Bakewell, born in 1725, became the master-breeder of Britain's sheep; he evolved methods of selection that have given us most of our present breeds. By the end of the eighteenth century Bakewell's Leicestershires were known the world over.

Meanwhile, the inventions of Hargreaves, Crompton, Arkwright and Kay had begun their revolution in the textile industry. Wool, like cotton, came out of the kitchen and into the mills.

The end of the eighteenth century saw such a speed-up in wool manufacture that local farmers were for the first time unable to cope with the demands of the industry. To keep the mills working, manufacturers were forced to look elsewhere for much of the raw wool that they needed. Spain and Germany helped to make up the deficit.

British Wool Industry

Throughout the nineteenth century, Yorkshire gradually became established as the centre of the world's wool trade, with other areas in Britain providing tweeds and special weaves. Industrial Britain, thriving in the prosperity that steam had brought, became the greatest textile manufacturing centre of the world.

As the demand for raw wool grew, manufacturers began recovering used wool from rags and old cloth. Fibres from these sources were respun and woven into cloth that was cheap enough to reach the pockets of the poorer classes. So the demand for wool increased still more.

Victoria's reign was a period of peace and plenty, with the Empire vibrant and flourishing as never before. Raw materials poured from the colonies and dominions into the busy factories of Britain, to be turned into manufactured goods for the markets of the world. Not least amongst these was wool. For the insatiable appetite of the Yorkshire mills was being fed by the great new wool-producing industries of the Dominions. Sheep in their millions were raised on the vast plains of South Africa, Australia and New Zealand, supplying thousands of tons of wool every year to the mills of Britain.

These dominion flocks were in the main bred from the famous merino sheep, which Spain had developed by careful breeding. The merinos yielded the finest and softest wool of all. In 1787, several merino rams and thirty-six ewes had been sent as a present to George III, but they did not thrive in Britain's damp climate.

South Africa

In the dominions the story was different. Two rams and four ewes presented by the King of Spain in 1789 to the Dutch Government became the nucleus of the great dominion flocks. Bred by Colonel Gordon, commander of the Dutch East India Company at the Cape, these merinos flourished in the warm climate of South Africa.

The colonization of South Africa during the nineteenth century was largely brought about by farmers seeking fresh pastures for their expanding flocks of sheep. By 1888, Cape Colony alone had 10½ million sheep; by 1927, South African flocks amounted to 44 million sheep with an annual wool clip valued at £18 million. During the 1930s, drought and depression reduced the numbers. But South Africa has rebuilt her flocks and produces a wool that is noted for its fineness and softness.

Australia

In Australia, similarly, wool production has become a major factor in the economy of the country. More than 134 million sheep graze on the Australian plains; they are direct descendents of 26 ewes and rams bought in 1795 from Colonel Gordon's merino stud at Cape Town.

As the number of sheep has increased so has their output of wool been multiplied by selective breeding. Modern merino flock sheep will yield 6.4kg (14 lb) of wool per head compared with 1.8kg (4 lb) of the early Spanish merinos.

Over three-quarters of Australia's sheep are merino breeds reared primarily for their wool. The clip is worth hundreds of millions of pounds a year.

New Zealand

New Zealand, the third great sheep farming country, has a climate more closely resembling that of Britain. The sheep are reared to a much greater extent for their mutton and lamb. Cold storage, developed in 1882, paved the way for the rapid growth of New Zealand's meat trade, and on the great Canterbury plains are bred the Southdown-Romney crosses that supply us with our Canterbury lamb.

But New Zealand is not solely concerned with meat. Dual purpose breeds of sheep now provide "Crossbred" wool in addition to meat. With more than 60 million sheep, New Zealand is a major wool producer.

World Production of Raw Wool (Greasy Basis) (1979–80)
(Million kg)

Argentina	176
Australia	722
Brazil	35
Bulgaria	35
Canada	1
Chile	20
France	24
Greece	10
India	35
Iran	39
Iraq	18
Irish Republic	9
Italy	12
Lesotho	2
Morocco	21
New Zealand	353
Pakistan	39
Peru	12
Portugal	14
Romania	37
South Africa	110
Soviet Union	472
Spain	29
Turkey	57
United Kingdom	51
United States	47
Uruguay	73
Yugoslavia	10
Other	248
Total	2,711

From these great countries, and from the U.S.A., South America and the U.S.S.R., comes a large part of the wool supplies of the world. Wool is an expensive fibre compared with cotton – it involves a second step, the animal, in its production. But wool is a quality fibre with a sustained demand from those who can afford it.

As the standard of living of the people throughout the world improves, so does the demand for wool increase. And as mass production brings down the price of wool garments, they are reaching into new fields.

Even in countries of the Far East, like China and Japan, where King Cotton has reigned unchallenged for centuries, the demand for wool is increasing. For wool will always sell on its merits in spite of its higher price. Even today, however, the consumption of wool in some countries is surprisingly small. New Zealand has a per capita consumption of up to 2.5kg (5.5 lb) a year, and that for the more prosperous European countries is 0.9–2.7kg (2–6 lb), but there are other European countries, like Poland, using less than a quarter of this amount. There are many millions of people, especially in Asia and Africa, whose means will not stretch so far as to allow them to possess a single woollen blanket.

The potential market for wool, therefore, is virtually unlimited. Only one thing restricts its use, and that is its limited production. Wool is so different a fibre, so unique and valuable in its properties, that were it cheaper it would be used for many purposes where at present we make do with other fibres.

Recovered Wool

The supply of raw wool available to the world every year amounts to about 2700 million kg (6000 million lb). After scouring, this is reduced to some 1550 million kg (3400 million lb) of pure wool.

This crop of wool is insufficient to meet the world's needs, and the supply is augmented to some extent by re-using wool which has already been made into yarns and fabrics, and even worn. Recovered wools of this sort are usually mixed with fleece wools and used for medium or low quality goods. Sometimes, fabrics are woven with cotton warp and a recovered-wool weft.

The rags and waste-fabrics used as raw materials for recovered wool are sorted and oiled before being opened out or teazed to fibre between rollers covered with wire teeth. There are three main types of recovered wool.

SHODDY is wool recovered from fabrics which have not been excessively milled (i.e. felted) during manufacture. Cloths such as tweeds, knitted goods and worsteds provide the bulk of shoddy supplies. The wool fibres in the yarns of the fabric have not been matted together deliberately to give them a felted appearance, and they can be teazed apart with a minimum of damage.

MUNGO is made from cloths such as velours and meltons, which have been milled or felted during manufacture. The fibres in these cloths are in a more matted condition than they are in an unmilled cloth. They are more difficult to disentangle, and suffer more damage in the process.

EXTRACT consists of wool recovered from cotton/wool union fabrics. The cotton is removed by treating the fabrics with hydrogen chloride or dilute sulphuric acid; the wool that remains is teazed apart.

In general, recovered wools are poor in quality compared with fleece wools. The so-called 'rag-grinding' and (for yarn waste) 'garnetting' processes used for teazing the fibres apart tends to snap the fibres and to remove some of their surface scales. The short length of the fibres, together with the surface and other damage, cause a lack of firmness and poor handle in fabrics with a high content of recovered wool. Garments made from low-grade recovered-wool fabrics do not wear as well as those from fleece wool, and tend to lose their shape. Moreover, recovered wools do not usually dye to such rich colours as new wool, so that recovered-wool garments are often dull in shade.

All Wool and Virgin Wool

A fabric or garment labelled as 'all wool' is not necessarily made from new fleece wool; it may contain a proportion of recovered wool. As such fabrics are inferior to those from new wools, it is customary to refer to new-wool materials as 'virgin wool'. The 'Woolmark', which designates such virgin wools, guarantees that a fabric is made from new wools.

PRODUCTION AND PROCESSING

When primitive man selected the sheep for domestication, he was guided in his choice by his clothing needs. He wanted an animal that would provide a skin of a size suitable for use as a human garment; and he wanted, at the same time, a creature that grew a soft and comfortable fleece. The sheep was an obvious choice.

The ancestors of our modern sheep grew coats of fibres that served in two essential ways. On the outside of their fleece was a layer of long, coarse hairs which acted as a protective overcoat; these hairs were shed every spring. Under the layer of coarse hair fibres, the sheep grew an undercoat of finer hair, much more delicate and downy; this inner layer acted as a blanket to keep the animal warm. This insulating layer has given us the textile fibre that we now know as wool.

Modern sheep have been bred to provide as large a proportion of wool as possible. Sheep that are used primarily as a source of wool may carry only a trace of the outer covering in their fleece. Certain mountain breeds retain a relatively high proportion of coarse hair fibres. These fibres are sometimes unusually white in colour, and are opaque; in the finer woolled breeds they are generally regarded as a sign of poor breeding.

The merino, most important of all the sheep used as a source of wool, has almost entirely dispensed with its outer coat. Moulting no longer takes place, and the wool will go on growing year after year if it is not cut off.

Quality of Wool

Merino Wool

The raising of sheep for wool is now an important industry in many countries, and the quality of different wools is correspondingly diverse. The merino sheep, which produces fine, soft wool forms the basis of wool production in Australia, South Africa and South America. Immense flocks of merinos are raised in these countries.

Australia

The quality of the merino wool from these sources depends upon environmental conditions, and upon the hereditary characteristics of the sheep. Port Philip wool is reputed to be the finest Australian fibre, and is used for making high-quality woollen and worsted fabrics. Sydney and Adelaide wools are not quite so fine as Port Philip, and they are a shade yellower in colour. Tasmanian wool is of first-rate quality and washes a beautiful white.

South Africa

Wool from South Africa is very crimped or wavy, and has a good white colour after washing. It is used for good-quality worsteds and woollens.

South America

South American wool is not generally of such good quality as wool from Australia or South Africa. Much of the South American wool is used by continental manufacturers. The best quality South American wool comes from Montevideo, with Buenos Aires next. Punta Arenas wool, which comes from cross-bred sheep, is a bulky wool and is widely used in making hosiery.

Europe

In Germany, France, Spain and other European countries, and in the U.S., the merino has been reared successfully and often provides wool of high quality. Saxony and Silesian merino wools, for example, have the reputation of being the finest in the world. The French Rambouillet is renowned for its high-quality wool.

Crossbred Wool

The merino sheep imported into Britain by George IV did not find conditions to their liking. In some other countries, however, crossing of the merino with other breeds of sheep was highly successful, and breeds originating from such crosses are now of great importance as wool and meat producers. Sections of the New Zealand sheep industry, for example, are based on cross-bred sheep which provide both wool and mutton. Australia and South Africa also export a great deal of wool produced by cross-bred sheep.

British Wool

British-grown wool can be graded into four main types described as lustre, demi-lustre, down and mountain wools.

LUSTRE WOOL comes from Lincoln, Romney Marsh, Cotswold and Leicester sheep. It is up to 30.5cm (12 in) long and is made into lustrous dress fabrics, buntings and linings.

DEMI-LUSTRE WOOL is shorter and has less pronounced lustre. It is made into serges, dress fabrics and curtains.

DOWN WOOLS are medium length 75–100mm (3–4 in) staple; fibre is curly and has a crisp handle. Sussex or Southdown sheep provide some of the finest of English wool; it is made into hosiery, cheviot suitings and flannels.

MOUNTAIN WOOLS from breeds such as the Scottish Blackface vary greatly in quality and length. Blackface wool is long and coarse and contains a high proportion of kemp fibres.* It is made into tweeds and carpets; the famous Harris tweed is commonly made from Blackface wool.

Cheviot, a medium length wool, is made into knitwear, tweeds, worsteds and cheviot suitings. It is strong and of bright colour, and has good felting properties. Welsh wool is used largely for making flannels.

Irish wool is too thick to be spun into fine yarn, and is used for homespun tweeds and woollens and for carpets.

In the Shetlands, wool is combed from the sheep instead of being removed by clipping. It has a very soft handle although it may contain a high proportion of hair, and is knitted into the shawls, cardigans and other garments that are known the world over.

Asian Wool

In China and other parts of Asia, in Turkey and Siberia, the production of wool is of growing importance. The wool is often long and coarse compared with fibre produced in Australia, South Africa and the other great wool-producing countries.

As in the case of cotton and other plant fibres, the quality of wool depends greatly upon the conditions under which it is grown. Wool derives from a living creature, and it is affected not only by the hereditary characteristics of the sheep but by the environment in which the sheep has lived.

Wool Production

Wool fibres grow from small sacs or follicles in the skin of the sheep. The wool fibres grow in groups of 5–80 hairs and there are 1550–3410 per sq cm (10,000–22,000 per sq in).

A typical Hampshire sheep will have some 16–40 million fibres in its fleece; a Rambouillet between 29 and 97 million, and an Australian merino may carry as many as 120 million individual wool fibres. These fibres grow on the average at the rate of 2.5cm (1 in) in two months; altogether they represent a considerable drain on the resources of the animal.

Shearing

Sheep are normally shorn of their fleece every year (in some countries, e.g. South Africa, up to twice a year). On large stations,

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* 'Kemps' are a short wavy type of hairy fibre which are shed periodically.

the fleece is removed in one piece by power-operated clippers. In efficient hands, the sheep is parted from its wool in two and a half minutes. A first-class shearer will get through two hundred sheep a day, from which he will clip a tonne or more of wool. This type of wool is known as 'fleece or clip wool'.

Immediately after it has been removed, the fleece is 'skirted'. This involves pulling away the soiled wool around the edges. Then the whole fleeces are graded by experts who judge the fineness, length, colour and other characteristics. Finally, the various grades are packed into large sacks and then sewn up into the bales which are a familiar sight in any Yorkshire town. Each bale contains about 136kg (300 lb) or more of wool.

Slipe Wool; Mazamet

Wool is also removed from the pelts of slaughtered sheep. The pelts are treated with lime and sodium sulphide or some other depilatory. This loosens the wool, which can be pulled away without damaging the hide. This wool is called 'slipe wool'. Hides can also be subjected to bacterial action to loosen the wool; the product is called fellmongered or 'Mazamet' wool, from the French town of Mazamet where it is produced in quantity. Wool removed from the skin in these ways is usually inferior in quality to clip wool; it is often used mixed with fleece wool.

Wool Sales

In the U.S.A. and in some South American and other countries, wool is sold direct by the shearer by private treaty, often with a minimum of preparation. In Australia, New Zealand and South Africa, fleeces are skirted and classed carefully into recognised categories before being sold at public auction. In Great Britain wool is sold by farmers to the British Wool Marketing Board who bulk-class the fleeces before selling the wool at public auction.

British Wool Industry

Raw wool reaching Britain is sent off to the great manufacturing centres. Most important of all is the West Riding of Yorkshire, where woollen fabrics of almost every type are made. Heavy and medium class woollens come from the mills of Leeds, Dewsbury, Morley and Batley. Carpets are made in south west England, Ireland and elsewhere.

The finest saxony woollens are made in the West of England, near Trowbridge. Tweeds and cheviots come from Galashiels, Hawick and other border towns, where Scottish cheviot wool is spun and woven into the famous 'Scotch Tweeds'. From Aberdeen come the world-renowned Crombie materials. Witney makes blankets, and Rochdale makes flannels. In the Leicester and Nottingham districts, woollen yarn is made into knitted materials.

The worsted industry is less scattered, and is centred in Yorkshire. Bradford – 'Worstedopolis' – makes all manner of dress goods and linings. Huddersfield has a reputation for the finest quality worsted suiting materials. Wakefield, Keighley and Halifax make worsteds in a great variety of forms.

Preparation of Wool for Spinning

Grading and Sorting

The quality of wool varies greatly with the breed of sheep and the conditions under which it has lived. Quality depends also upon the characteristics of the individual sheep, and upon the region of the sheep's body in which the wool has grown.

As the fineness and length, the softness and colour of wool determine the uses to which the fibre is put, grading and sorting of wool are essential preliminaries to spinning.

Counts

The first grading of wool takes place as it is being prepared for sale. The price of raw wool depends upon the buyer's assessment of its fineness and length. Quality is defined by numbers which at one time described the limiting fineness or 'count' of yarn into which it could be spun on the English worsted count system. An 80s wool, for example, was at that time considered capable of being spun into a yarn of 80s count. This meant that 1 lb (454g) of wool would yield 80 hanks each containing a fixed length of yarn. In the worsted industry, the standard length of a hank is 560 yd (504m). 1 lb (454g) of 80s wool would thus be capable of spinning into 80 hanks each of 560 yards if it was spun to the finest limit. Under modern conditions these spinning limits are no longer valid, but the traditional numbers continue to be used to describe wool quality or fineness. (In woollen manufacture, the unit of skein-length is shorter and varies from place to place. In Yorkshire, the standard is 256 yd (230.4m), whereas in the West of England it is 320 yd (288m).

Thus, although wool quality numbers no longer relate directly to the worsted yarn count system, they form an arbitrary scale whereby the higher the quality number, the finer is the wool. A merino wool usually lies between 60s and 100s; wool from cross-breds is 36s – 60s, and coarse wool such as that used in carpets is less than 44s.

Fibre Length

The average length of wool fibres is described by special terms such as 'combing' or 'clothing'. When the fibres are long enough to undergo combing and be made into worsteds –65mm (2½ in) or more – they are combing wools; 176mm (7 in) they are long wools. Fine fibres, 38–65mm (1½–2 in), can be combed in the French comb and are 'French combings'. Short wools of less than about 32mm (1¼ in) are described as 'carding or clothing wools'.

Classifying

When the bales of wool are opened in the mill, the fleeces are skirted if this has not already been done. The fleece may be classified as a whole or, if variable in quality, separated into sections such as shoulders, sides, back, thighs and britch and belly. In general, the shoulders provide the best wool, and the flanks a slightly lower quality wool. The belly, tail and legs yield the poorest quality of wool. In medium and long wool breeds of sheep, the head, legs and britch usually produce the highest proportion of hair and kemps. Some breeds, such as the Scotch blackface, produce hair and kemp fibres in all parts of their fleece.

Lamb's Wool

The finest wool is obtained from young sheep. Lamb's wool clipped at eight months is very fine and of excellent quality.

