H. Eberle
E. Gonser
H. Hermeling †
M. Hornberger
R. Kilgus
R. Kupke
D. Menzer
A. Moll
W. Ring

Clothing Technology

... from fibre to fashion

Sixth Edition

VERLAG EUROPA-LEHRMITTEL · Nourney, Vollmer GmbH & Co. KG
Düsselberger Straße 23 · 42781 Haan-Gruiten · www.europa-lehrmittel.de

Europa-Nr.: 62218

Authors

Hannelore Eberle	Director of Studies	Ravensburg
Elke Gonser	Lecturer	Metzingen
Hermann Hermeling †	Dipl.-Ing (FH), Principal	Frankfurt
Marianne Hornberger	Diplom-Modellistin, Lecturer	Munich
Renate Kupke	Senior Lecturer	Stuttgart
Dieter Menzer	Dipl.-Ing (FH)	Nussloch
Andrea Moll	Instructor	Darmstadt
Werner Ring	Dipl.-Ing (FH), Director of Studies	Eningen

Editor and Team Leader:
Werner Ring, Dipl.-Ing (FH), Director of Studies, Eningen
Roland Kilgus, Principal, Neckartenzlingen (German Editions 1 to 9)

Fashion Drawings: Studio Salo-Döllel, Aufkirchen bei Erding

Picture Processing: Design Department, Verlag Europa-Lehrmittel, Ostfildern

This book was produced according to the latest German Industrial Standards (DIN-Blätter). Conformance is strictly limited to the DIN-Blätter. The DIN-Blätter are published by: Beuth-Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin.

Tenth German Edition 2013

Print 5 4 3, reprint 2020

All prints of the same edition are interchangeable, excepting correction of printing errors.

Sixth English Edition 2014

Translation: Cotton Technology International, 27 Winnington Road, Marple, Stockport SK6 6PD, England
http://www.cottontech.co.uk

ISBN 978-3-8085-6226-0

http://www.europa-lehrmittel.de
Cover design: braunwerbeagentur, 42477 Radevormwald
Setting & layout: Satz+Layout Werkstatt Kluth GmbH, 50374 Erftstadt
Printing: Himmer GmbH, 86167 Augsburg

Preface
10th German Edition

This is a vocational book, directed primarily at students of the clothing industry: cutting, sewing, and assembly for fashion and mass markets. However, it will also be found useful in either college- or industry-based training for managers and technologists, and as a general reference work.

A key feature of the book is its concise and compact design. The chapters generally follow the flow of textile and clothing manufacture. Each page is complete in itself. Particular emphasis has been laid on providing a simple layout and straightforward language, which students will find easy to grasp. Numerous colour diagrams are an effective aid to the comprehension of some of the more difficult topics. These coloured illustrations are a particularly useful feature of the chapters on Commercial Terminology and the History of Clothing.

The book is organised largely according to the different technological sectors, but teaching requirements have also been kept in mind. There are fifteen chapters:

- Fibres
- Labelling of Textiles
- Functions of Textiles
- Ecology
- Yarns
- Textile Fabrics
- Dyeing and Finishing
- Commercial Terminology
- Leather and Fur
- Clothing Manufacture
- Company Management
- Garment Sizing
- Product Development
- Product Groups
- History of Clothing

Improvements for the 10th Edition: The sections on Labelling of Textiles, Functions of Textiles, Ecology, Yarns, Fabrics, Dyeing and Finishing, Commercial Terminology, Company Management, Product Development, and Product Groups have been rewritten or extended according to the latest technical developments. Many illustrations have been enhanced by the use of colour or changed to reflect current fashion trends.

We would like to give special thanks to the persons, companies and associations listed on *page 307 ff* for their assistance in the clarification of questions and for the provision of pictorial material.

Many clothing companies today employ offshore manufacturing. Therefore, it is useful to note that "*Fachwissen Bekleidung*" has been translated into English ("*Clothing Technology*") and from there into several other European languages. Maybe this can provide some stimulus to intra- and extra-European communication via the language of technology. The new generation will need competence in both language and technology to succeed in an era of global market competition.