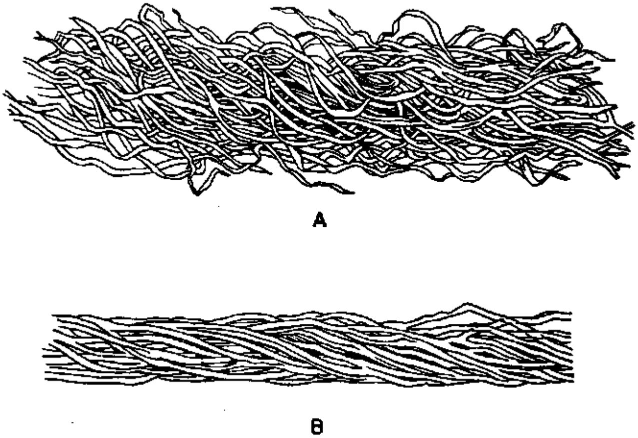
Hog Wool

Six months later, when the sheep is fourteen months old, the wool ('hog') is stronger and thicker. As the animal grows older, the quality of the wool decreases slightly.

Altogether, a sheep, on the average, will provide between 0.9 and 4.54kg (2–10 lb) of wool per year, according to breed.

Scouring

Raw wool is dirty and contaminated with natural substances that must be removed before processing can be carried out. Often, as much as 50 per cent of the weight of raw wool consists of impurities



Wool. Woollen and Worsted Yarns. In a woollen yarn (A), the random arrangement of the fibres results in a bulky yarn with a fuzzy surface.

In a worsted yarn (B), the fibres are lying more parallel, and are more tightly twisted, producing a thinner yarn with a smoother surface.

of one sort or another. In addition to dust and dirt, the wool is mixed with natural grease (yolk) and with dried perspiration (suint). In general, the finer wools such as merino contain a higher proportion of natural impurities than the coarser wools.

Raw wool is washed or scoured by being agitated gently in tanks filled with warm water containing detergent. The raw wool is propelled gently through a tank, then squeezed between rollers and carried into another tank. It may pass through four or more tanks in this way, until eventually it is rinsed in clean water. It is then dried until about 20 per cent of water remains in it.

Other methods are now being used for cleaning raw wool. It can be washed, for example, in a grease solvent fluid.

Although these processes clean raw wool by removing unwanted substances from it, they do not necessarily produce a white fibre. The wool may contain natural colouring matters.

Processing and Spinning

Wool is spun into two types of yarn, woollen and worsted, and the treatment of the fibre after scouring varies accordingly.

Woollen yarns are thick and full; the fibres are held loosely and subjected to only a limited twist during spinning. These yarns, made usually from short-staple wool, are woven into thick, full-bodied materials such as tweeds or blankets and used for knitting.

Worsted yarns, on the other hand, are finer, smoother and firmer. The fibres in worsted yarns are aligned so that they lie closely alongside each other in the direction of the yarn; for woven fabrics they are twisted tightly together to form a fine strong yarn. Worsteds are spun commonly from fibres 5–38cm (2–15 in) long. These yarns are woven into fine dress materials and suitings. Worsted spun yarns with less twist are used for knitting yarns and knitted fabrics.

Woollen Yarns

Although scouring will wash most of the grease and suint from the raw wool, it does not necessarily remove any burrs, twigs and other vegetable material from the fibres. These impurities can be destroyed by steeping the wool in dilute sulphuric acid and then heating at high temperature. The cellulosic material is charred and can then be broken up and beaten out of the wool. This process is called CARBONIZING.

Burrs and other vegetable impurities can also be removed mechanically by passing the wool through heavy crushing rollers before the intermediate stage of carding, so that the vegetable impurities are removed as a powder in subsequent carding.

Often, woollen yarns are spun from a mixture of new wool with reclaimed wool, or with rayon, cotton or other fibres. After scouring and cleaning, the wool is blended to mix various grades together and to incorporate any other fibres.

Carding

The wool is now ready for carding in machines equipped with rollers covered with sharp steel wires which disentangle the matted fibres. There are usually three parts to the machine used in woollen carding, called the scribbler, intermediate and carder. They all perform in much the same way, separating the fibres and mixing them thoroughly. The wool emerges from the carding machine as a thin blanket of fibres about 1.5m (5 ft) wide, holding together as a fluffy mass.

Woollen Spinning

This blanket of loosely-held fibres is split up and formed into ribbons which hang together sufficiently to be able to support their own weight. The fibres in the ribbon – or condensed slubbing, as it is called – are lying quite higgledy-piggledy. The slubbings are drawn out and spun to form a yarn. The fibres in the slubbing have been lying in all directions, and when they are twisted during spinning they produce the soft yarn so characteristic of woollen goods.

Woollens spun from merino wool are described as *saxony woollens*; woollens made from cross-bred wools are generally called *cheviot woollens.*

Worsted Yarns

Wool to be spun into woollen yarns may be scoured and dried by commission firms and stored until wanted. It is bought as blends or separate types. But wool for spinning into worsteds is normally scoured and dried immediately before carding.

After drying, the wool is carried straight to the carding machines. The mass of fibre is opened, teased and cleaned, emerging in the usual flimsy sheet. This is brought together to form card slivers which are wound up into balls or allowed to fall into deep cans.

Gilling

When the wool is of very long staple, for example 23–38cm (9–15 in), instead of being carded it is often subjected to a process called gilling. The wool is passed through a gilling machine in which the moving strand is combed by rows of pins that move rapidly through the mass of fibres. The fibres are straightened and aligned in the direction in which the wool is moving.

Combing

This alignment of the wool fibres so that they lie parallel is a characteristic feature of worsted manufacture. The wool, after carding or 'preparing', is passed through a combing machine which continues the process, combing out short fibres and aligning the long fibres accurately alongside each other. It is also usual to pass the wool through gilling machines between carding and combing and after combing.

The combed wool in this form of an untwisted strand called the 'top', is then drawn out into a roving and spun by twisting it into a yarn. The long fibres, lying parallel to one another in the combed roving, are able to cling tightly together on twisting to form a fine, strong worsted yarn.

Worsted Spinning

The spinning of worsted yarns is carried out in one of four different ways.

FLYER SPINNING is used with long wools (100–250mm (4–10 in), mainly 150mm (6 in) fibres, yielding smooth yarns used largely for hosiery.

CAP SPINNING (almost obsolete) is used very largely with botany and fine cross-bred wool. Its production rate is high and the yarn tends to be hairy.

RING SPINNING has the highest output and is used for making the fine yarns. It now accounts for 80% of the world's spindles.

MULE SPINNING (now obsolete) is used for making continental worsteds, giving a full, soft yarn.

In worsted spinning, 454g (1 lb) of wool may spin into more than 63,000m (70,000 yd) of yarn which is made into hard-wearing, high-quality fabrics. The use of expensive raw wools and the number of processes involved in manufacture mean that worsted fabrics are usually high-priced.

As in the case of cotton, the finer wool fibres provide the better quality yarns and fabrics. Fine fibres can be spun into uniform, smooth yarns that yield firm, lightweight materials which are soft and warm, drape well and retain their shape when made into garments.

The long, fine fibres of good quality wool have many more scales to the cm than the coarser fibres, and are usually more crimped.

Worsteds made from merino wool are described as *botany worsteds*; worsteds made from cross-bred wools are *cross-bred worsteds*.

Twist

The amount of twist put into a yarn when it is spun depends upon the nature of the fibres and purpose for which the yarn is designed. Long fibres need less twist to hold them strongly together than short ones do. Thick yarns need less twist than finer ones. In general, worsted weaving yarns are spun much tighter than woollen yarns.

When the yarn is to be made into a hard-wearing fabric, such as a worsted for suiting or a gabardine for an overcoat, it is twisted tightly to give a strong, weather-resisting material with a comparatively hard texture.

If, however, the yarn is to be used for clothes that are worn near the skin, it must be soft and yielding, warm and light. The yarn is therefore given less twist than is needed for a worsted.

Fabrics from lightly-twisted yarns, unless subjected to modern finishing treatment, e.g. 'Superwash', will also felt more easily than the tighter-spun yarns. Low-twist yarns are used in fabrics that are to be milled or felted deliberately, for example in making meltons.

Bleaching

If the wool is to be dyed to especially bright or pale shades, or when it is to be spun and woven into white yarns and fabrics, it can be whitened by bleaching. This is usually carried out on the yarn or fabric, rather than on the loose wool.

STOVING consists of the exposure of wool to sulphur dioxide in a large closed chamber. The gas, produced by burning sulphur, converts coloured impurities in the fibre into colourless substances. Wool is usually bleached in this way in the form of skeins of yarn or as fabric. The material is left overnight in the chamber, and is well washed the following morning.

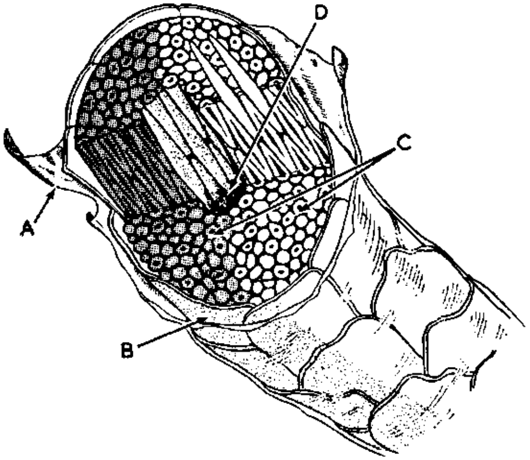
Although stoving produces a good white wool, the effect is often impermanent. The wool tends to revert to its natural colour as oxygen in the air converts the colourless substances into coloured materials again.

HYDROGEN PEROXIDE BLEACHING is a more expensive process than bleaching by sulphur dioxide. The effects, however, are more permanent. The wool is immersed for several hours in a dilute solution of warm hydrogen peroxide. The coloured impurities are destroyed and the effects of the bleaching are permanent.

Dyeing

Wool may be dyed at several stages during manufacture, from raw wool to piece goods. The fibre passes through many processes when it is being made into textiles, and dyes must be chosen which can withstand the conditions they will have to meet. In addition, the dye must, of course, be satisfactory with respect to the purposes for which the finished fabric will be used.

THE WOOL



The Wool Fibre. In a typical wool fibre there are four distinct regions, which can be distinguished readily through the microscope.

(A) *The Outer Sheath or Epicuticle.* This is the outermost layer, and is a thin, water-repellent membrane. It is the only non-protein part of the fibre, and it protects the fibre like a covering of wax.

The membrane repels water, and in this sense acts as a waterproof coating on the fibre. Wool fabrics will repel the water that falls on them during a short rain shower. The epicuticle is, however, permeated

FIBRE

by many microscopic pores, through which water vapour may penetrate into the interior of the fibre. Wool fabrics will thus absorb water vapour from the body without feeling damp, and will release it again slowly into the air.

The outer membrane is easily damaged by mechanical treatment, and the wool then becomes more easily wetted.

(B) *The Scale-Cell Layer.* Beneath the epicuticle there is a layer of flat, scale-like cells which overlap like the shingles on a roof. The free ends of the scales point towards the tip of the fibre. The epicuticle and scaly layer together form the cuticle of the fibre.

(C) *The Cortex.* Enclosed within the cuticle is the bulk (more than 90 per cent) of the wool fibre. This is the cortex, which consists of millions of long spindle-shaped cells, thick in the centre and tapering to points at each end. These cortical cells are 100–200 microns in length and 2–5 microns wide.

The cortical cells are themselves built up from fibrous components called fibrils, which are in turn constructed from protofibrils. These may be seen through the electron microscope as globular particles which possibly consist of the keratin molecules themselves.

The cortex of the wool fibre is constructed in the form of two distinct sections in which the proteins differ slightly in chemical and physical properties. The fibre can be regarded, in fact, as being formed from two half-fibres of semi-circular cross section which are joined lengthwise. The sections are twisted spirally round one another, the twists being in phase with the natural waviness of the fibre.

(D) *The Medulla.* Many wool fibres, especially the coarser fibres, have a hollow space running lengthwise through the centre. This is the medulla. It may be empty, or may contain a loose network of open cell walls – *After The Wool Bureau Inc.*

A wide range of wool dyestuffs is now available, which enable the manufacturer to meet his most exacting requirements. Most important are the acid, chrome, premetalized, mordant, vat, reactive and milling dyestuffs.

STRUCTURE AND PROPERTIES

Fine Structure and Appearance

The wool fibre grows from a sac-like organ, called the follicle, in the skin of the sheep. The mouth of the follicle forms a tiny hole in the animal's skin, and the wool fibre grows up through it from a growing point at the base of the sac.

The young wool fibre has a tip tapering to a point, but a fibre that has been cut retains the flat tip left by the shears. Above the skin level the fibre is dead material, mainly keratin, a protein similar to that from which horn, finger-nails and feathers are made. There is no way in which the wool can change its physical form once it has left the follicle; if the tiny rod of keratin is cut, it remains cut.

Although the wool fibre is essentially a rod of protein, it is constructed in the first place as a result of living processes. The fibre is not merely a homogeneous rod, but consists of a complex structure built on a cellular basis.

There are four distinct regions in the wool fibre. On the outside is a delicate membrane forming the outer sheath or epicuticle. Beneath this is a layer of scale-like cells, followed by the cortex which makes up the bulk of the fibre. In the centre, there is commonly a hollow core or medulla.

Outer Sheath or Epicuticle

The outer membrane, the epicuticle, is about 100 Å thick. It repels water, but is permeable to water vapour which passes through microscopic pores in the sheath.

Scale-Cell Layer (Epithelial Scales)

This layer, together with the epicuticle, forms the cuticle of the fibre. It consists of horny, irregular scales, called epithelial scales, which cover the fibre. The scales project towards the tip of the fibre and overlap like the tiles on a house-roof. In the finer fibres, they encircle the fibre completely, giving it the appearance of a stack of flowerpots sitting one inside the other. In coarser wools the scales may not encircle the fibre, but overlap in two directions.

These epithelial scales are, on average, 0.05–0.5μ thick. They fit closely together forming a protective covering that plays an important part in controlling the properties of woollen yarns and fabrics.

The number of scales varies greatly, depending on the fineness of the fibre. The finest fibres, such as those in a saxony wool (merino), may have 790 to the cm (2000 to the inch). A coarse wool, such as that from a Scottish blackface, may have only 276/cm (700/in).

In fine wools, only 10μ or less of each scale may be exposed, although the scale itself is about 30μ long and 36μ wide. In coarser fibres, as much as 20μ of the scales may be exposed although they do not project so far as those of the finer fibre.

Cortex

The cortex forms the main central portion of fine wool fibres. It is built up from long, spindle-shaped cells which provide the strength and elasticity of the wool fibre. These cortical cells are held together by a strong binding material.

The average length of the cortical cells is about 80–110μ, the average width 2–5μ and the thickness 1·2–2·6μ.

The remains of a nucleus is usually visible in each cell, and the cells are sometimes coloured by natural pigments. They have a striated appearance.

Detailed studies of the cortical cells of wool have shown that they are built of many tiny fibrils, which are in turn constructed from even smaller micro-filaments. These elongated structures lie roughly parallel to the long axis of the spindle cells.

There are two types of cortex cell – orthocortex and paracortex – which differ in the way their constituent fibrils are arranged.

In crimpy merino wools the orthocortex and paracortex cells form two half-cylinders lying alongside one another. The two half-cylinders are twisted spirally along the length of the fibre, with the softer orthocortex cells forming the outer edges of the crimp curves. (See fig., page 103.)

In coarser, straighter wools, such as lustre wools, the orthocortex cells form a central cylinder with the paracortex cells forming a sheath around them.

Medulla

The medulla of the wool fibre is sometimes a hollow canal, and in coarser fibres may consist of a hollow tubular network. Coarse and medium wools are characterized by the presence of a greater proportion of medullated fibres. In the majority of merino fibres, the medulla is either absent or so fine as to be almost invisible. It may account for 90 per cent of a kemp fibre.

The coarse hair-fibres, with their pronounced medullae, are usually straighter and more lustrous than the finer wool fibres. They have poor spinning properties and cause difficulties by dyeing to a lighter shade than the true wool fibres. This is a result of the internal diffusion of light by the cells of the medulla and the fact that there is not much thickness of cortex to take up the dye.

Dimensions

The dimensions of wool fibres vary between considerable limits. Fine wools are about 38–125mm (1½–5 in), medium wools 65–150mm (2½–6 in) and long wools 125–375mm (5–15 in). The measurement of the actual length of a wool fibre is complicated by its crimp (see below). The stretch length of a fibre may be nearly twice that of its natural length.

The average width of a top quality merino fibre is about 17μ; a medium wool fibre is about 24–34μ, and a long wool about 40μ. The fibres are therefore thicker, on the whole, than cotton fibres. Wool fibres are roughly oval in cross-section.

Crimp

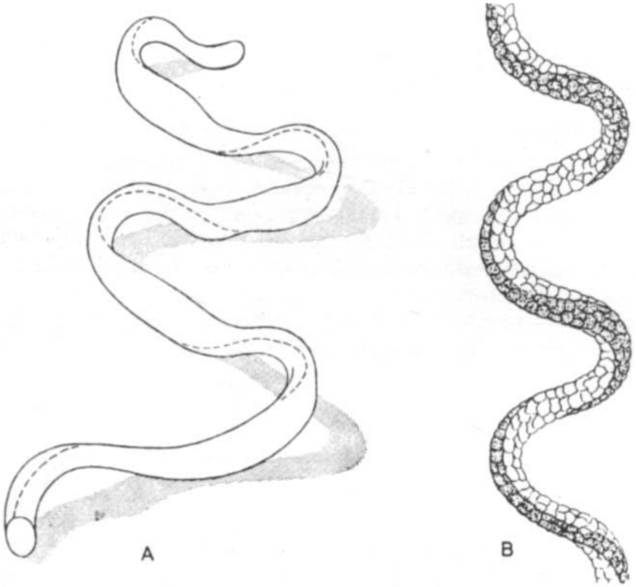
Wool fibres are unique among natural textile fibres in having a wavy structure, which is of supreme practical importance. It enables the fibres to hold together when twisted into a yarn, just as the convolutions of cotton fibres do in a cotton yarn. This waviness or crimp of wool fibres is most pronounced in the fine wool fibres. The best merino wools, for example, will have as many as 12 waves to the cm (30 per inch) in a fibre 15μ wide. Lower quality wool will have 2 or even less to the cm (5 per inch).

This waviness endows wool fibres with unusual elasticity; they can be stretched out like small springs and will return to their wavy form when released. This ability to return to the natural form is made possible by the inherent elasticity of the material of the fibre itself.

Lustre

Wool fibres have a natural lustre which varies in its characteristics, depending on the type of wool.