We would welcome any suggestions for improving or supplementing the material in this book.

Eningen, Summer 2013 — Editor and authors

Preface
6th English Edition

Fachwissen Bekleidung is now in its tenth edition and has been a firm favourite in the German-speaking area of Europe since it first appeared in 1989. So far as we are aware, the book is unique in its scope and presentation, so it was perhaps natural that a demand should arise for an English-language version.

Although this English edition follows quite faithfully the general content and layout of the German, it is not always a literal translation. There are several instances in the original where the treatment of the subject matter naturally has a distinctively central-European bias. In the English, an attempt has been made to present a more international perspective. Wherever possible, ISO or ASTM or EN standards have been referenced rather than DIN.

For an international readership, there is always the problem of whether to use British or North American terminology. For this edition, wherever there is a conflict between the British and American traditions, the British has generally been selected, although the American is often acknowledged and occasionally preferred – *Fairchild's Dictionary of Textiles (7th Ed.)* has been frequently consulted.

The German approach to Work Measurement has been retained, as a valid and comprehensive example of the technique. Most of Chapter 12 on Garment Sizing has been completely rewritten for the English edition.

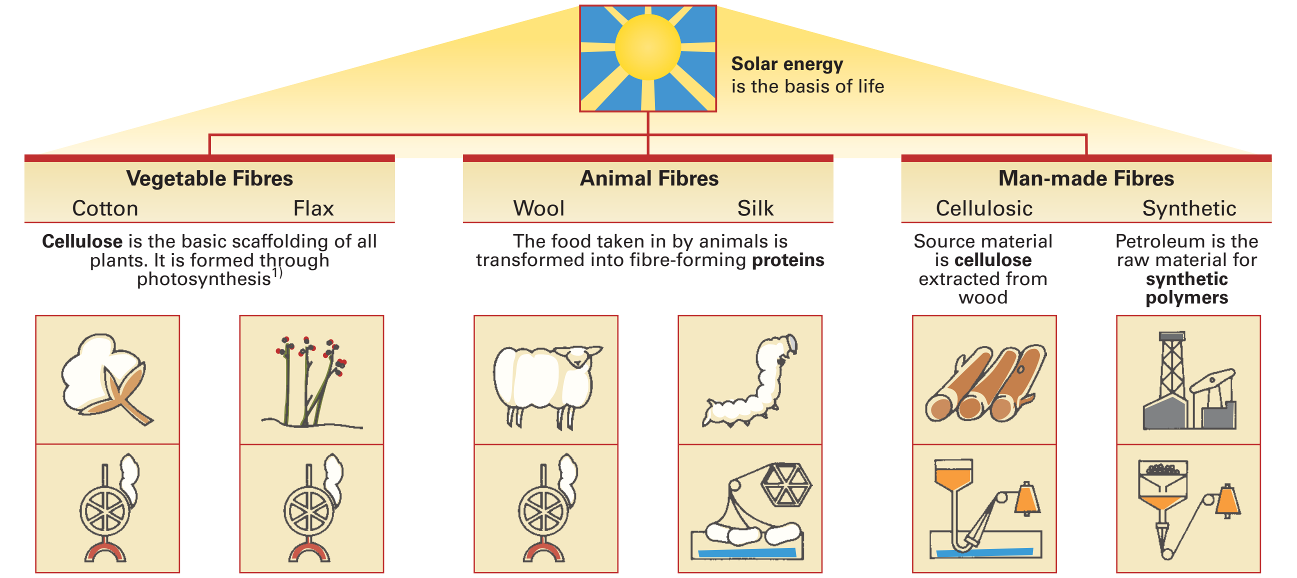
Stockport, Winter 2013–14

Allan Heap & Jill Stevens
Cotton Technology International

Contents

1.1.1 Sources and Demand for Textile Fibres

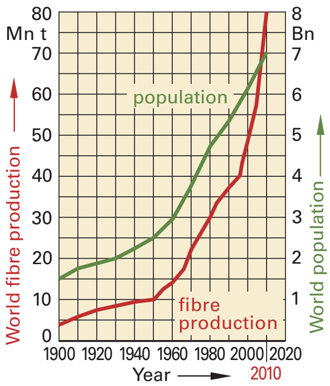
Sources of Textile Fibres



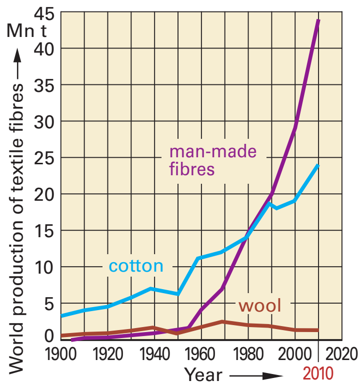
Fibres from plants and animals are constructed from natural **polymers.** Polymers are very large molecules. Cellulosic man-made fibres are formed from the natural polymers of plants (cellulose). The cellulose is dissolved and then forced through spinning jets. Synthetic man-made fibres are derived from petroleum products. Their polymers are formed synthetically (artificially). The common feature of all fibres is that they are constructed from large polymer molecules which lie alongside each other and are bonded together.

1) Synthesis of carbohydrates by green plants from carbon dioxide using solar energy.

Production of Textile Fibres



1: World population and fibre production



2: World production: man-made fibres, wool, cotton

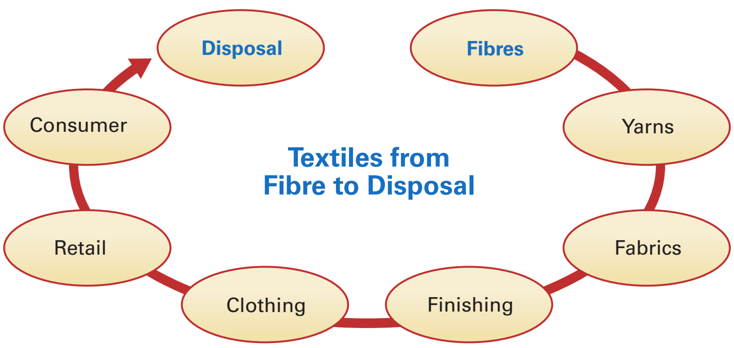
The demand for **textiles,** and therefore for textile fibres has increased rapidly due to growing prosperity and the large increase in world population (*Figures 1 and 2*).

Apparel fabrics satisfy the basic requirement of the population for clothing.

Household textiles, e.g. bed and table linen, decorative fabrics, furnishings and blinds, curtains and floor-coverings are utilised in dwellings.

Technical textiles are used in increasing volumes for functional and protective clothing in medicine, packaging, engineering, house and road building, as well as in all forms of transport (including space travel).

The Textile Chain, from Fibre to Consumer



3: The Textile Chain

Figure 3 shows the **textile chain.** Textile **fibres** are spun into **yarns** (spun yarns, filaments) and the yarns are formed into **fabrics** (wovens, knits, nonwovens). The fabrics are **finished** (e.g. bleaching, dyeing, functional finishing). The fabrics are made into **clothing** which is brought to the **consumer** via small **shops** and large **stores.**

The consumer utilises and cares for the clothing.

At the end of the textile chain comes **disposal** e.g. by recycling, landfill or incineration.