Lustre seems to depend very largely on the nature of the fibre surface. Light is reflected from the fibres in such a way as to create a lustrous appearance. The 'lustre wools' from Lincolns, Leicesters



Crimp. The wool fibre has a natural waviness or crimp, which is unique among natural fibres of major commercial importance. The crimp does not consist of waviness in a single plane, but takes the form of a three-dimensional waviness as shown above. It is related to the spiral form of the two core sections of different constitution, which twist spirally around one another in phase with the twists of the crimp – *After The Wool Bureau Inc.*

and other English breeds have a surface which provides a silky lustre.

Merino wools do not reflect light so perfectly. They have a delicate lustre.

Colour

Most of the wool from modern sheep is white or near-white in colour. Some breeds of sheep produce a quantity of brown or black wools, the proportion being highest in the breeds that provide the coarsest wool.

Tensile Strength

Wool has a tenacity of 8.8–15.0 cN/tex (1.0–1.7 g/den) dry, and 7–14 cN/tex (0.8–1.6 g/den) wet.

The tensile strength is 1190–2030 kg/cm^2 (17,000–29,000 lb/in^2).

Elongation

Wool has an elongation at break of 25–35 per cent under standard conditions, and of 25–50 per cent when wet.

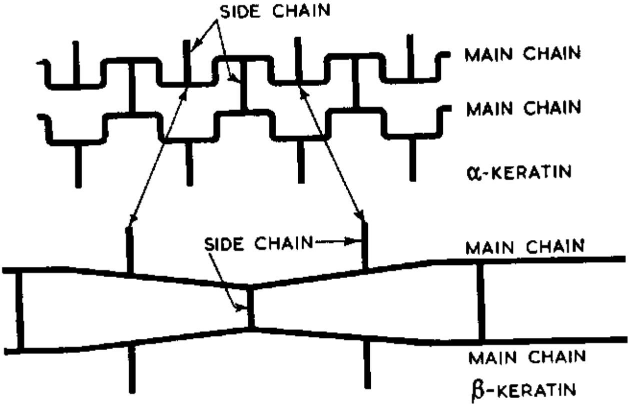
Elastic Properties

Wool is an unusually resilient fibre. Its high elongation at break is combined with a high elastic recovery that gives wool unique properties in this respect. The natural crimp of the wool fibre contributes to the overall elasticity, but the property is a fundamental one which derives from the curled, cross-linked structure of the wool molecules themselves.

Wool has an elastic recovery of 99 per cent at 2 per cent extension, and of 63 per cent at 20 per cent extension.

Specific Gravity

Wool is a light-weight fibre of specific gravity 1·32.



Elasticity of Wool. Wool fibres are highly elastic, and after stretching will return to their original shape again. In this respect they have a resemblance to rubber, and the reason for this behaviour is in both cases the same. The molecules of wool, like those of rubber, are highly folded.

In the wool fibre, millions of protein molecules are lying alongside one another, held together at intervals by chemical cross links. When the fibre is stretched, the chains unfold; then, when the stretching force is removed, they return to their folded state again. The simplistic diagram shows the folded molecules of alpha-keratin changing into the stretched molecules of beta-keratin – *After The Wool Bureau Inc.*

Effect of Moisture

Wool absorbs moisture to a greater extent than any other fibre, and yields it up readily to the atmosphere. Under ordinary atmospheric conditions, wool will hold 16–18 per cent of its weight of moisture. Under suitable circumstances, wool will absorb about a third of its weight of water.

The readiness with which wool adjusts its water-content in response to changes in atmospheric conditions is of great commercial importance. The weight of wool changes accordingly, and the definition of moisture conditions form part of any contract in the buying and selling of wool.

When a fibre absorbs moisture in this way, heat is liberated. This effect is particularly marked in the case of wool, and a woollen garment will become warmer as it absorbs moisture from the air.

In common with all other fibres, wool is composed of molecules that are long and thread-like. The atoms forming the molecule of wool keratin are joined together in such a way as to form molecular threads. The ultimate particles of wool material are, in fact, like fibres in themselves. It is the association of millions of these molecules to form the bulk of the wool keratin that gives wool its fibre characteristics. The molecules are aligned one beside the other, held together by chemical and electrical forces.

As in the case of cellulose, the mutual forces of attraction between the keratin molecules of wool can be influenced by the absorption of water. When wool absorbs water, the relatively small molecules of water are able to penetrate between the long molecular threads, prising them apart and so weakening their hold one upon the other.

In the case of wool, the forces that play between neighbouring keratin molecules are more complex than those which hold cellulose molecules together in cotton or flax. Keratin molecules are bridged by definite chemical bonds which are not easily broken. The action of water on wool is complicated by this chemical cross-linking that holds wool molecules together.

When wool is soaked in water at ordinary temperature, it absorbs water and swells until its volume increases by about one-tenth. As the wool dries, it returns to its original size.

Hot water or steam have a deleterious effect on wool over a period of time. The wool loses its strength; heated under pressure at 120°C. it will eventually dissolve.

In boiling water, wool fibres lose much of their resiliency; they become plastic. The plasticizing effect of water increases with increasing temperature and time. The longer the wool is heated, and the higher the temperature, the greater the effect of water will be.

Effect of Heat

Wool becomes weak and loses its softness when heated at the temperature of boiling water for long periods of time. At 130°C. it decomposes and turns yellow, and it chars at 300°C. As it decomposes, wool gives off a characteristic smell, similar to that from burning feathers.

Wool does not continue to burn when it is removed from a flame. Each fibre forms a charred black knob; this is a test used in the identification of wool.

Effect of Age

Wool shows little deterioration when stored carefully.

Effect of Sunlight

The keratin of wool decomposes under the action of sunlight, a process which begins before the wool has been removed from the sheep. The sulphur in wool is converted into sulphuric acid; the fibre becomes discoloured and develops a harsh feel. It loses strength and the dyeing properties are affected.

Wool subjected to strong sunlight is particularly sensitive to alkalis, including soapy water.

Chemical Properties

Whereas cotton, flax and the other plant fibres are basically cellulose, wool is protein. Keratin, the substance of wool, is similar in its essential structure to the other proteins from which much of the animal body is built. The chemical structure of wool differs only slightly from that of feathers, hair and horn.

In their chemical behaviour, proteins are quite different from cellulose. They are more easily degraded and attacked by chemicals, particularly of certain types. They do not, in general, have the resistance to environmental conditions that is so characteristic of cellulose.

Contaminants

As it comes from the sheep, wool is contaminated by a variety of materials. The animal itself exudes a supply of wool grease and suint onto the fibres as they grow. Raw wool may contain 20 per cent or more of grease, and 12 per cent of suint. The finer wools contain the highest proportion of these natural impurities.

WOOL GREASE is removed from the wool before spinning, and is a commercially valuable material. In its purified form it is known as lanolin, which is widely used as an emollient.

Lanolin itself has become a source of medicinally important chemicals such as cholesterol.

SUINT consists essentially of salts that are left behind when the perspiration exuded by the sheep has dried. It contains a high proportion of potassium salts.

Keratin

The wool protein itself, keratin, is, like all proteins, an extremely complex chemical. It contains the elements carbon, hydrogen, oxygen, nitrogen and sulphur.

The general sensitivity of wool keratin to chemicals affects all aspects of the processing of wool. Bleaching, for example, must be carried out with great care. Hydrogen peroxide, commonly used as a bleach for wool, will damage the fibre if the conditions of bleaching are not adequately controlled.

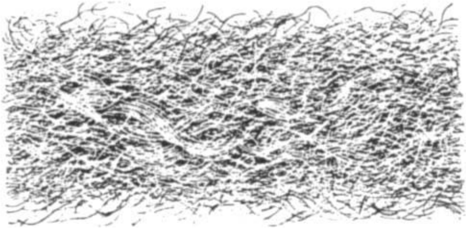
Wool is discoloured and damaged by alkaline hypochlorite solutions; many domestic bleaches based on hypochlorite should never be used on wool.

Effect of Acids

Wool is attacked by hot concentrated sulphuric acid and decomposes completely. It is in general resistant to other mineral acids of all strengths, even at high temperature, though nitric acid tends to cause damage by oxidation. Dilute acids are used for removing cotton from mixtures of the two fibres; sulphuric acid is used to remove vegetable matter in the carbonizing process.

Effect of Alkalis

The chemical nature of wool keratin is such that it is particularly sensitive to alkaline substances. Wool will dissolve in caustic soda solutions that would have little effect on cotton. The scouring and processing of wool is carried out under conditions of low alkalinity. Even weakly alkaline substances such as soap or soda are used with care. Soda will tender wool and turn it yellow if used in too concentrated a solution, particularly if the solution is too hot. Ammonium carbonate, borax and sodium phosphate are mild alkalis that have a minimum effect on wool. Ammonia, carefully used, will not cause damage.



The Warmth of Wool. The natural crimp of the wool fibre results in a bulky or lofty fabric, each fibre standing away from its neighbours. Air is trapped in the spaces between the fibres, creating an insulating layer which restricts the passage of heat through the fabric. Depending upon the texture and thickness of the fabric, as much as 60 to 80 per cent of the volume of a wool cloth may be air.

The elasticity of wool enables it to retain this loftiness throughout the life of the fabric, the texture being restored after the fabric has been flattened.

The drawing above shows an edge-view of a lofty wool fabric.

Effect of Organic Solvents

Wool has a good resistance to dry-cleaning and other common solvents.

Insects

Wool is attacked by moth-grubs and by other insects. (See 'Wool in Use').

Micro-organisms

Wool has a poor resistance to mildews and bacteria and it is not advisable to leave wool for too long in a damp condition.

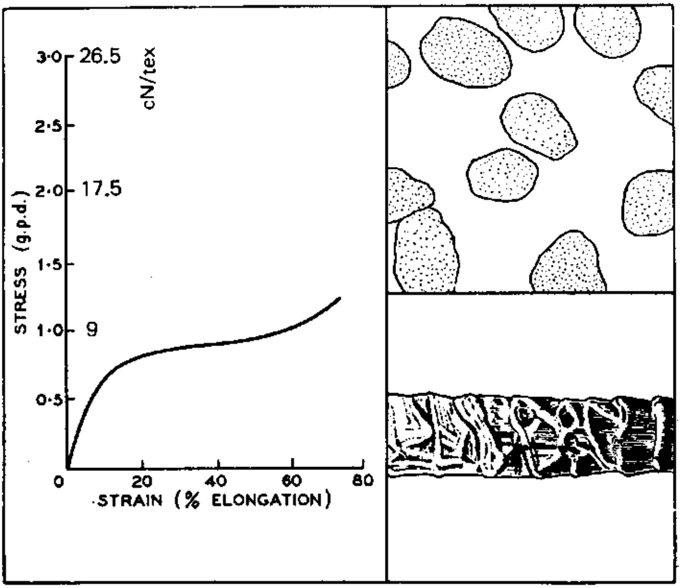
WOOL IN USE

One of the first things we meet on entering the world is wool. And, although it is no longer compulsory by law, wool is still very often our closest companion when we leave. Woollies are worn by babies because they are warm and airy. Wool clothes are healthy and hard wearing. They have many other properties – some desirable, some not. All are in one way or another a direct consequence of the properties of the fibre itself.

The wool fibre has excellent spinning characteristics. Its crimp enables the fibres to cling tenaciously together when they are spun.

Because of this, it is possible to make a relatively strong yarn from wool fibres without twisting them very tightly. Knitting wool, for example, can be spun very loosely and yet is quite coherent.

The crinkliness and resilience of the wool fibre and the looseness of the yarn are largely responsible for wool's warmth as a material. The fibre itself is a poor conductor of heat, but the real insulation is provided by the air trapped inside the fabric. Wool's high natural crimp means that woollen yarns and fabrics tend to be lofty open structures which hold much heat-insulating air inside them. The high elasticity and resilience of wool prevent the fibres from bedding down and the fabric becoming thin during wear.



Wool

The flexibility and elasticity of wool fibres contribute to the high resistance of wool fabrics to crushing and creasing. The fibres can be distorted, but they will tend to return to their original shape again. Wool fibres can be bent backwards and forwards tens of thousands of times without breaking. Elbows and knees of wool suitings can withstand repeated flexing to which they are subjected.

Effect of Water

Wool's thirst for water is one of its most important characteristics. Water molecules can penetrate between the long molecules of keratin in the wool fibre, loosening the mutual grip of the molecules lying close alongside each other. The molecules are able to move more easily relative to one another, and the wet wool becomes softer and more plastic.

Setting

This lubricating effect of water on wool is only one aspect of the influence of water on the properties of the fibre. Water will attack wool keratin, causing changes in the chemical structure of the protein itself.

When a wool fibre is stretched, the coiled-up molecules are extended into a less-folded form. The extent to which this happens is controlled by chemical bonds and forces of attraction that link the long molecules laterally together. When the stretching force is removed, these lateral links pull back the deformed molecules into their original folded state.

If, however, links between the molecules are destroyed as the wool is held in its extended state, and new links are created between the molecules in their new positions, these new links will serve to hold the wool in its extended state. The fibre will have acquired a 'permanent' set.

This is the basis of practical techniques developed for setting woollen fabrics and garments into shapes that will be retained during normal use. The reactions involved in breaking down and rebuilding lateral links between wool molecules are almost invariably reactions in which water plays a part, and are accelerated by the use of elevated temperatures.

Ironing

In ironing a woollen garment, we remove the creases and set the fabric in the shape we want by subjecting it to a combination of moisture and heat. Creases are put into worsted trousers and pleated skirts by 'steam setting'; the fibres are induced to remain in their 'unnatural' shape by the combination of heat, moisture and pressure.

Absorption

Apart from the chemical effect of water on the wool fibre, the purely physical absorption of moisture is of great practical importance. The moisture disappears into the fibres and there is no feeling of clamminess or dampness about the garment, even though it may be holding quite a large quantity of water.

As it absorbs moisture in this way, a woollen garment will generate heat. Putting water onto wool is like adding it to quicklime; heat is produced, but not, of course, to the same degree. A woollen overcoat can therefore have a double warmth-inducing effect. On the one hand, the wool prevents heat escaping from the body and into the surrounding air. In addition, as it absorbs body moisture or rainwater, the wool generates heat on its own account.

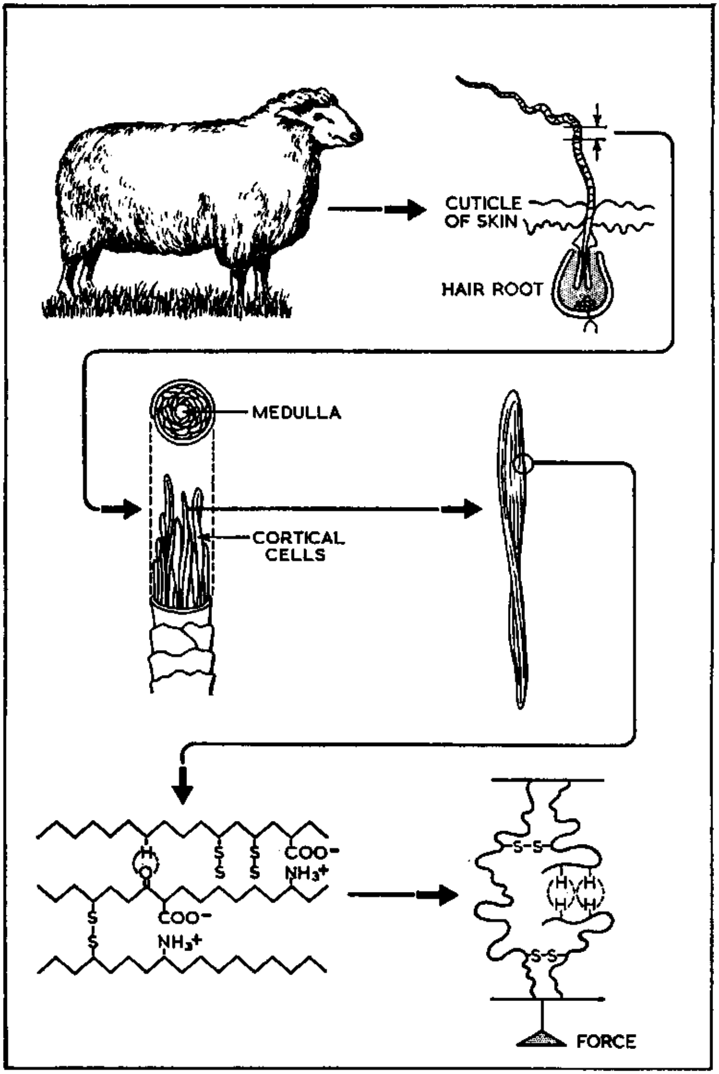
When it has absorbed water, wool will get rid of it again slowly into the surrounding air. Evaporation of a liquid in this way always causes a drop in temperature; if this happens rapidly it can produce quite a chill. Wool, however, evaporates its moisture slowly and gently; there is no sudden cooling to chill the body surface and encourage rheumatism and similar ailments. Woollen bathing costumes, for this reason, are safe and healthy. They can be worn as they dry without chilling the body by permitting rapid evaporation of the water from the fabric.

Attack by Insects

This combination of unusual and valuable characteristics makes wool extremely popular as a high-quality fibre. Unfortunately, this popularity extends beyond the human race; wool is in great demand in other quarters too.

Like meat, wool is a form of animal protein. To insects like the clothes moth, the carpet beetle, the tapestry moth and the case-bearing clothes moth there is no more attractive diet than an appetising woollen jumper. Between them, the larvae of these insects do an immense amount of damage every year. They consume a vast amount of wool, and in doing so they cause an immeasurably greater amount of damage by ruining expensive made-up goods. A tiny hole chewed by a moth grub in a Parisian creation, for example, can cost the owner of the garment a small fortune. The clothes moth is the most destructive of all wool-loving insects.

The moth itself does not do any damage; its sole aim in life is to procreate and ensure survival of the species. The female moth lays her eggs in a suitable place, and within little more than a week the



Structure of the Wool Fibre – After The Wool Bureau Inc.

eggs will hatch into little white grubs. It is at this stage that the moth does all the damage. The grubs settle down and begin to chew their way through the wool in which their mother has so thoughtfully deposited them. The grubs may remain at this stage for as long as three years; after this they are ready to turn themselves into pupae and then moths, and are ready to start the whole life cycle all over again.