1.1.2 Classification of Textile Fibres[1)]

TEXTILE FIBRES[1)]

NATURAL FIBRES

Group Sub-group	Name or Generic Name
Vegetable Fibres	
Seed	Cotton Kapok Coir
Bast	Flax Hemp Jute Ramie
Leaf	Sisal Manila
Animal Fibres	
Wool	Wool Virgin wool
Fine hair	Alpaca Llama Vicuna Guanaco Camel Rabbit Angora Mohair Cashmere Cashgora Yak
Coarse hair	Cattle Horse Goat
Silk	Cultivated Wild (Tussah)
Mineral Fibres	
Rock fibres	Asbestos[2)]

MAN-MADE FIBRES

Group Sub-group	Name or Generic Name
Natural Polymers	
Cellulosic	Viscose Modal Lyocell Cupro Acetate Triacetate
Alginate	Alginate
Rubber	Rubber
Protein	Azlon
Synthetic Polymers	
Elastomeric	Elastane Elastodiene
Fluorofibres	Fluoro
Polyacrylics	Acrylic Modacrylic
Polyamides	Nylon Aramid
Chlorofibres	Vinyl chloride Vinylidene chloride
Polyesters	Polyester
Polyolefins	Polyethylene Polypropylene
Vinylal	Polyvinyl alcohol
Inorganics	
Glass Carbon Metallic	Glass Carbon Metallic

[1)] Standards for generic names are in ISO 2076 and ISO 6938

[2)] Asbestos is classified as a hazardous substance; the appropriate health and safety regulations must be observed.

1.2.1 Cotton (1)

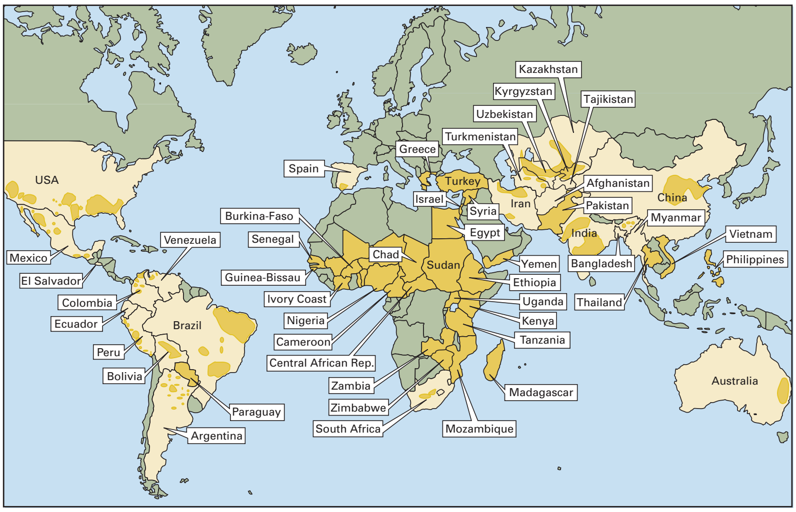
Cotton German: Baumwolle French: Coton Spanish: Algodon

History

Archaeological findings in Mohenjo-Daro, in modern Pakistan, and in the Tehuacán valley in Mexico, both dating from about 3000 BC, suggest that the cotton plant was already domesticated and being used for making textiles over 5000 years ago. Cotton fabrics from India, of outstanding fineness and quality, were traded in the Mediterranean area from the time of Alexander, who had established the trade routes to the East. Alexandria became the major dispersal point for these goods. Later the rise to power of the city-state of Venice is said to have been built largely on trade in Indian cotton cloth.

In the 8th century, cotton growing and fabric manufacture were introduced into Spain by the Moors, where it thrived until the expulsion of Islam in the 15th century. Thereafter, the opening of the sea route to India promoted Portugal to the prime source of cotton fabrics.

During the 17th century textile manufacturing expertise and sea power began to concentrate in England which then became the dominant centre of textile manufacture. Meanwhile cotton growing was expanded in North America and the Caribbean. These trends were reinforced in the late 18th century by the invention of the cotton gin in America, and by the development of spinning and weaving machinery, plus the harnessing of water and steam power, in Britain.



1: Cotton growing regions

2: Cotton field

3: Cotton flower

4: Fruit capsule

5: Open bolls

Production and Sources

By 1930 cotton accounted for 85% of the world consumption of textile fibres but, during the last half of the twentieth century, its market share fell to about 40% due to the introduction of synthetic fibres. Current annual production (2010-12) is about 26 million tonnes.

Although cotton production has tripled in recent decades, the amount of land utilised has not increased. This is a result of constant improvements in cotton varieties and farming techniques. Cotton is grown in about 80 different countries world-wide (*Figure 1*).

Leading Producers	Others
China India USA Brazil Pakistan Uzbekistan Australia	**Africa:** Egypt, Sudan, East Africa, West Africa **Asia:** Israel, Turkey, Central Asia, East Asia **Latin America:** Mexico, Peru **Europe:** Spain, Greece

The Cotton Plant

Cotton is a member of the Mallow family. Its height ranges from 25 cm to over 2 m, depending on variety, climate, and agronomy. It is normally grown as an annual shrub but, in parts of South America and the Caribbean, it is cultivated as a perennial shrub (tree cotton).

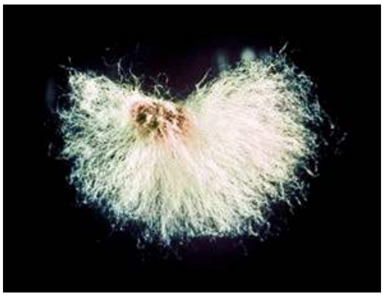
From planting to maturity takes between 175 and 225 days. At planting and during its growth, cotton needs plenty of water (*Figure 2*). For ripening, it needs heat. Therefore, the world's cotton belt is located mainly in the tropics and sub-tropics.

After flowering (*Figure 3*), the fruit nodes, located in the calyx (bracts), grow into capsules (bolls) which eventually crack open to reveal the seed hairs (*Figures 4 and 5*). In each boll there are about 30 seeds. The number of hairs on each seed ranges from less than 1000 to more than 10000, depending on the variety.

1.2.1 Cotton (2)

1: Hand picking

2: Machine picking



3: Seed with fibres

4: Cotton staple length standards

5: Seeds with linters (left)
Seeds without linters (right)

Like any agricultural product, the way that cotton is grown in different countries varies widely, depending on the level of development: in the USA, Australia, Brazil, Uzbekistan and Israel large machines are utilised; in poorer countries, oxen or buffalo may be used for traction, and manual labour is the rule.

Harvesting

Harvesting is either by hand or by picking machines.

Hand picking (*Figure 1*) extends over several weeks. In principle, it has the advantage that only the fully ripened bolls are collected and no leaves are included.

A picking machine (*Figure 2*) will usually harvest the whole crop in one passage. It has a tendency to include some unripe bolls, together with various quantities of dead leaves and other plant parts.

Drying

If the newly-harvested seed-cotton is wet, then it may have to be dried using warm air before it can be stored in large piles to await ginning. In many countries drying is an integral part of the ginning process.

Ginning

Ginning is the separation of the fibres from the seeds (*Figure 3*) using special machines. The separated fibres, called lint, have a staple length of between 15 and 50 mm, depending on the cotton variety (*Figure 4*).

On many types of seed, there are some very short fibres, called **linters.** They are made of cellulose and they find many uses, including the production of man-made fibres. The **seeds** can also be utilised for the production of edible oil, and as cattle feed (*Figure 5*).

100 kg of clean seed-cotton yields about 35 kg of fibre, 62 kg of seed and 3 kg of waste.

Processing into Yarn

Cotton fibres are made into staple fibre yarns predominantly by ring spinning or OE rotor spinning.

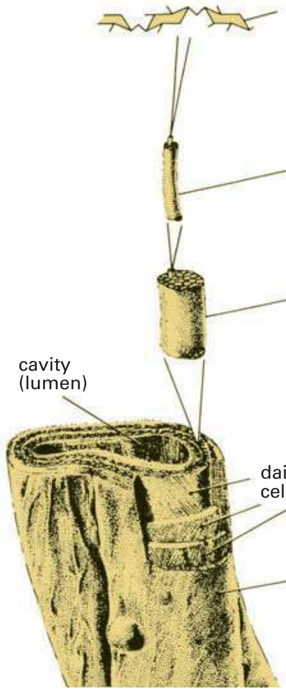
Commercial Quality

Commercially, cotton is usually designated according to its variety and origin. Different varieties are grown in different countries – about 40 in the USA alone. Thus the country of origin is only a partial guide to quality. The high-quality, long-staple cottons, such as the Gizas of Egypt and the Pimas of the USA, Peru, and Israel, account for less than 10% of total production. Sea Island cotton, from the West Indies, is a very high quality type produced in vanishingly small quantities. The most common type world-wide is the American Upland cotton, with about 85%.