Anti-Insect Processes

The powerful synthetic insecticides developed in modern times are being used effectively against moths and beetles that attack wool. Hundreds of chemicals have been examined for this purpose, but only a comparatively few have been used industrially over significant periods of time. All are organo-chlorine insecticides stemming from the researches that led to the discovery of DDT. They include the mothproofing agents Dieldrin, Eulan U33, Mitin FF and Eulan WA new.

The insecticide Dieldrin is one of the most effective agents against moths and beetles. It is relatively simple and inexpensive to use, being applied as an aqueous emulsion that may be added to the liquors used in normal textile processing operations such as dyeing. Applied in this way Dieldrin is completely sorbed into the wool fibres and is removed only very slowly by washing. It resists removal by drycleaning agents such as white spirit and perchlorethylene.

Some of the organo-chlorine insecticides are equipped with chemical groupings that enable them to anchor themselves chemically to the wool fibre in the same way as dyestuffs. They are resistant to washing, drycleaning, light, rubbing, pressing etc. They are odourless and colourless, and produce no undesirable changes in the properties of the wool.

The use of these insecticides has come up against the difficulties associated with their use in other fields. Many are toxic materials if absorbed in significant amounts. Although the possibility of acute poisoning from wool treated with such materials is negligible under normal circumstances, there is the possibility of slow sorbtion through the skin with prolonged contact producing chronic effects.

Storage

Wool is attacked by mildews which may damage and ultimately destroy the fibres. Stored in a badly ventilated warehouse, a damp and slightly alkaline wool offers ideal conditions for mildew attack. Chemicals such as sodium pentachlorophenate, mixtures of certain copper and chromium compounds and proprietary substances such as Shirlan NA can be used as mould preventatives, but wool is best stored dry in a well-ventilated place even when these materials have been applied to it.

Shrinkage

The scaly surface and the elasticity of the wool fibre play an important role in the shrinkage of wool fabrics and garments. Shrinkage can take place in two ways, by relaxation or by felting.

RELAXATION SHRINKAGE is caused by the tensions introduced during spinning, weaving and finishing. Wool is an elastic fibre, and will stretch when pulled. As fibres are being spun into yarns, yarns knitted or woven into fabrics and fabrics subjected to finishing treatments, the wool fibres are stretched. In the finished garment, the fibres sometimes retain some of this stretch; they have a tendency to try and return to their original unstretched state.

So long as the garment is kept dry, the fibres will be unable to recover their normal sizes and shapes. But once the wool becomes wet, the fibres are softened and lubricated and are able to relax into more natural positions.

A garment made up from wool in this sort of 'touchy' condition will therefore shrink when it is washed, no matter how carefully it is treated. A shower of rain will often provide sufficient moisture to loosen the fibres and cause relaxation shrinkage.

FELTING SHRINKAGE takes place in a different way. Unlike relaxation shrinkage, felting is unique to wool and other animal fibres.

Felting takes place when a wool fabric is subjected to mechanical action when it is wet. The fabric shrinks, but it also undergoes characteristic changes in its structure. The fabric becomes thick and the fibres are matted into closely-packed masses. The outline and character of the yarn pattern in the fibre become indistinct, and the fabric loses much of its elasticity. The surface of the fabric is covered by fibres, and its appearance is altered.

Although much research has been carried out on the felting of wool, the exact cause is not known. It seems almost certain that the characteristic scaly surface structure of wool and other animal fibres is the most important factor in felting.

The scales on a wool fibre are arranged with their edges pointing in one direction along the fibre. This means that a wool fibre is rougher in the tip-to-root direction than in the root-to-tip direction. A single fibre would therefore be able to move more easily through a mass of fibres in a root-first direction than in a tip-first direction. (There is some analogy with the movement of a head of wild barley placed inside a jacket sleeve; if the barley is inserted so that the hairs are pointing downwards, the barley head will move upwards through the sleeve. The bristly hairs will allow the head to move only one way; it is only movements influencing the barley in this direction that have any effect.)

Felting appears to take place most readily in a wool fabric when it is subjected to any treatment which causes the fabric to be repeatedly compressed, and then allowed to relax when it is wet. This treatment tends to bend the fibres into loops inside the fabric, and it has been suggested that felting occurs when 'travelling fibres' penetrate these loops to form knots and entanglements.

It has been shown that wool fibres will felt more readily when the tips of the fibres are softened or the roots hardened. If the tips are softened, the fibres are able to form loops more easily, and if the roots are hardened the travelling fibres can penetrate more readily into the loops.

The tumbling or stirring actions of washing machines, the prolonged use of the 'posser' (familiar in the north of England) and particularly any form of rubbing will all cause felting in wool. Some types of indoor dryer, which tumble the damp fabrics during drying, may also cause felting. Some wool fabrics felt more easily than others – a fluffy hand-knit sweater, for example, will felt more easily than a tightly-woven worsted flannel skirting.

Felting and Milling

This felting characteristic of wool fibres is used to advantage in the production of 'felts'. These are simply masses of fibres held together entirely by their natural holding-power without being spun or woven. Some types of woollen fabric are woven and then felted deliberately by the process known as *milling* to give them a fluffy, matted texture. Blankets, for example, are often felted to the stage at which the weave is indistinct before they are given a final raised finish. Deliberate felting is used in making fabrics such as beavers, meltons, doeskins and velours.

Washing

Compared with many fibres, wool is easy to wash; dirt and grease can be removed from it without difficulty. It is essential, however, that wool garments should be washed with care.

The temperature of the water used for washing wool has little or no effect on the shrinkage of wool garments in domestic washing. Water temperature does have an important effect on the fastness of wool dyes; hot water increases the risk of colours running and of white fabrics going yellow. The ideal temperature of water for washing wool is about 38°C (100°F), i.e. lukewarm. When a garment is soiled with heavy grease, rather hotter water may occasionally be used.

Washing Agents

Most of the washing products sold for domestic use are suitable for washing wool, and the type of product used will have little effect on shrinkage. Some products, however, will be more likely than others to cause colour bleeding and the yellowing of whites. In this respect, liquid synthetic detergents are generally the safest washing products, followed by soap flakes and detergent powders, and powders based on soap. There is no very great difference, however, between the 'safety factors' of these products with respect to their use in washing wool.

The manner in which the washing agent is used is very much more important than the agent itself. Solid agents must be completely dissolved before the wool fabric is put into the water. Undissolved particles of soap or other detergent may adhere to the garment and cause localized colour loss.

The actual concentration of washing agent used under normal conditions does not have a serious effect on the bleeding of wool dyes (excessive concentrations may cause damage). The correct amount to use is normally indicated on the package.

Hypochlorite bleaches must not be used on wool.

Minimum Handling

The washing procedure for wool articles should always be such as to involve a minimum of mechanical action. Mechanical action is the main cause of shrinkage; prolonged agitation, tumbling or stirring will cause felting. Above all, wool should never be rubbed.

The best way of washing wool garments is to leave them to soak for a minute or two in the washing solution. They may be squeezed gently by hand in the solution, and then left again undisturbed for a few minutes. This cycle of soaking and squeezing may be repeated several times.

The mechanical action necessary to remove dirt from blankets, without causing felting, can be applied by a wringer. After soaking for a few minutes in the washing solution, the blanket is passed through the wringer. This cycle of soaking and wringing may be repeated several times, the liquid is squeezed from the blanket by the wringer carrying away the dirt without felting the wool.

This soaking and wringing technique can be used effectively with other wool fabrics. Socks, sweaters and knitted garments, for example, can be washed safely in this way. (Knitted garments should be supported carefully when being handled, to ensure that no part of the garment is dragged down under it own weight.)

Close-fitting garments such as cardigans or sweaters are not affected seriously by any slight changes in shape caused during washing. Garments which hang to a definite length, however, such as jersey dresses, need extra care during washing. Jersey dresses should be dry-cleaned if possible. If they are washed, they must not be allowed to stretch by hanging when wet, or subjected to any twisting or rough handling.

Machine Washing

The stirring and tumbling actions of washing machines are not ideal for woól. Delicate wool garments, such as jersey dresses, fashion sweaters and loosely-knit fabrics should be washed by hand if possible. More robust fabrics, such as blankets, flannel shirts and shorts, socks or underwear may be washed in washing machines so long as the washing time is kept to a minimum. Even so, the vigorous mechanical action may cause felting after repeated washing.

A useful method of washing wool garments in a washing machine is to follow a soaking-agitation cycle which may be repeated several times. The load of wool garments is chosen so that there is no danger from colour-bleeding. After soaking for a minute or two in the washing solution, the garments are agitated for five seconds. The paddle is then switched off and the garments are allowed to soak again. After going through one or two soaking-agitation cycles in this way, the garments are passed through the wringer.

Wool garments should not be allowed to become very dirty before being washed. Wool can withstand frequent gentle washing without taking any harm. If a wool garment *does* become heavily soiled, it should not under any circumstances be subjected to an increased period of agitation in the washing machine. When the normal gentle methods fail to dislodge the dirt, the garment should be left to soak in cool suds for several hours, or even overnight.

This treatment is perfectly safe on undyed garments, or on single-colour fast-dyed articles, particularly when a liquid detergent is used.

Single-colour articles in which the dye tends to run a little will not, as a rule, suffer any serious loss of appearance when soaked in this way. There may be some lightening of shade.

Multicoloured wool fabrics should, however, be treated with especial care, as there is always the danger that dyes will bleed and affect another part of the garment which is white or of a different colour.

Rinsing and Drying

Wool garments should be rinsed in several changes of water after washing. They should be handled as gently as they are during the washing itself, and may be passed through the wringer between rinses, or squeezed carefully by hand. Knitted garments should never be twisted, or the fabric will be distorted.

After the final rinse and squeeze, the garment may be folded in a towel and passed through the wringer, pressed by hand or by being knelt on. This will remove much of the water that remains in the fabric.

Robust wool garments, such as socks, flannel shorts and skirts or blankets can be dried on a line in the usual way. More delicate fabrics and fashioned garments – such as jersey dresses, sweaters and cardigans, in which shape is important – should not be hung up to dry. These garments should be dried flat, away from intense heat. Sometimes, elaborate precautions are taken to return the garment to its original dimensions; the size and shape may be marked out on a piece of paper, for example, and the garment adjusted to this outline before drying. Special 'shapes' made from wire or plastic may be used as formers on which wool garments can be dried to their original dimensions.

Drying flat has an additional advantage in that it keeps colour-running to a minimum during drying.

When drying is done out-of-doors on a line, white woollies should be hung in the shade to avoid yellowing which may be caused by direct sunshine.

Shrink-resist Processes

Shrinkage and felting have been studied by textile scientists for many years in an effort to improve the washing characteristics of wool. Many processes have been developed and some have been brought into practical use by the wool trade.

London Shrink Treatment

Relaxation shrinkage can be prevented by ensuring that the tensions in the fabric are eased before a wool garment is sold. The well-known London shrink treatment consists in wetting the cloth and allowing it to remain in a slack condition for a few hours. The fibres are then able to relax and the cloth shrinks before it reaches the customer. Fabrics treated in this way are described as 'London-shrunk'.

Although pre-shrunk fabrics of this sort will have lost much of their tendency to relaxation shrinkage, they will still felt and shrink if treated harshly during washing. To avoid felting, it is necessary to make some fundamental changes in the fibre-properties which cause it.

Anti-Felting Treatments

The felting of wool fibres which occurs during agitation in water is caused primarily by unidirectional movement of the fibres. This results in large measure from the 'stacked flowerpot' configuration of the scales on the fibre surface, causing greater resistance to fibre movement in one direction than in the other.

Anti-felting treatments developed for wool have evolved from attempts to modify the fibre surface in such a way as to minimise this unidirectional movement.

(1) *Chemical Modification of Fibre Surface*

In the early days of anti-felting research, processes were developed which aimed at the removal or smoothing-down of projecting edges of the surface scales on the fibres. Chemical teatments were often harsh, causing significant degradation of the fibre and damaging the cortex as well as the surface scales. Later research showed, however, that reducing the frictional differences by eroding the protruding scales was not essential in preventing unidirectional movement of the fibres. Anti-felting properties could be realised by increasing the general level of fibre friction, so making fibre movement more difficult. Chemical anti-felting treatments were developed which involved comparatively mild attack on the fibre structure.

Many chemical anti-felting treatments have been in commercial operation for half a century and more, and are now in widespread use throughout the world.

WET CHLORINATION, one of the earliest processes, has undergone many modifications and developments since it was introduced. Sodium hypochlorite is the active agent, serving as a source of chlorine which attacks and modifies the surface of the wool fibre.

The process must be used with care or chemical degradation can be rapid and uneven, causing unsatisfactory shrink resistance, unnecessary damage to the fibre and difficulties in dyeing.

DRY CHLORINATION is carried out by treatment of the wool with chlorine gas. Wool subjected to this treatment should not contain more than some 8 per cent of water. It is necessary, therefore, to dry the wool which contains about 16 per cent of water in its air-dry state. This adds to the operating costs, which are generally higher than those of the wet chlorination process. On the other hand, dry chlorination can result in very even treatment of the wool.

Many other processes are now established in which a variety of chemicals are used to attack the fibre surface and produce anti-felting effects. Each has its own particular merits, the choice of process depending on the type of fibre, the manner in which it is to be processed and the intended use.

(2) *Addition of Polymeric Materials to the Fibre*

Anti-felting processes involving a chemical attack on the fibre must inevitably bring about changes in the characteristics of the wool. By removing part of the fibre surface they may cause significant loss of weight, and they can affect the strength and physical properties of the wool.

Since World War II much attention has been directed towards the development of anti-felting, shrink-resist processes in which material is added to the wool, notably by the formation or deposition of synthetic polymers in and on the fibre.

During the 1960s a wide range of inexpensive water-soluble or emulsifiable polymers became available, and many were examined as potential anti-felting agents for wool, with varying degrees of success. A particularly effective technique combined pretreatment with chlorine followed by the application of polymer from emulsion. This process could be used for the continuous treatment of wool tops – a more difficult problem than the treatment of wool fabric.

From this work have come modern processes culminating in the commercial production of fully shrink-proof wool, including the chlorine-Hercosett treatment used effectively on tops, loose wool and knitted garments.

Superwash Wool

The development of a range of processes now permits the textile manufacturer to produce any desired degree of shrink resistance in finished wool products, including completely shrink-proof materials. The degree of treatment provided depends upon many factors, including cost, type of wool, fabric construction, the demands of fashion, and the launderability requirements of the finished garment. Inevitably, this situation has created difficulties in the defining of shrink-resistance. What is shrink-resistant under one set of circumstances is not necessarily shrink resistant under other conditions. Moreover, the modern consumer, brought up in a world of synthetic fibres, has become accustomed to regard machine-washability as almost an essential requirement of everyday clothing and materials. A garment marked as shrink-resistant is expected to withstand machine washing.

To rationalise this situation and remove all risk of felting occurring during laundering, the International Wool Secretariat has prescribed high standards of shrink resistance and introduced the concept of Superwash wool. Goods treated for shrink resistance must conform to stringent specifications established and controlled by International Wool Secretariat before qualifying for labelling as Superwash. This indicates that the garment is fully machine-washable.

The Superwash appellation does not refer to any specific anti-shrink treatment; it signifies a standard of performance which may be achieved by treating wool with one of a number of commercial processes.

The Setting of Wool

It has been known since the earliest times that wool and other animal fibres can be formed into a desired shape and then persuaded to retain that shape for a period of time, perhaps short or perhaps long. Before the days of recorded history, for example, women were winding their hair around curlers and then allowing it to dry, when it remained in its curled shape. The effect was only temporary; when the hair became wet again, the curls fell out and the hair returned to its original shape.

More permanent forms of setting, as this process became known, have been used in the textile industry for a very long time, usually involving the simultaneous use of water and heat. Three well-known processes of this sort are crabbing, blowing and potting.

In CRABBING, cloth is wound under tension on a roller and steeped in boiling water, Stresses and strains introduced during weaving are dissipated and the fabric is set in a more stable form.

BLOWING is a related process, usually applied later in the finishing routine. Again, fabric is wound on a roller, usually interleaved with a smooth-surfaced wrapper, and subjected to the action of steam.

In POTTING or ROLL BOILING, fabric is wound under tension on a perforated roller, covered with a cotton or canvas wrapper and placed vertically in water which is slowly brought to 60 degrees C. It is kept at this temperature for times varying from 3 hours to 3 days, producing a cloth with a soft handle and smooth glossy surface.

The set introduced into wool fabrics by simultaneous use of water and heat in this way is more permanent than that produced by setting in cold water. The set shape will usually be retained if the fabric is wetted. But the set will be released if the wet fabric is heated to a temperature higher than that used in the setting process.

It is apparent, therefore, that there are different degrees of setting of wool, and in practice, set is graded empirically into three degrees; cohesive, temporary and permanent set.

COHESIVE SET is set that disappears when a fibre of fabric is released in cold water.

TEMPORARY SET is set that persists in cold water but disappears on release in boiling water.

PERMANENT SET is set that remains in the fibre or fabric even after release in boiling water.

The introduction of synthetic thermoplastic fibres led to the development of fabrics and garments capable of being set by the action of heat into desired configurations that are retained during subsequent wear and laundering. Garments can be set with permanent pleats and creases, and with permanent smoothness that resists the formation of wrinkles. These characteristics, which make for easy-care garments, were accepted gratefully by the consumer, who found them attractive and desirable. The establishment of the minimum-care concept stimulated interest in setting processes that could provide similar characteristics in traditional fibres, including wool.

The features of easy-care garments that make them what they are include the ability to withstand normal wear, dry cleaning and laundering. The aim has been, therefore, to achieve a degree of set as high as possible, with the ultimate target the production of permanent set.

Industrial Setting Processes

Research into the setting of wool fibres, extending over many years, showed that the rapid achievement of a high degree of set required the simultaneous action of a reducing agent, heat and water. These three influences could disrupt the bonds holding wool molecules together, permitting them to take up new positions determined by the shaping forces, and to re-establish bonds between the molecules that would hold them in their new positions.

Many industrial processes for setting wool fabrics and garments have been developed using the principle of simultaneous application of reducing agent, heat and water. Permanent pleats and creases set in wool garments are a match for those set in synthetic fibre garments. The processes used in setting wool differ from one another in the choice of reducing agent and the conditions under which it is applied; the agent may be introduced during finishing, or sprayed onto the finished garment prior to the final pressing or steaming operation.