Naturally-coloured cottons, mostly in brown shades, have been adapted for commercial production on a very limited scale.

Staple length	This is the most important aspect of quality. It generally lies between 20 mm and 40 mm. Spinnable fibres have a staple length greater than about 16 mm. Sea Island cotton can be as long as 50 mm. Giza and Pima are about 36 mm, Upland is about 28 mm.
Fineness, Handle	Cotton fibres are fine. Their weight per unit length is between 1 and 4 dtex. Generally, the longer the fibre, the finer it is and the softer its handle.
Preparation, Impurities	Large amounts of contaminants, such as leaf or seed fragments, or of very short fibres, or of immature and "dead" fibres are severely detrimental to quality.
Strength	A high quality cotton will have a high strength relative to its fineness.
Colour and Lustre	The colour of cotton varies, according to the variety, from white (Upland) through creamy (Giza, Pima) to light yellow or brown. The lustre is usually subdued. High quality types, such as Giza and Pima have a silky lustre.

1.2.1 Cotton (3)



1: Model of the cotton fibre

Construction of the Cotton Fibre (*Figure 1*)

Cotton is composed of cellulose, the foundation of all plants.

Whilst it is growing inside the boll, the fibre is circular (annular) in section. When the boll opens, the fibre begins to dry and it collapses to a kidney-shaped cross-section. At very strong magnification in the electron microscope a suitably prepared cross-section shows daily growth rings, comparable with the annual rings in wood. These are the result of daily deposits of layer upon layer of fresh cellulose, proceeding from the outside inwards. The first-formed outer layer is composed of an especially tough kind of cellulose. At the end of the growth period, a cavity remains at the centre. This is called the Lumen. During drying the fibre twists along its length axis and looks like a flattened, twisted tube. A layer of natural wax coats the surface.

Each cellulose layer is formed from fibrillar bundles composed of individual fibrils (fibril = tiny fibre). The fibrils are made of cellulose macromolecules. The fibrillar bundles of succeeding cellulose layers are inclined at an angle to the length axis of the fibre. Spaces between the ordered lattice of the fibrillar structure, as well as the hollow fibre centre, are easily penetrated by water. Moisture can be stored in the cavities. Sweat can be absorbed and will be removed during subsequent washing. Cotton is stronger when it is swollen by water. This is because the presence of water promotes a more uniform distribution of stresses across and along the cellulose layers.

The high strength of the cotton fibre is a consequence of its construction from highly organised cellulose chain molecules in the fibre interior (crystalline regions). Its low elasticity is due to slippage between the crystalline regions.

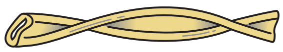
Clothing Comfort (*see pages 48, 49*)	
Thermal insulation	Cotton fibres are relatively fine and flexible. Therefore they are often made into textiles which have a relatively low proportion of entrapped air (low specific volume). Warmer, more voluminous materials can be made, however, by appropriate choice of yarn and fabric constructions and through roughening (raising) the surface.
Moisture absorption	Cotton can absorb up to 20% of water vapour without feeling wet. Cotton fabrics absorb liquid very rapidly and can contain up to 65% (wovens) or 90% (knits) of their own weight without dripping. Cotton dries slowly.
Next-to-skin comfort	Cotton is very comfortable next to the skin because of its fineness and softness.