In any textile manufacturing procedure, anything that adds to the production schedules is apt to cause complications and increase costs. Every effort has been made, therefore, to develop wool setting processes that will cause as little disruption as possible to normal manufacturing procedures.

SI-RO-SET Process

The Si-Ro-Set process, developed in Australia establisheda chemical spray-on technique for setting wool garments that has become the basis of subsequent processes. Permanent creases may be set in trousers, skirts and other garments by spraying a solution of a reducing agent – such as ammonium thioglycollate, monoethanolamine sulphite or sodium bisulphite – onto the garment prior to the final pressing operation, Processes of this type are now in widespread use; they are generally simple, cheap and effective.

Presensitizing Technique

The spray-on techniques described above involve the garment manufacturer in an extra manufacturing stage. With the object of avoiding this, setting processes have been developed in which the reducing agent – notably sodium bisulphite – is added to the fabric during finishing. Setting takes place during the garment manufacturer's final pressing operation, and he is no longer involved in the application of reducing agent to the garment.

Dry Processes

The need to add water to a finished garment prior to setting can also create difficulties for the clothing manufacturer, and many attempts have been made to devise setting processes in which he is no longer required to wet the garment. Techniques have been developed in which reducing agents are applied to the wool fabric during finishing, together with a humectant – a chemical that attracts water. During the final steam pressing of the finished garment, the humectant causes condensation of water in the cloth, thus fulfilling the three fundamental requirements for setting – simultaneous action of reducing agent, water and heat.

Flat Setting

Any technique adopted in the establishment of an 'easy-care' concept is required to contribute two vital characteristics to the garment. On the one hand, it must ensure dimensional stability; on the other hand it must provide for the retention of appearance during wear and laundering.

In their normal state, wool fabrics cannot meet these requirements. Firstly, the felting power of wool may lead to shrinkage and a resulting change in the shape and dimensions of fabrics and garments. Secondly, some wool fabrics may distort and become wrinkled during laundering.

To achieve easy-care characteristics in a wool garment, therefore, it is necessary to apply techniques that will overcome dimensional instability and loss of appearance during laundering.

Effective modern shrink-proofing processes are able to overcome the first obstacle. The second obstacle – how to ensure retention of appearance – may be overcome by applying established setting techniques to wool fabrics to stabilise them in flat form. Development of these techniques has centred around the application of water and reducing agent to a fabric and then subjecting it to steam treatment, for example on the blower. Sodium bisulphite is a reducing agent commonly used.

Modifications and variations of these techniques are now widely used. Combination of shrinkproofing with flat setting provides wool garments and fabrics which retain admirable dimensional stability and appearance under normal conditions of domestic use.

Permanent Press

The processes outlined above may be used effectively for garments that are required to withstand soaking in water or mild washing followed by drip drying. The garment remains in its desired shape for most of the time during laundering, and the set is sufficient to hold it in that shape.

If, however, a garment is to be subjected to severe machine washing and tumble drying, it will be for much of the time in a distorted shape. Changes in the fibres may take place which re-set them in their distorted shape during laundering. To prevent this happening and to achieve a really effectivce permanent set, a third requirement must be met in addition to shrink-proofing and setting. The wool must be stabilised in its desired shape.

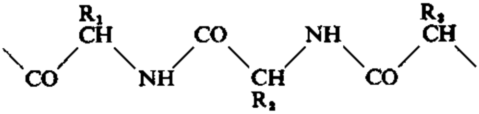
This can be done in various ways. For example, the garment may be hung in a steam oven and subjected to superheated steam. Resin may be added to the fabric to encourage retention of the desired shape.

By making use of techniques now available, wool garments may be produced with outstanding easy-care characteristics that compare favourably with those associated with any synthetic fibre.

TECHNICAL NOTE

The keratin of wool is a protein of empirical formula $C_{72}H_{112}N_{18}O_{19}S$ (approx.). The exact composition depends upon the position of the material in the fibre and the treatment to which it has been subjected. Keratin is affected, for example, by the action of sunlight, and by the quality of the food which the sheep has eaten.

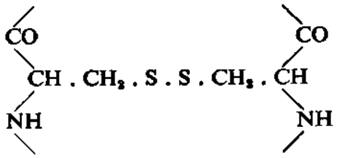
Keratin is hydrolysed by boiling with hydrochloric acid, yielding a mixture of some 17 α-amino acids of general formula $NH_2.CHR.COOH$. These acids are linked through their amino and carboxyl groups into a polypeptide chain as follows:



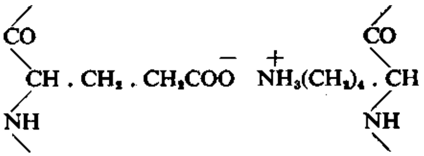
It is believed that there are about 600 amino acid residues in the main peptide chain of the keratin molecule. The molecular weight is probably about 68,000.

The strength of the wool fibre derives from these long molecules which lie alongside one another. They are held together by numerous strong hydrogen bonds between the carbonyl (C = O) and imino (NH) groups in adjacent molecules, and also by covalent disulphide and electrostatic salt linkages.

Disulphide linkages are formed by the amino acid cystine which has two amino groups and two carboxyl groups. When one of each of these groups is incorporated in adjacent polypeptide chains a disulphide bridge is formed: –



Salt linkages are formed by association between side chains on the polypeptide molecule, which contain free carboxyl and amino groups: –



The unusual elasticity of the wool fibre may be explained by the coiled or folded state of keratin molecules in the relaxed fibre; this is alpha-keratin. When the fibre is stretched in steam, the molecules tend to uncoil or unfold; in this form, the material is described as beta-keratin.

THE PRINCIPLES OF SETTING

Supercontraction

During the 1930s a systematic scientific investigation of wool setting was carried out. W. T. Astbury and H. J. Woods studied the behaviour of wool fibres exposed to water and steam for varying periods of time whilst held in an extended state. It was found that fibres held at 40% extension and steamed for less than about 15 minutes would contract when released in steam to a length shorter than their original length. This phenomenon became known as supercontraction; it occurs to a maximum extent when the initial steaming is continued for only 2 minutes.

When fibres were extended and steamed for more than about 15 minutes, they retained a degree of permanent elongation when subsequently released in steam. The longer the initial steaming, the greater was the permanent increase in fibre length. This became known as permanent set.

Physical Mechanism

The action of steam on an extended wool fibre sets up two competing effects. Initially, some of the stabilizing cross-linkages and bonds in the fibre are broken. This permits the structure to relax and the fibre contracts into its foreshortened state. Disruption of these linkages takes place rapidly on steaming, but as steaming continues a cross-linkage rebuilding takes place, serving to stabilise the fibre in its extended state. On release after more than 15 minutes steaming, the fibre is no longer able to contract to its original length. Permanent setting has occurred.

In any practical setting treatment, the aim is to retain as much as possible of the deformation put into the fibre or fabric. This can be achieved in two ways: (1) by reducing the retraction forces that tend to pull the fibre back into its original state, and (2) by strengthening or increasing the number of new cross-linkages formed in the extended or distorted fibre.

One method of reducing the forces of retraction in an extended fibre is to hold it in water at an elevated temperature. The effect increases with increasing temperature and time; at 100 degrees C after 1 hour the retraction force is reduced by a factor of 30–40, so that only weak bonds are needed to set the fibre in its extended state. The degree of set given to a wool fibre during crabbing, for example, is much greater than that given to a woman's hair set in curlers at room temperature.

Chemical Mechanism

From his researches during the 1930s, J. B. Speakman concluded that the initial breakdown of wool on steaming involved hydrolysis of the disulphide cross-links in keratin molecules.

$$\begin{aligned}|\text{—}CH_2.S\text{—}S.CH_2\text{—}| + H_2O \rightarrow \\ |\text{—}CH_2.SH \quad HOS.CH_2\text{—}|\end{aligned}$$

The second stage, i.e. rebuilding of cross-links, involved formation of new covalent bonds by reaction of some of the breakdown products with side chains in the wool molecule. This theory is still believed to be basically correct, the new cross-links contributing to the stability of permanently set wool, but the cross-links produced are now generally accepted as being different from those postulated in the 1930s.

Speakman suggested that the rebuilding of cross-links took place by reaction of sulphenic acid group formed as above with amino side chains to form –S–NH– cross links. Alternatively, and perhaps simultaneously, the sulphenic acid groups underwent further breakdown to form aldehyde groups which reacted in turn with amino side-chains. These reactions are as follows: –

$$|\text{—}CH_2.SOH + H_2N\text{—}| \rightarrow |\text{—}CH_2.S.NH\text{—}|$$

$$|\text{—}CH_2.SOH \rightarrow |\text{—}CHO + H_2S$$

$$|\text{—}CHO + H_2N\text{—}| \rightarrow |\text{—}CH = N\text{—}|$$

It is now generally believed that the disulphide bonds undergo a rearrangement stimulated by thiol groups introduced as a result of the action of reducing agents. These groups set up a thiol-disulphide interchange, breaking and reforming disulphide bonds which are thus rapidly rearranged into new positions corresponding to the extended state of the fibre. This interchange can occur slowly in boiling water, more rapidly in alkaline solutions and very rapidly in the presence of reducing agents.

This rearrangement removes the restoring force of the disulphide bonds originally present in the molecules and so prevents immediate contraction on release of a set fibre. But the new disulphide bonds are equally capable of rearrangement during release, and they do not make a significant contribution to the long-term stability of the set unless interchange is inhibited in some way after setting. This can be done by blocking or otherwise removing the thiol groups which catalyse the interchange.

It is now accepted that hydrogen bonds, which are present in great profusion in wool fibres, play a major role in the breakdown and rebuilding mechanisms that influence setting. Once the stabilising influence of the disulphide bond has been removed, massive hydrogen bond rearrangement occurs under the action of the boiling water.

This concept of setting suggests that fibres can be set at low temperatures by subjecting them to the combined acton of a reagent capable of breaking and rearranging disulphide bonds and one capable of breaking hydrogen bonds. This is the basis of low-temperature setting processes using, for example, solutions of reducing agents containing urea – a powerful hydrogen bond breaker. The reducing agent takes care of the disulphide bonds and the urea disrupts the hydrogen bonds, enabling the wool molecules to remain in the new positions they have taken up. If they can now be locked in these new positions, the fibre will have acquired a permanent set.

Many suggestions have been made as to the sort of mechanisms which can result in permanent set in this way. New covalent links may be formed, for example, by monosulphide lanthionine linkages created in the following way: –

$$|-\mathrm{CH_2.S{-}S.CH_2}-| \xrightarrow{\text{alkali}} |-\mathrm{CH_2.S.CH_2}-|$$

Another cross-link – lysinoalanine – is known to occur spontaneously in set wool as follows: –

$$-\mathrm{CH_2.S{-}S.CH_2}-| \rightarrow |{=}\mathrm{CH_2} + \mathrm{S} + {}^{-}\mathrm{SCH_2}-|$$
$$|{=}\mathrm{CH_2} + \mathrm{H_2N(CH_2)_4}-| \rightarrow$$
$$|-\mathrm{CH_2}-\mathrm{NH}-\mathrm{(CH_2)_4}-|$$

Side chains other than lysine can also become involved in cross-links of this sort.

As these new cross-links cannot rearrange in the same way as disulphide bonds, they contribute stability to the set. On the other hand, if they should be formed before the necessary disulphide bond and hydrogen bond rearrangement has occurred, they can diminish the degree of set that takes place.

General Mechanism of Setting

A general mechanism of setting may be outlined which incorporates most of the accepted theories that have emerged.

Permanent set requires changes akin to melting; one crystalline form of wool keratin (alpha-helices) is converted to another (beta-crystallites). This necessitates rearrangement of relatively strong hydrogen bonds which requires the presence of water (or another hydrogen-bond breaker) and, usually, heat.

There is a simultaneous rearrangement of disulphide bonds generated, for example, by alkalis or reducing agents. And whilst these rearrangements are occurring, several new types of cross-link arise spontaneously. These new cross-links do not rearrange in the manner of disulphide bonds and they contribute to the stability of the set provided they are introduced after adequate hydrogen bond and disulphide bond rearrangement have occurred.

The various reactions involved in setting can be accelerated by heating at elevated temperature with steam under pressure. And additional stability can be obtained by hindering the reverse thiol-disulphide interchange that occurs during release by removing thiol groups or by introducing non-exchangeable cross-links after setting.

Insects which eat Wool

MOTHS *Tineola bisselliella* (Common Clothes Moth)
Tinea pellionella (Case-bearing Clothes Moth)
Tinea pallescentella (Large Pale Clothes Moth)
Trichophage tapetzella (White Tip Clothes or Tapestry Moth)
Endrosis lactella (White Shouldered House Moth)
Borkhausenia pseudopretella (Brown House or False Clothes Moth)
Tinea lapella

BEETLES *Attagenus piceus* (Black Carpet Beetle)
Attagenus pellio (Furrier's Beetle)

Anthrenus scrophulariae (Common or Buffalo Carpet Beetle)
Anthrenus flavipes (Furniture Carpet Beetle)
Anthrenus verbasci (Varied Carpet Beetle)
Anthrenocerus australis (Australian Carpet Beetle)

In every case, it is the larva which causes damage by eating wool. The keratin of wool is an indigestible form of protein. It is believed that the larva secretes a substance in the middle intestine which reduces the disulphide bond linking the polypeptide chains together. This increases the solubility of the wool and enables it to be attacked more readily by protein-digesting enzymes.

A larva is able to cut a fine wool fibre with a single bite, but may have to gnaw its way through a thicker one. It is significant that larvae prefer finer wools.

Life Cycle of Common Clothes Moth

The life cycle of any insect is determined very largely by the conditions of its environment. Under ordinary circumstances, the Common Clothes Moth will begin to lay eggs the day after emerging from the pupa. It will continue to do so for a week to a fortnight; the adult moth will die within a fortnight to a month.

The eggs hatch in a week to a month. The larvae may persist for between three months to three years before turning into pupae. After 10–44 days the moth emerges from the pupa.

Moth Proofing

(1) Wool itself can be modified chemically to make it unpalatable to the grub. Reduction of the disulphide links followed by alkylation introduces a methylene group between the sulphur atoms. The new link is not broken down so easily by the digestive processes of the larva.

$$\left| \mathrm{-CH_2\,.\,S\,.\,S\,.\,CH_2-} \right| \longrightarrow \left| \mathrm{-CH_2\,.\,SH \quad HS\,.\,CH_2-} \right|$$

$$\longrightarrow \left| \mathrm{-CH_2S\,.\,CH_2\,.\,S\,.\,CH_2-} \right|$$

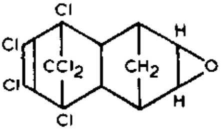
(2) The following chemicals are typical of those used for moth-proofing wool.

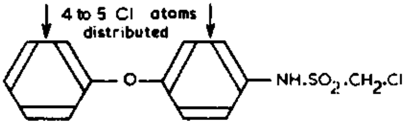
(*a*) Martius Yellow. 2:4 dinitro-α-naphthol
(*b*) D.N.O.C. Dinitro-o-cresol

(*c*) Inorganic fluorides
e.g. Eulan Extra—a double fluoride of aluminium and ammonia.
Eulan W Extra—potassium acid fluoride.

(*d*) Organo-Chlorine Compounds.

DIELDRIN





EULAN U33

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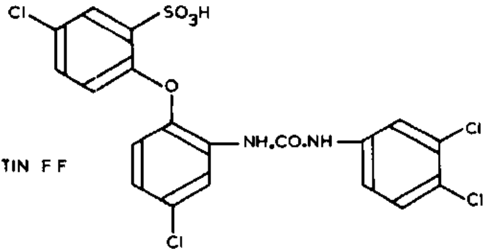


MOHAIR

Although wool is by far the most important animal fibre, there are a number of hair fibres which are of considerable commercial value. These come mostly from animals of the goat and camel families.

The Angora goat, which originated in Turkey, has a coat of long, lustrous hair which provides the textile fibre known as mohair. Much of the world's production of mohair is in Turkey, South Africa and the U.S.A.

Until early in the nineteenth century, Turkey was almost the sole producer of mohair. As the manufacture of textiles expanded during the period of the Industrial Revolution, efforts were made to raise the Angora goat in other parts of the world. Mohair production established itself in South Africa and in certain parts of the U.S., notably Texas and California towards the end of the nineteenth century. The U.S. is now the chief producing country and also the biggest consumer of mohair.

PRODUCTION AND PROCESSING

The goats are usually clipped twice a year, providing about 1.8–2.3kg (4–5 lb) of mohair per animal at each clip.

The quality of the fibre varies, depending on its source and the conditions under which the goat has lived. Fleeces are graded into tight lock, flat lock and fluffy types.

Tight lock is characterized by its ringlets and is usually very fine. Flat lock is wavy and of medium quality. Fluffy or open fleece is the least valuable.

As in the case of wool, mohair contains the dead, dull fibres that are known as kemps.

STRUCTURE AND PROPERTIES

Fine Structure and Appearance

Like wool, mohair is contaminated with natural grease, dirt and vegetable impurities. These may account for as much as one-third of the weight of the raw fibre. The clean, scoured fibre is usually white and silky.

The fibres vary in length, depending upon the age of the goat. At six months, an Angora kid will provide fibres 10–15cm (4–6 in) long; at twelve months, they will be 23–30cm (9–12 in) long.

The surface of a mohair fibre has some resemblance to that of wool. It is covered with epidermal scales which are anchored much more closely to the body of the fibre than are wool scales. There are only about half as many scales as there are on wool. Mohair has some 5–6 scales per 100 microns length of fibre, whereas fine wool will have about 11. The overlap is very slight, so that the fibre has a smooth handle; light is reflected from the surface to give mohair its characteristic lustre. Individual scales usually encircle the whole fibre in the finer fibres.

As in the wool fibre, the bulk of the mohair fibre consists of a cortical layer built up from spindle-shaped cells. About one fibre in every 100 has a well-marked central core or medulla.

Mohair has a circular cross-section. Seen under the microscope, the cut end of a mohair fibre is marked by small spots or circles. These are caused by strings of air bubbles which lie between the spindle cells of the cortex.

Tensile strength

Tenacity: 11.8–12.8 cN/tex (12–13 g/tex).

Elongation: 30 per cent

Elastic Properties

Elastic Recovery from –
50 per cent breaking load: 0.8
50 per cent breaking extension: 0.6
Work of rupture: 2.65 cN/tex (2.7 g/tex).
Initial modulus: 353 cN/tex (360 g/tex).

Specific Gravity. 1·32

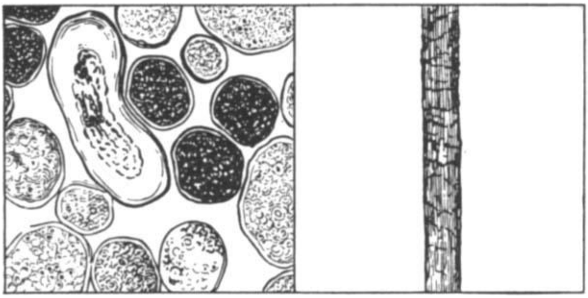
Effect of Moisture

Mohair absorbs water readily, and under normal conditions will hold as much moisture as wool.

Regain 13 per cent.

Effect of Heat, Age, Sunlight, Chemicals, Organic Solvents, Insects, Micro-organisms

Similar to wool.



Mohair

MOHAIR IN USE

Mohair is characterized by its remarkable resistance to wear. Mohair fabrics are therefore used wherever durability is the first essential. Upholstery in public vehicles, car hoods, etc., are often made from mohair where resistance to wear and tear can be combined with attractiveness.

In combination with wool, mohair is often used for summer suitings. Mohair dyes well and has a beautiful natural lustre. It is made into all manner of dress materials, plushes and astrakhans.

Mohair is attacked by moths and should be protected in the same way as wool. It felts to a lesser extent than wool.

CAMEL HAIR

In north-west China and Mongolia, the Bactrian (two-humped) camel is an important animal. It serves as a means of transport in desert regions, and it also provides a supply of the camel hair which is used as a textile fibre.

Camel hair is shed by the animals in matted locks which are collected as they fall to the ground. Each animal yields some 2.27kg (5 lb) every year, and the total output of camel hair from China is more than 0.45 million kg (1 million lb) per year.

The camel has an outer coat of tough hairs that may reach 30cm (12 in) or more. Beneath this is a downy undercoat of fine soft hair 2.5–15cm (1–6 in) long. This camel hair undercoat is the really valuable part of the fleece. It is as soft and fine as merino wool. The downy wool is separated from the coarser hair by combing.

STRUCTURE AND PROPERTIES

Fine Structure and Appearance

Camel wool fibres are not so fine as cashmere; they are usually about 10–40μ wide. The surface of the fibre is covered with scales which cannot easily be seen under the microscope. The scales have diagonal edges.

The cortical layer of the camel wool fibre is marked by striations due to strings of coloured pigment granules that give the fibre its characteristic pale red-brown colour.

Some fibres have distinct medullae which are often fragmentary. Seen in cross-section, the fibres are circular or oval.

Tensile strength

Tenacity: 15.7 cN/tex (16g/tex).

Elongation. 39–40 per cent.

Elastic Properties

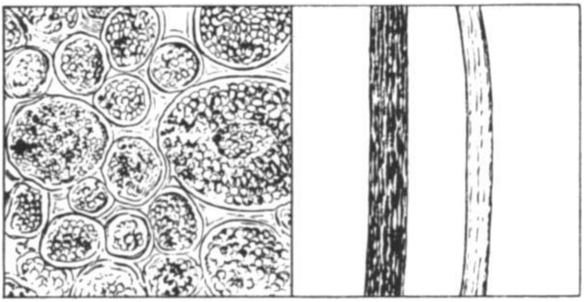
Elastic Recovery from –
50 per cent breaking load: 0.8
50 per cent breaking extension: 0.7
Work of rupture: 4.6 cN/tex (4.7 g/tex).
Initial modulus: 294 cN/tex (300 g/tex).

Specific Gravity. 1·32

Effect of Moisture. Regain 13 per cent

Effect of Heat, Age, Sunlight, Chemicals, Organic Solvents, Insects, Micro-organisms

Similar to wool.



Camel Hair

CAMEL HAIR IN USE

Camel hair fabrics are warm and comfortable, and are used very largely for making overcoats, dressing gowns and knitted goods.

The coarse outer hair is made into ropes and industrial belting, tent-fabrics and blankets.

CASHMERE

In parts of China, northern India, Tibet, Iran and Afghanistan, the Tibetan cashmere goat is reared as a domestic animal. It has an outer coat of long coarse hair with an inner coat of down. This fine, soft down is the source of the fibre that is known all over the world as cashmere.

The downy cashmere fibre is combed from the goat's fleece during spring, and in the process is separated as much as possible from the coarser hair. Each animal will provide little more than 110g (4 oz) of cashmere fibre every year. The combined output from 30–40 goats provides enough fibre to make an overcoat.

STRUCTURE AND PROPERTIES

The downy fibres are usually 2.5—9.0cm (1–3½ in) long, and the coarser hairs 5.0–12.5cm (2–5 in) long.

Like other hair fibres, cashmere fibres are covered with epidermal scales. There are about 5–7 scales per 100μ on average. They have serrated edges and project from the fibre causing an irregular surface.

The cortical layer of the cashmere fibre consists of spindle-shaped cells with occasional long narrow spaces between the cells forming striations in the fibre. The fine cashmere fibre does not have any distinct medulla.

Cashmere wool is usually grey, buff-coloured, or white. The coloured fibres are full of tiny granules of pigment.

In cross-section, the fibre is circular or slightly oval; the pigment granules can be seen clearly in the cortical layer.

Cashmere wool fibres are extremely fine, averaging about 15μ in diameter, which is considerably finer than the best merino wool. The coarser beard hairs which are mixed with the true wool fibres are thicker, averaging about 60μ in diameter. The latter have well-marked medullae.

Chemical Properties

Cashmere is chemically similar to wool. It wets out with water much quicker than wool, and is more sensitive to the effect of chemicals, largely as a consequence of its greater fineness.

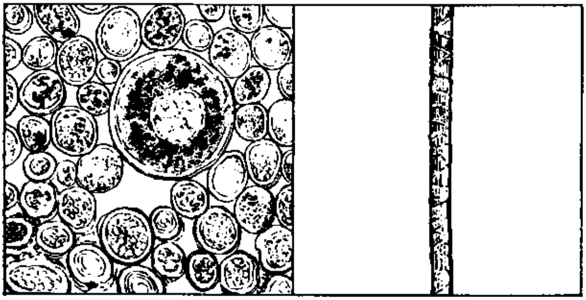
Cashmere is very easily damaged by alkalis such as washing soda. It will dissolve readily in solutions of caustic soda.

CASHMERE IN USE

The world output of cashmere wool is very small, and production is a costly process. Inevitably, the fibre is expensive.

Cashmere is so fine and soft, however, that it is regarded as one of the most desirable textile fibres of all. Cashmere fabrics are warm and comfortable, and have a beautiful drape. The fibre is used very largely for making high-quality clothes, shawls and hosiery, either alone or mixed with other fibres.

Garments made entirely from cashmere are properly labelled 'Pure Cashmere'. Sometimes, fabrics woven from fine botany wools are incorrectly described as 'cashmere'.



Cashmere

PERSIAN GOAT HAIR

The down from Persian goats is often marketed as Persian cashmere. It is, in fact, much coarser than true cashmere; the fibres are about 20μ in diameter. It is available in various shades of brown between a pale cream and a dark tan.

LLAMA

In the high mountain regions of the Andes, in Ecuador, Peru, Bolivia and north-west Argentina, the llama or South American camel is a beast of burden of immense economic importance. Like the Asian camel, it also provides a fleece which is a valuable textile fibre.

The fleece of the llama consists of a mixture of fine soft fibres and dull inelastic coarse hairs. The natural colours of the fleece are black, brown and white.

The fine fibres from the undercoat of the llama are not so fine as those of the Bactrian camel. Llama fibres are soft and strong, however, and often 30cm (12 in) or more long. They resemble camel hair in appearance; the fibre surface is scaly but the outlines of the scales are often difficult to detect. The medulla is pigmented.

Raw llama fleece contains only about 3 per cent of grease.

Llama hair is used locally, being made into carpets, rugs and hand-made clothing fabrics.

ALPACA

The alpaca is a close relative of the llama; it inhabits the same regions of South America. The animal has a soft fleece that may grow to a length of 60cm (24 in) if left uncut.

Alpaca fleece is strong, with an attractive glossy appearance when spun and woven into fabrics. It is generally finer than mohair but not so shiny.

Alpaca

Alpaca has become an important article of commerce and the alpaca is now the most valuable of the fleece-bearing animals of the Andes regions. It provides much more and rather finer fibres than the llama.

The fleece colour is normally black, brown, fawn or white. The scales on the surface of the fibre are indistinct. The cortical layer is striated and there is rarely any medulla.

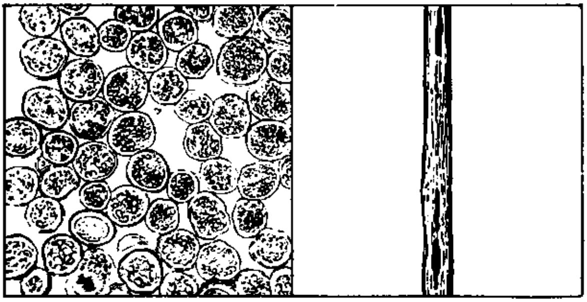
Alpaca is made into dress fabrics, linings, plushes and tropical suitings.

HUARIZO WOOL

The huarizo is a cross between the llama and the alpaca. Its fleece has a fine soft undercoat of lustrous fibes which are made into fabrics of first-rate quality. The outer hair covering is used for ropes and twine.

VICUNA

In Peru, there is a small species of llama called the vicuna, which provides a supremely fine fibre.



Vicuna

The vicuna runs wild in the Andes regions in Peru, and attempts at large-scale domestication have so far been unsuccessful. It is likely, however, that the vicuna will be domesticated in due course and vicuna fibres will become more plentiful. At present, the animal is shot for its fleece, which weighs only about 0.45kg (1 lb). The production of vicuna in Peru amounts to only a few thousand kilograms per year. The Peruvian government allows only a limited number of vicunas to be killed annually; there is little prospect of any increase in supplies until the animal has been domesticated successfully.

Vicuna fibre is generally regarded as being the finest and rarest wool-like fibre in the world. Its natural colour is white, fawn or brown, and garments made from it are usually left undyed. The fibres are about 5cm (2 in) long.

Vicuna fibres are only about half the diameter of fine wool fibres. The surface scales are regularly spaced and can be seen distinctly. The cortical layer is striated and there is rarely any medulla.

Vicuna wool is extremely expensive; it is made into superfine quality dressing gowns, coating materials and shawls.

GUANACO

The guanaco is a llama-like animal that roams wild over a large area of South America. It yields a wool that is similar to vicuna, but not so fine. It lies between vicuna and alpaca, with an average fibre diameter of about 20μ.

GENERAL PROPERTIES OF LLAMA-TYPE FIBRES

The llama, alpaca, huarizo, guanaco and vicuna animals are all related species, and their fibres are of a similar general type. They resemble the other hair fibres chemically and they behave accordingly towards processing liquors, bleaching and scouring agents, etc.

The llama-type fibres usually contain about 3 per cent of natural grease, with a total content of foreign matter amounting to perhaps 20 per cent.

The fibres are generally stronger than wool of comparable fineness. Their average diameters are as follows:

Llama	20–27μ
Alpaca	26–27μ
Huarizo	26μ
Vicuna	13μ

Llama, alpaca and huarizo can be compared with 55s to 60s wool, and vicuna with 120s or 130s wool (which are extremely rare qualities).

The surface scales of llama-type fibres are often difficult to detect under the microscope. The cortical layers are generally striated and filled with pigment granules in the case of coloured wools. There is usually a well-defined and unbroken medulla.

Llama-type fibres do not felt readily.

FUR FIBRES

The fur of animals such as the rabbit has long been used as textile fibre. There are two types of fur fibre; an outer coat of long, spiky fibres acts as a protective covering for an inner coat of soft, fine fibres which keeps the animal warm.

Angora rabbit-hair (often described erroneously as 'angora wool') has been in widespread use in European countries for a century or more.

The rabbits are clipped every three months; the fibres are 7.5cm (3 in) long. The outer 'guard hairs' are separated from the fine fur by blowing the fibres in a stream of air. Both hair and fine fur are used for making textiles, the former giving strength and beauty to the fabric and latter warmth and softness. The two types of fibre are mixed in such proportions as to provide the desired effect.

Other breeds of rabbits, including the wild rabbits that have become such a pest in Australia, are also used as a source of fur fibres. Much of the supply of rabbit fibre is used for making felts. The fibres are felted together without being spun or woven.

STRUCTURE AND PROPERTIES

The dimensions of rabbit fibres vary over a wide range. In general, the fine fibres are less than 20mm (¾ in), whereas the guard hairs may reach a length of several centimetres.

Seen in cross-section, the fine fur fibres are round, oval or rectangular. The coarser guard hairs are often dumb-bell shaped, or in the form of a sharp-edged oval.

The scales on the surface of fine fur fibres are fairly uniform in shape. They often extend half-way round the fibre.

Scales on the guard hairs have serrated edges, and the edges often run slantwise across the fibre.

Both types of fibre have thick medullas, which contain many pockets of air.

Chemical Properties

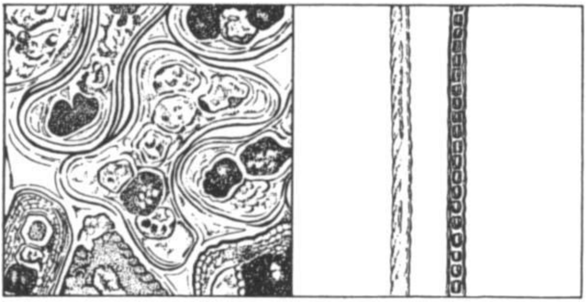
The keratin of fur fibres is probably a mixture of several closely related proteins. The chemical behaviour of these fibres is generally similar to that of wool and other animal fibres.

Water is absorbed less readily by rabbit fibres than it is by wool. Hot water tends to soften or plasticize the fibres. Alkalis dissolve fur fibres.

FUR FIBRES IN USE

Rabbit hair and fur are used very largely for making felts and for knitted goods such as cardigans, gloves and berets. For knitted goods they are usually blended with wool before spinning.

Rabbit fibre fabrics have an attractive appearance and a soft luxurious handle. They wash like wool, and tend to felt very easily. This property is made use of in the manufacture of 'felts'.



Rabbit Hair

SILK

Like wool, silk is an animal fibre. But instead of being grown in the form of hair, it is produced by insects as a handy material with which to build their webs, cocoons and climbing ropes.

Almost the entire commercial silk industry is based on one insect – the silkworm. In spite of its name, this is really a caterpillar; the silk is made by it when it wants to change into a chrysalis and then a moth. It spins the silk and wraps the fibre round itself in the form of a cocoon inside which it can settle down in comfort.

According to Chinese legend, silk culture dates back to the year 2640 B.C., when the Empress Si-Ling-Chi learned how to rear the caterpillars and unwind the cocoons that they made. The Empress devoted herself personally to rearing the worm, and it was largely through her encouragement that the silk industry became established in China.

For three thousand years China held a monopoly in the silk industry. Then sericulture – as silk production is called – spread to Japan via Korea. An ancient Japanese book – *Nihongi* – describes how in A.D. 300 a number of Koreans were sent from Japan to China to engage people experienced in the weaving and finishing of silk cloth. Four Chinese girls were brought back, and they instructed the court in the art of plain and figured weaving. The Japanese erected a temple to their honour in the province of Settsu.

Gradually, silk production spread westwards over Asia. Many tales are told of the ways in which the eggs of the silkworm and the seeds of the mulberry tree on which it fed were smuggled from one country to another. According to legend, they were carried to India by a princess who concealed them in her head-dress.

Between the Ganges and the Brahmaputra the Indian silk industry soon became established. From India, sericulture moved west again to Persia and the countries of the Mediterranean. Aristotle gives us our first description of the silkworm as 'a great worm which has horns and so differs from others. At its first metamorphosis it produces a caterpillar, then a bombylius and lastly a chrysalis – all these are changes taking place within six months. Then, from this animal, women separate and reel off the cocoons and afterwards spin them. It is said that this was first spun on the island of Cos by Pamphile, daughter of Plates.'

In this, Aristotle was probably incorrect, as raw silk was imported into Cos and woven some time earlier than this. The gauzy tissue that was made – *Coa vestis* – was notorious for its lack of covering power.

By the beginning of the Christian era, silk became one of the most coveted of all the treasures from the east; it was a royal cloth. The Emperor Justinian even monopolized the silk trade for himself, and looms were set up in the palace at Constantinople. Justinian learned of two monks who had lived in China and knew the art of sericulture. In A.D. 555 he persuaded them to return to China and bring back a supply of eggs from which a silk industry could start. The two monks made the journey and returned with silkworm eggs inside a hollow bamboo cane. From these eggs came the silkworms which established an industry in Europe that has lasted over a thousand years.

European Industry

By the eighth century, sericulture had been carried by the Moors to Spain and Sicily, and from there it spread to Italy and France. Florence, Milan, Genoa and Venice were all famous for their silks in mediaeval times. Silk weaving began at Tours in France in 1480; then in 1520, Francis I brought eggs from Italy and reared silkworms in the Rhône Valley.

During the reign of Edward III, the silk industry reached England. By the sixteenth century, silk was in widespread use among the wealthy nobility. Queen Elizabeth I wore silk stockings.

During the reign of James I (1603–25), silk workers from Italy were attracted to England in an effort to encourage the silk industry. In 1681, Charles II offered a grant of naturalization to weavers from the Continent, and in 1685 the revocation of the Edict of Nantes brought skilled French Huguenot weavers to England in their hundreds. During the twenty years 1670–90, some 75,000 immigrants were admitted into England. Many of them settled in the Spitalfields district of London; others went to Southampton, Bristol, Norwich, Canterbury and Sandwich.

By 1718 the first silk-throwing* mill in England was brought into operation at Derby. During the early part of the eighteenth century, other mills opened up at Congleton, Stockport and Macclesfield.

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* 'Throwing' is a term that describes the twisting of long filaments of silk into a yarn. It is comparable with the 'spinning' of short fibres into yarn.

Since then, silk-throwing and weaving have been carried out continuously in Britain.

Silk in America

James I's efforts met with some success in 1619. Silk culture was encouraged by bounties; in their enthusiasm for sericulture the Virginians even expressed themselves in rhyme:

> 'Where worms and food do naturally abound,
> A gallant Silken Trade must there be found.
> Virginia excels the world in both –
> Envie nor malice can gainesay this troth.'

In 1622, James I sent instructions to his colonists in America that 'they should apply themselves diligently and promptly to the breeding of silk worms, bestowing their labours rather in producing this rich commodity than to the growth of that pernicious and offensive weed, tobacco'. But James's efforts failed; 'despite the royal countenance the attempt was never attended by even partial success.'

Since then many efforts have been made to establish a silk industry in America. The high spot of the industry was in 1838, when a speculation fever gripped America. The South Sea Island mulberry, it was said, was especially suitable for feeding silkworms. Mulberry plantations sprang up like mushrooms overnight and America prepared to go in for silk growing in a big way. Young mulberry trees sold for many times their normal price, and speculators cashed in on the eagerness with which money was offered for anything to do with silk.

In 1839 the whole thing collapsed and the plantations were uprooted. By this time it was becoming apparent that silk cultivation was an economic proposition when plenty of cheap labour was available. Japan, China, India, Italy – these were the places where the necessary conditions prevailed. And it is in these countries that silk production has become important.

Japanese Supremacy

Before World War II, Japan was the world's leading silk producer – a position she established for herself in little more than half a century. After 1885, Japanese sericulture began on a big scale. During the fifteen years between 1892 and 1907 the output doubled; by 1930 it had become seven times that of 1892. The Japanese have devoted a great deal of study and intensive work to silk culture, and their success was largely due to the scientific approach they made to the many problems set by a unique industry.

During the present century, the silk-production industry has experienced severe setbacks. Viscose rayon took over much of the silk market during World War I, and had established itself when silk became available again after the war. During the 1920s and 1930s silk held its ground, particularly in the American hosiery trade. During World War II, however, nylon captured the ladies' stockings trade. Most of the silk producing countries were involved in the war; production in Japan, for example, was almost at a standstill.

Since the end of World War II, Japan, China, India, Bulgaria, Italy, France, Mexico, Turkey and other silk-producing countries have made great efforts to re-establish their position in the world's textile industry. But with new synthetic fibres joining nylon in the quality fabrics field it has proved an uphill task.

PRODUCTION AND PROCESSING

The silkworm is the caterpillar of a small off-white moth belonging to the species *Bombyx mori*. It lives on one thing only – the leaves of the mulberry tree. First essential for a silk industry, therefore, is an adequate supply of mulberry leaves – and the quantities needed are prodigious, for the silkworm spends its life doing little else but eat.

In Europe, silkworms are fed largely on the white-fruited mulberry, though other species are suitable. Much depends on the conditions under which the mulberries are grown, for this determines whether the leaves will be suitable for the worms.

Rearing of the silkworms starts as soon as leaves begin to appear on the mulberry trees. Eggs that have been laid by the moth and stored in a cool place during the winter are warmed up to encourage them to begin hatching. In large, scientifically-run farms, warming is done artificially; but where silk production is a part of peasant economy, as in many regions of China, the eggs are warmed by contact with the human body.

Hatching

After a few days the eggs hatch out to tiny caterpillars less than 3mm ($^1/_8$ in) long. 28g (1 oz) of eggs yields as many as 36,000 silkworms.

Every effort is made to get the eggs to hatch out in batches at the same time, as the economy of silk production depends largely on this; the worms will sleep and eat and spin at roughly the same time. Hatching is normally done by spreading the eggs over trays in the hatching shed. When the worms appear, perforated paper is placed over them and a supply of chopped mulberry leaves is spread on the paper. The worms climb through the holes and set to work on the leaves; dirt and egg-residues are left behind.

Moulting

During this stage the silkworms do nothing but eat, except for four periods of sleep lasting a day at a time, during which they shed their skins and grow new ones. Mulberry leaves are the sole diet. And they must be just right or the silkworm will refuse to eat them. They must be fresh and slightly wilted – but not faded.

After its fourth moult, the silkworm settles down to a final feed lasting approximately ten days, during which it eats twenty times its own weight of leaves. About thirty-five days have passed since it was hatched, and the worm is ten thousand times as heavy as when it was born. It is over 76mm (3 in) long and weighs about 7g (¼ oz). It has become a huge bloated greenish-white caterpillar filled with liquid silk, and is ready to start spinning. Rearing up on its hind legs, the silkworm weaves about looking for somewhere to settle down and build its cocoon. Bundles of straw are put on to the trays where the worms have been feeding, and those that are ready to spin climb ponderously up into the straw and begin to make their cocoons.

Spinning the Cocoon

The liquid silk is contained in two glands inside the silkworm. From these glands it flows in two channels to a common exit tube, called the spinneret, in the silkworm's head. As it emerges, the liquid silk hardens into very fine filaments and these are coated and stuck together by a gummy substance called sericin which comes from two other glands nearby.

The silk used by the worm, therefore, is really a twin filament held together as a single strand by the sericin cement. As the silk exudes, the silk worm moves its head backwards and forwards in a figure 8 movement. Gradually, it surrounds itself with a strongly built cocoon made from a continuous silk strand that may be up to 1.6km (1 mile) in length.

Spinning usually takes two or three days, during which time the silkworm has shrunk to a mere vestige of its original silk-bloated self. Inside its cocoon it begins to change into a chrysalis or pupa and then into a moth. On the silk-farm, the crysalis must be killed before this happens. For the moth escapes from the cocoon by secreting a fluid that dissolves away a section of the cocoon to make a hole through which it can crawl out. The continuous silk filament is thus broken up into thousands of short pieces which are useless for reeling. So within a few days of making its cocoon, the crysalis is killed by heating or stifling. It is baked in the sun or in an oven, or stifled in hot air or steam. The cocoon can then be kept indefinitely without damage until it is wanted for reeling.

Egg Production

From 28g (1 oz) of eggs, the rearer gets up to 63kg (140 lb) of cocoons. These yield some 5.5kg (12 lb) of raw silk. To produce it, the worms consume a ton of mulberry leaves. In many countries it is forbidden for silkworm rearers to provide themselves with eggs from their own moths. This is essential to control the many serious diseases to which the worm is prone. Egg production is thus an entirely separate branch of the industry and is carried out under rigorously controlled conditions.

The moths emerge from their cocoons as small greyish-white insects with rudimentary wings. They cannot fly; they have no mouths and cannot eat. The sole job in life of the silkworm moth is to mate and lay its batch of 350–400 eggs.

In order to check and control the health and vitality of the worms for spinning, each moth, after mating, is put into a linen bag 50mm (2 in) square. This has previously been cleaned and disinfected. After its eggs have been laid, the moth dies. Its body is examined microscopically, and if germs are present the bag and its contents are burned. In addition, some of the eggs – or 'seeds' as they are called by the rearers – are crushed and examined. It they are germ-free the eggs are passed for hatching.

Pests and Diseases

This careful control of silkworm eggs has been made necessary by the susceptibility of the silkworms to a number of epidemic diseases. For more than four thousand years the silkworm has been living an artificial life, and it has become as delicate as a hot-house plant.

A hereditary disease called *pébrine* is caused by a Protozoan parasite (*Nosema bombycis*). Infection of the silkworm causes black spots on the skin, and development of the insect is slowed.

Flacherie is a disease which may be due to digestive disorder or to an infective organism. It causes a swelling and blackening of the insect's body. It is not inherited.

Grasserie is a virus disease. The worms become yellow and bloated. They are filled with small crystals.

Muscardine is a fungus disease which kills the worm quickly. The silkworm's body is white and covered with spores. This is the most contagious of all silkworm diseases.

In hot countries, silkworms are attacked by a tachina fly (*Tricholyga sorbillaria*) which lays her eggs on the insect's body. As the eggs hatch, the maggots eat their way into the silkworm. They may emerge when the cocoon has been spun, eating through the silk and breaking the continuous filament into smaller lengths.

Pébrine

Worst of all the silkworm diseases is that known as pébrine. This first became serious at Cavaillon in France in 1850. It was extremely infectious and contagious and spread rapidly through the French silkworm industry. Within a year or two, France was having to import eggs from other countries to keep her silk industry going. But as the disease spread, production fell rapidly. In 1853 France produced 26 million kilos of cocoons; by 1865 this had fallen to 4 million. From France, pébrine spread to the silk industry of Italy, and within thirteen years of its occurrence the disease had resulted in a total loss of 120 million pounds to the silk trade in this area of Europe.

Gradually, pébrine spread to Asia and the Far East, until only Japan remained unaffected. But it proved less fatal in this part of the world; the life of the worms was more natural in these warmer countries, and they were more resistant to the disease.

To France, the pébrine epidemic was disastrous; but to the world it was to prove a blessing in a strange disguise. For it was through his investigation of pébrine that Louis Pasteur arrived at his germ theory of disease. Pasteur, in 1865, undertook a Government investigation of pébrine. He found that the disease was always accompanied by some sort of living corpuscles inside the body of the silkworm. These had been noticed before, but their direct connection with disease had not been suspected.

Pasteur found that the corpuscles – or germs as we now call them – were a characteristic of diseased worms. They were parasites living inside the body, and it was by transmission of such germs that the disease was spread.

Once the identification of these germs as the cause of the disease had been established, the way was open to control. Pasteur recommended that the stock from which eggs were hatched should be examined and strictly supervised. Any moth or eggs showing signs of germs should be destroyed, and every precaution must be observed to see that silkworm rearing was carried out cleanly and scientifically.

In this way, pébrine was brought gradually under control, and in many countries the silkworm industry today is run on hygienic and scientific lines that would do credit to a hospital.

Wild Silk

Although the domesticated silkworm *Bombyx mori* is the mainstay of the silk industry, there is a considerable trade in some countries in silk produced by silkworms living 'wild'. Most important of these wild silks is that which is known as Tussah ('Tussur', tussore).

Tussah Silk

Tussah silk is the product of several species of silkworm of the genus *Antheraea* – particularly *A. mylitta,* indigenous to India and *A. pernyi* which is native to China. These worms feed almost exclusively on the oak *Quercus serrata.*

Despite the fact that different species of worm produce Tussah silk, the cocoons are sufficiently alike for the silk to be regarded as a reasonably homogeneous material. The silk is affected more by the climatic conditions and the environment in which it has been produced than by the species of silkworm that produced it.

The tussah silkworm differs considerably in appearance and habits from *Bombyx mori.* It is usually larger, and may be 15cm (6 in) or more. It is a greener colour and is covered with tufts of gingerish hair.

The tussah silkworm lives an outdoor life, feeding on the leaves of dwarf oak trees. Crops of cocoons are produced twice a year, in the spring and autumn. The latter is the most important as a source of silk; the spring crop provides the worms that make the autumn cocoons.

Tussah silk production is an important peasant industry in northern China and Manchuria, and in parts of India. Manchurian cocoons are generally heavier than those from the Shantung region of China, and Manchurian silk is darker in colour. It has been estimated that $4 \times 10^3 m^2$ (1 acre) of oak trees can support 60,000 cocoons; this is equivalent to about 360kg (800 lb) of raw silk.

The tussah silkworm leaves one end of its cocoon open, sealing the hole with a layer of sericin gum before settling down to its metamorphosis. When the moth wishes to emerge from the cocoon, it breaks through the sericin wall without damaging the continuous silk filament from which the cocoon has been made. Tussah silk cocoons are not necessarily treated, therefore, to kill the chrysalis before the silk is reeled.

Other Wild Silks

Although tussah silk is the most important wild silk in commercial use, there are other types of wild silk produced by caterpillars of different species in many parts of the world. In Japan, *Antheraea yama-mai* produces a silk that was at one time reserved for royal use. It feeds on oak leaves.

Attacus ricini provides a high-quality white silk; it is found in both the American and Asian continents. It feeds on the castor oil plant.

In Africa there is a silkworm of the Anaphe family which feeds on fig leaves. Groups of these caterpillars will build large nests inside which they make their individual cocoons. The nests and cocoons are made entirely from silk. This type of wild silk is collected in considerable quantities in Uganda and Nigeria, and used for making native fabrics.

In India, *Antheraea mylitta* and *Antheraea assama* are important silk-producing caterpillars. They make cocoons often more than 5cm (2 in) long. *A. mylitta* feeds on the bher tree, *Zizyphus jujuba.*

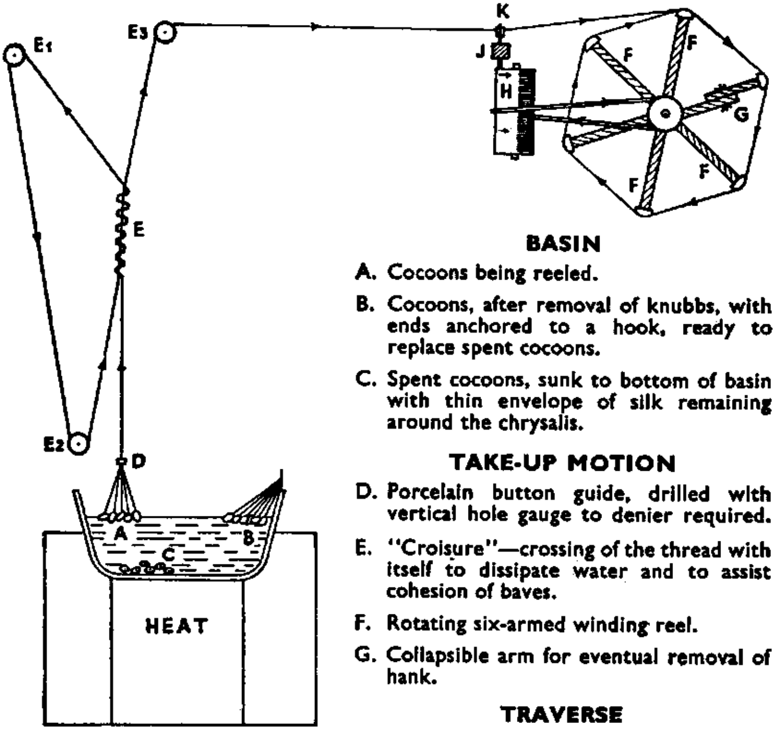
Reeling and Throwing

Vegetable fibres such as cotton, and hair fibres such as wool have one thing in common; they are produced in relatively short lengths. Cotton and wool fibres are usually a few centimetres long; even flax, which is one of the longest of the vegetable textile fibres, is only about 60cm (2 ft). In order to convert these short fibres into long threads or yarns, we have to align the fibres and then 'spin' them by twisting the fibres together. In this way, innumerable short fibres are made to grip one another to form a thread or yarn that is long enough to be used for weaving purposes.

Silk, however, is quite different from these other natural fibres; the silkworm makes its cocoon from a twin filament that is extruded from its spinneret in a continuous strand. This filament may be as much as 1.6km (1 mile) in length.

The production of a 'thread' or 'yarn' of silk suitable for weaving

ELEMENTARY PRINCIPLES OF RAW SILK REELING



BASIN

A. Cocoons being reeled.

B. Cocoons, after removal of knubbs, with ends anchored to a hook, ready to replace spent cocoons.

C. Spent cocoons, sunk to bottom of basin with thin envelope of silk remaining around the chrysalis.

TAKE-UP MOTION

D. Porcelain button guide, drilled with vertical hole gauge to denier required.

E. "Croisure"—crossing of the thread with itself to dissipate water and to assist cohesion of baves.

F. Rotating six-armed winding reel.

G. Collapsible arm for eventual removal of hank.

TRAVERSE

H. Drum rotated by belt from winding reel.

J. End of sliding rod, pinned eccentrically to drum top, causing to and fro movement across the direction of the thread.

K. Guide eye, set on sliding rod, to spread the ends and so give width to the hank.

Courtesy: P. W. Gaddum

is therefore a process different from that which is used in the case of shorter fibres. All that is necessary, in principle, is to unwind the long continuous filaments from the cocoons and then twist a number of these together to form a thread of useful thickness.

The unwinding of the fine silk filaments from the cocoons is called reeling, and the process is carried out in a building called a filature. The cocoons are soaked in hot water to soften the sericin gum that is cementing the filament in place. A revolving brush is then used to find the end of the filament – a difficult job with something so fine that it is almost invisible.

When the end of the filament has been picked up, it is drawn through a guide along with the filaments from several other cocoons. The filaments may be given a slight twist to hold them together and are reeled steadily off the cocoons which are left floating in hot water to keep the gum softened.

Tussah cocoons are gummed more firmly than those of cultivated silk, and contain more calcium salts. They are usually soaked in sodium carbonate before reeling.

Reeling requires great skill, as the operator must produce a uniform thread by combining the silk filaments in suitable fashion. Each filament is narrower towards the beginning and the end than it is in the middle, and the reeler must join the filaments in such a way as to allow for this variation in width. The actual size of the threads produced is denoted by weighing a certain length in half decigrams. This is called the denier of the silk.

Silk is wound up by the reeler in the form of skeins. These are made up into bundles of about 2.7kg (6 lb), called 'books'. These are then packed into bales for shipment.

When the raw silk arrives at the manufacturing centre, it is in the form of continuous strands in which the individual filaments are cemented together by the sericin. Silk may, for some purposes, be woven without further preparation. Usually, however, two or three of these multi-filament strands are twisted together to form heavier threads; this process is called 'throwing' from the Anglo-Saxon word 'thrawan' meaning to whirl or spin.

Degumming

The natural gum, sericin, is normally left on the silk during reeling, throwing and weaving. It acts as a size which protects the fibres from mechanical injury. The gum is removed from the finished yarns or fabrics, usually by boiling with soap and water.

Silk fabrics woven with the sericin still on the yarn have a characteristic stiffness of handle; they are also dull in appearance. After degumming, the silk acquires its beautiful lustre.

As much as one-third of the weight of the fabric may be lost when the gum is removed in this way.

Raw silk with the gum still on the filaments is called 'hard silk'. Degummed silk is 'soft silk'.

Foulard fabric, georgette, chiffon and crêpe de chine are woven from hard silk which is afterwards degummed.

Types of Thrown Yarn

There are a number of different types of thrown yarn, which are described by the manufacturer as follows:

TRAM. This is a lightly-twisted thread formed by twisting two or three strands of silk together. Low twist tram will have only two or three twists to the inch (2.5cm); high-twist tram may have 12–20 twists to the inch (2.5cm).

Tram is moderately strong; it is soft and has a full handle. Tram yarns are used as weft in woven fabrics.

ORGANZINE. This is a very strong yarn made from high-quality silk. Two or more strands are each twisted and the compound thread then twisted in the opposite direction, from about 9–30 turns to the inch (2.5cm). Organzine is used mainly as warp in a woven fabric.

CRÊPE. These are yarns with a very high twist, as many as 30–70 to the inch (2.5cm). They are used for crêpe fabrics and chiffon, and for knitting to hosiery.

GRENADINE. This is a tightly-twisted yarn, in which two or three twisted strands are combined and twisted in the opposite direction. It is twisted more tightly than organzine.

Grenadine yarns have extra good weaving qualities and a delustred appearance. They are used for high-quality silk hose.

COMPENZINE. This yarn is made from two tightly twisted yarns and one untwisted yarn. When these are twisted together, about five turns to the inch (2.5cm), the untwisted yarn crinkles up, giving the 'knobbly' appearance characteristic of crêpe threads.

SEWING SILKS. These are tightly-twisted strong yarns. They are made by twisting two or three silk strands together and then combining several of the resulting threads by twisting in the opposite direction.

EMBROIDERY SILKS are often simple untwisted strands united by a slight twist.

Silk Wastes

Although the silkworm spins its cocoon from a continuous filament of silk, the throwster is fortunate if he can make use of half of the available silk in filament form. The rest of the silk is unsuitable for reeling, and is known as 'waste silk'.

This waste silk is much too valuable to throw away, and it is used for making the yarns we know as 'spun silk'.

Waste silk consists of the silk brushed from the outside of the cocoon during reeling, the unusable inner portions of the cocoon, broken filaments from damaged cocoons such as those from which the moth has been allowed to emerge, and waste material from the reeling and throwing generally. It is packed into bales, and arrives at the spinning mill as a mass of filaments of different lengths, contaminated with dirt and straw.

The waste silk is cleaned and degummed in one of two ways. In the *English process* of degumming, the gum is removed by boiling the silk in soapy water. This dissolves the sericin and leaves a clean, smooth filament. The *Continental process* uses a fermentation technique, and about 20 per cent of the gum remains on the silk. Waste silk degummed in this way is called 'chappe' or 'schappe' silk; it is used for making velvet.

After degumming, the silk filaments are subjected to processes similar to those used for wool and other short-staple fibres. The silk is opened and loosened in a machine that delivers it in the form of a gauze-like blanket or lap. The fibres are then combed and sorted into length-groups, and then drawn into rovings and spun by twisting so that the short fibres hold tightly together.

Spun silk yarns are used for making scarves, ties, velvets and pile fabrics, woven dress materials, knitted goods, lace, shirts and a variety of union fabrics.

Silk Counts

NETT SILK (Filament yarn). The fineness of a silk yarn is denoted by its 'denier'. This is the weight in grams of 9,000 metres of the yarn. The lower the denier, therefore, the finer is the silk.

SPUN SILK. Spun silk yarns are defined by counts in the same way as cotton yarns. The count is the number of hanks, each 840 yards (756m) long, that will weigh 1 lb (454g).

Dyeing

Silk is dyed very largely in the form of hanks or woven pieces. There is an immense range of dyestuffs available for use with silk; almost every class of dyestuff used for cotton or wool can be used for dyeing silk. In general, the dyestuffs are applied by techniques similar to those used for wool or cotton.

Spider Silk

The silken filaments spun by spiders are so fine that they can often be seen only with difficulty. The golden garden spider spins a filament only 0.00001 in (0.00025mm) in diameter.

Many attempts have been made to use spider silk as a textile fibre. More than 200 years ago, a Monsieur Bon of Languedoc in France collected enough silk from spider cocoons to spin into a yarn. He made silk stockings and gloves from the fine grey silk and exhibited these at the Academy of Science in Paris in 1710.

Great excitement was aroused in France and M. Bon was loaded with honours. René Réaumur, the famous physicist, was commissioned to examine the feasibility of setting up a spider silk industry. But in spite of his initial enthusiasm, Réaumur concluded that the difficulties would be too great. The spiders were temperamental and unco-operative; they became excited and resented the food they received so much that they ate each other instead. Such silk as they produced was delicate and extremely difficult to spin.

In 1864, Dr. Wilder, an American army surgeon stationed in South Carolina revived the idea of using spider silk for textiles. He found that instead of waiting for the spiders to spin their cocoons he could 'milk' the silk artificially from the spider. A pair of stockings made from this spider silk cost over 100 dollars. They represented the life's work of nearly 500 spiders, and the stockings were so sheer that they were of little practical value.

Since then, attempts have been made in other parts of the world to domesticate the spider and relieve it of its silk. A 2½ in (6.35cm) spider living in Madagascar has been used. 'Milked' of its silk by native girls five or six times a month, it yields about 3.2km (2 miles) of filament and then dies.

A fabric of spider silk, 18 yd (16m) long and 18 in (45cm) wide was shown at the Paris Exposition in 1900. It contained 100,000 yd (90km) of thread containing 24 strands – the work of more than 25,000 spiders.

Today, we have virtually given up the attempt to use spider silk in textiles. It still finds an important outlet for making 'crosswires' in optical instruments. The silk is uniform and strong, and withstands changes in humidity and temperature. Spider silks used in this way have often outlasted the life of the optical instrument, remaining unchanged after half a century or more.

STRUCTURE AND PROPERTIES

Fine Structure and Appearance

The raw silk strand from which a cocoon is built consists of two fine filaments cemented together by sericin gum. Seen under the microscope, raw silk has a rough and irregular surface, and it is marked by lumps, folds and cracks in the sericin layer. Often, the twin filaments of silk are separated for considerable distances, each with its own coating of sericin.

Seen in cross-section, the strand of cocoon silk is of irregular shape. It is roughly oval with average diam. of 0.178mm (0.007 in). The individual filaments (brins) can be distinguished inside the sericin coating. They are triangular in cross-section, with rounded angles. Usually, the filaments lie with one flat side of each facing the other.

The degummed filaments are smooth-surfaced and semi-transparent. The diameter fluctuates from place to place, averaging 0.0127mm (0.0005 in). The filaments become thinner towards the inside of the cocoon.

In the raw state, silk varies in colour from cream to yellow. Most of this colour lies in the sericin gum, and is lost when the filaments are degummed. The silky sheen develops after degumming.

Wild Silk

There is naturally much more variation in the physical properties of wild silk than there is in cultivated silk. Colour, for example, may be yellow, grey, brown or green.

Seen under the microscope, wild silk may be distinguished from cultivated silk by its irregular width. It is also marked by longitudinal striations and tends to have flattened areas on which are transverse markings. These flattened areas are caused by filaments pressing against one another in the cocoon before the material of the silk has hardened.

Treatment of the wild silk filament with chromic acid will disintegrate it into a bunch of finer filaments, fibrils or micelles about $1{\cdot}0\mu$ in diameter.

The same effect can be obtained by severe mechanical or chemical treatment of cultivated silk, in which the fibrils are more closely compacted.

Seen in cross-section, the twin filaments in wild silks are wedge-shaped, with the short bases facing one another. The cut section of the filament is dotted with markings corresponding to the striations running lengthwise through the filament. These mark the boundaries between the fibrils, which are less closely held together than in cultivated silk.

Tensile Strength

Silk is a strong fibre. It has a tenacity usually of 30.9–44.1 cN/tex (3.5–5.0 g/den). Wet strength is 75–85 per cent of the dry strength.

Elongation

Silk filaments have an elongation at break of 20–25 per cent under normal conditions. At 100 per cent R.H. the extension at break is 33 per cent.

Elastic Properties

The elastic recovery of silk after spinning is not so good as that of wool, but is superior to that of cotton or rayon. Once it has stretched by about 2 per cent of its original length, silk tends to remain permanently stretched. There is a slow elastic recovery or creep after extension, but the silk does not regain its original length.

Elastic recovery from	*Japanese*	*Tussah*
50 per cent breaking load:	0.56	0.40
50 per cent breaking extension:	0.38	0.41
Work of rupture (cN/tex):	5.98	7.46
Initial modulus (cN/tex):	735.8	490.5

Specific Gravity

Degummed silk is less dense than cotton, flax, rayon or wool. It has a specific gravity of 1·25. Silk fabrics are often weighted by allowing the filaments to absorb heavy metallic salts; this increases the density of the material and affects its draping properties.

Effects of Moisture

Like wool, silk absorbs moisture readily. It can take up a third of its weight of water without feeling wet to the touch. Silk has a regain of 11·0 per cent.

If there are salts or impurities in the water, silk tends to absorb them too. Hard water, therefore, will contaminate silk. Degummed silk will swell as it takes up moisture; the extent of the swelling depends upon the relative humidity of the atmosphere. At 100 per cent R. H., silk absorbs 35 per cent of its weight of water and increases in cross-sectional area by 46 per cent (from 65 per cent R.H.).

Effect of Heat

Silk will withstand higher temperatures than wool without decomposing. Heated at 140°C. it will remain unaffected for prolonged periods. It decomposes quickly at 175°C.

Silk burns, emitting a characteristic smell like that of burning hair or horn.

Effect of Age

Silk is attacked by atmospheric oxygen, and may suffer a gradual loss of strength if not carefully stored.

Effect of Sunlight

Sunlight tends to encourage the decomposition of silk by atmospheric oxygen.

Chemical Properties

The strands of raw silk as they are unwound from the cocoon consist of the two silk filaments mixed with sericin and other materials. About 75 per cent of the strand is silk and 23 per cent is sericin; the remaining material consists of fat and wax (1·5 per cent) and mineral salts (0·5 per cent).

As would be expected in a fibre of animal origin, silk is a protein. The filament itself is the protein fibroin; it is similar in composition to the sericin protein, despite the differences in physical behaviour between the two materials.

Silk fibroin differs fundamentally from the keratin from which animal hair fibres are made. The fibroin molecule contains only carbon, hydrogen, nitrogen and oxygen; there is no sulphur in it.

Silk does not dissolve in water, and it withstands the effects of boiling water better than wool. Prolonged boiling tends to cause a loss of strength.

Silk will readily absorb certain salts from their solutions in water; aluminium, iron and tin salts, for example, are used for 'weighting' silk fabrics in this way.

Silk dissolves in solutions of zinc chloride, calcium chloride, alkali thiocyanates and ammoniacal solutions of copper or nickel. Silk fibroin is attacked by oxidizing agents; bleaches such as hydrogen peroxide must be used with care. Hypochlorite bleaches must never be used, as they rapidly tender silk.

Effect of Acids

Like wool keratin, the fibroin of silk can be decomposed by strong acids into its constituent amino acids. In moderate concentration, acids cause a contraction in silk; this shrinkage is used to bring about crêpe effects in silk fabrics.

Dilute acids do not attack silk under mild conditions. Organic acids are used for producing the scroop of silk, which may be due to the surface-hardening of the filaments. Acids are readily absorbed into silk filaments, and are not easily removed.

Effect of Alkalis

Silk is less readily damaged by alkali than is wool. Tussah silk is particularly resistant. Weak alkalis such as soap, borax and ammonia cause little appreciable damage. More concentrated solutions of caustic alkalis will destroy the lustre and cause loss of strength.

Silk dissolves in solutions of concentrated caustic alkali.

Effect of Organic Solvents

Silk is insoluble in the dry-cleaning solvents in common use.

Electrical Properties

Silk is a poor conductor of electricity, and tends to acquire a static charge when it is handled. This causes difficulties during manufacture, particularly in a dry atmosphere, but is of value for insulating materials in the electrical trade.

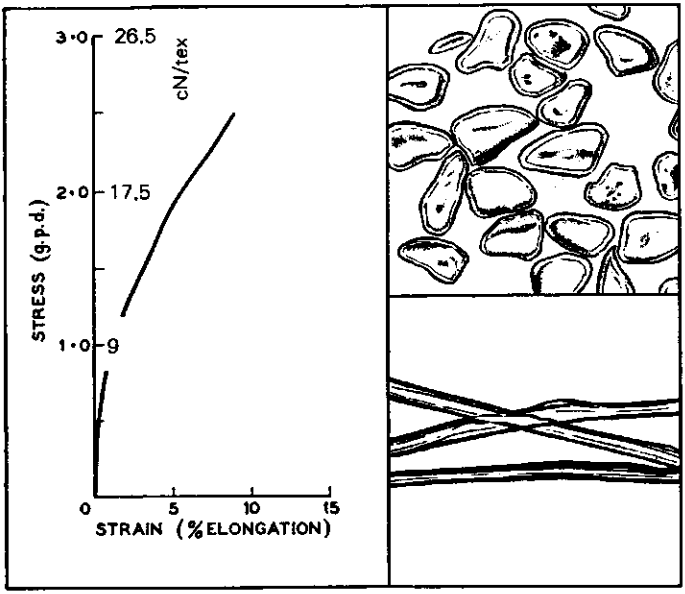
Other Properties

Raw silk has a rough handle; it acquires its smooth 'silky' feel only when the gum has been removed.

The peculiar noise or 'scroop' made by silk when it is crushed is not an inherent property of the fibre. It is given to the silk by treatment with dilute acids, possibly through a surface-hardening effect. Scroop is not a sign of quality, as is commonly supposed.

SILK IN USE

For thousands of years, silk has reigned as the queen of fibres. It is expensive, tedious to produce and subject to all the hazards inevitable in an industry whose assembly line is a living thing. Yet until a few years ago, silk has been unchallenged in its position as the most desirable of all textile fibres.



Silk

The combination of properties that has made this possible is all the more amazing in that the fibre is manufactured by the larva of an insignificant moth.

Silk combines a high strength and flexibility with good moisture absorption, softness and warmth, excellent wearability and a luxurious appearance.

Silk is so versatile that it is woven and knitted into a wide variety of fabrics; it provides all manner of materials from the sheerest chiffon to the richest of heavy pile velvets. Silk is cool and comfortable in underwear or summer clothes; it is hard-wearing and easy to clean in dresses and sturdy suitings. The smooth-surfaced filaments from which silk fabrics are made do not hold on to dirt.

Laundering

Despite its resistance to wear, silk is a delicate fabric. The filament of silk is fine and easily torn. It can be damaged by chemical action, and must be washed with care. Human perspiration can degrade the fibroin of silk, and silk garments should be washed regularly.

Silk should be laundered with soap flakes or a mild detergent, rinsed thoroughly in soft water, dried gently and ironed while damp. Wild silk fabrics should be ironed dry.

The plasticity of silk is made use of in finishes where pressure is applied to the fabric. The soft, warm filaments are pressed out of their normal shape, and fabrics can be given special glazed effects. If carelessly ironed, silk garments may acquire an undesired glaze in this way; the iron should be used at moderate heat, and a pressing cloth put between the iron and the silk. This will prevent distortion of the plastic silk filaments.

Crêped garments should be dried after gently stretching to their original shape. Ironing should be done on the wrong side of the fabric, with a blanket as support.

Weighted silks are often affected drastically by washing or dry cleaning. This may be caused by removal of the metallic salts from the fibre. The effect can be restored to some extent by dipping the fabric in a dilute solution of gum arabic.

Weighting

Silk is so costly that it is rarely made up into heavy fabrics of pure fibre. Many techniques have been devised for increasing the density of silk by artificial means; the weighting of silk with metallic salts such as tin chloride, for example, has long been in use, though not now to the same extent as before.

Degummed silk is steeped in a solution of tin chloride, and the silk filaments absorb some of the salt. After washing, the silk is steeped in a solution of sodium phosphate. This double steeping process is repeated several times, after which the silk is soaked in a bath of sodium silicate solution.

The quantity of metallic salt absorbed by the silk in this way is adjusted over a wide range. A moderately weighted silk will contain 25–50 per cent of salt.

A crêpe-de-Chine is normally weighted with 25–45 per cent of salt; satin may contain 50 per cent and georgette 30 per cent. Heavily weighted tie fabrics will contain as much as 60 per cent of absorbed material.

In general, weighted silk fabrics are not as strong as those made from pure silk. They have a fuller handle which is often preferred for certain applications. Heavily weighted fabrics are more sensitive to the effects of light and air, and deteriorate rapidly under certain circumstances. Perspiration, for example, will attack weighted silk and make it rot; loaded silk garments should not be used as underwear.

TECHNICAL NOTE

Chemical Constitution

The fibroin of the silk filament is a protein similar in composition to the sericin gum surrounding it. Like wool and other proteins, silk fibroin is formed by the condensation of α-amino acids into polypeptide chains. It differs from the hair proteins in that it does not contain sulphur; the long chain molecules are not linked together by the disulphide bridge as they are in wool.

When silk fibroin is hydrolysed by treatment with strong acids, it yields a mixture of amino acids, including:

glycine	$NH_2\,CH_2\,COOH$	41·2 per cent	(grams of amino acid per 100 grams of protein)
alanine	$NH_2\,CH\,CH_3\,COOH$	33·0 per cent	,,
serine	 $NH_2\,\underset{\underset{\displaystyle CH_2OH}{\vert}}{CH}\,COOH$	16·0 per cent	,,
tyrosine	 $NH_2\,\underset{\underset{\displaystyle CH_2\,C_6H_4OH}{\vert}}{CH}\,COOH$	11·4 per cent	,,

Molecular Structure

The molecular weight of fibroin is not known with any accuracy. It has been estimated as between 84,000 and 220,000.

X-ray analysis of silk fibroin has shown that there is a high degree of crystallinity in the silk filament. The polypeptide chains are able to pack together in such a way that they form regions of regularity typical of a crystal. The atoms of the molecules in these crystalline regions are exerting natural forces of attraction which hold the molecular chains tight against one another.

In the silk filament, the polypeptide chains are fully extended, whereas in the wool fibre they are folded. Silk has, in this respect, a close resemblance to the stretched wool fibre.

The closely packed and aligned molecules of silk fibroin are associated into regions of high order or crystallinity whilst regions of disorder also occur where the fibroin is amorphous and the molecules are not orientated (see 'Cellulose'). Individual fibroin molecules may form part of several crystalline regions, and of the amorphous material in between.

The fully extended nature of the silk molecules and the high degree of orientation accounts for the low elasticity of silk. The molecules cannot unfold like wool molecules when a filament is subjected to a pull. There is only a small amount of distortion before slippage of the molecular chains takes place.

The close packing of the silk molecules and the high degree of crystallinity confer great strength on the silk filament. The natural forces of attraction between the molecules can operate with maximum effect.