Other Important Properties (*see pages 41, 42, 43*)	
Strength	The strength of cotton is good: 20 to 50 cN/tex in a fibre-bundle tensile test. It is stronger when wet than when dry. Abrasion resistance and durability are good.
Extensibility	The extensibility is relatively low, at about 6 to 10%.
Elasticity/creasing	Cotton has very poor elasticity and therefore it creases easily.
Electrostatic charge	Under normal conditions it develops scarcely any electrostatic charge because it always contains moisture, which conducts the charge away.
Fineness and Handle	Cotton fibres are fine and soft; they have a pleasant handle.

Improvement of Properties by Finishing (*see Chapter 7*)	
Mercerizing	Treatment of cotton under tension with caustic soda solution causes the fibre cross-section to become more circular. This results in higher strength and lustre.
Easy-care finish	The elasticity of cotton, and hence its resistance to creasing, can be improved by cross-linking the cellulose chains, using synthetic resins. There is a consequent reduction in strength and absorptivity, and an increase in the rate of drying.
Anti-shrink finish	Shrinkage is induced in the fabric to avoid such shrinkage appearing after subsequent wet treatments. This process is important for improving the laundering characteristics of cotton textiles – especially when a household tumble dryer is used.
Water repellency	Cotton textiles can be made water repellent by treatment with special chemicals (e.g. silicones).

1.2.1 Cotton (4)

Fibre Identification

Microscopy	Burning Test	Tearing Test	Solubility Test
 1: **Longitudinal View** of a mature fibre  2: **Cross sections**	**Combustion:** Quick, bright, with afterglow. **Smell:** Like burnt paper. **Residue:** Pale grey, powdery ash.	**Dry tearing:** Short fibres appear at the torn edges (cf. linen). **Wet tearing:** If a spot of water is applied, the yarns will not tear across the wet area (cf. viscose).	**Sulphuric acid:** Dissolves; cotton is destroyed (cf. wool). **Alkalis:** Safe in washing liquors. Caustic soda is utilised in finishing (cf. wool).

Typical Cotton Fabrics

Batiste	Cambric	Damask	Gabardine	Plain rib
Buckram	Chintz	Denim	Interlock	Poplin
Bedford Cord	Corduroy	Drill	Oxford	Terry
Calico	Cretonne	Flannelette	Piqué	Velvet

Fibre Blends (*see page 44*)

Fibre blending allows for the disadvantages of one fibre to be offset by the advantages of another, or for special effects to be achieved, or for the cost to be reduced. Cotton is most often blended with polyester but also with nylon, acrylic, viscose and modal fibres. Blending with synthetic man-made fibres improves the easy-care and durability of clothing. Blending with viscose and modal fibres may be for their lustre and uniformity, whilst preserving good moisture absorption. Modal fibres are a good match for cotton in their strength and extensibility. Blends with other fibres are also possible. The most common blends are 35:65, 50:50, and 70:30 cotton:polyester. Note that different varieties of cotton are frequently blended together in 100% cotton yarns.

Applications

Apparel Fabrics	Accessories	Household Textiles	Technical Textiles
Shirts, blouses, underwear, nightwear, outerwear, rain-wear (water-repellent finish-es), trousers (jeans, chinos), leisure wear, workwear.	Handkerchiefs, laces, ribbons, trimmings, umbrellas.	Bed clothes, table and kitchen cloths, decorative fabrics, furniture coverings, hand and bath towels.	Workwear and protective clothing, awnings, tarpaulins, sewing threads.

Aftercare

The most severe laundering conditions that a fibre could tolerate are seldom those to be recommended for a given item of clothing. Limitations may be imposed, for example, by yarn and fabric construction, type of finish, garment construction and decoration. **Care symbols,** used to indicate the appropriate aftercare regime, are illustrated and explained on *pages 46 and 47*.

Washing	Bleaching	Drying	Ironing	Professional Cleaning
			 steam iron	

Textile Labelling

The laws governing product descript-ions allow the name "Cotton" to be applied only to fibres obtained from the seeds of the cotton plant.

International Cotton Emblem

The Cotton Emblem is registered internationally. It serves clearly to identify textiles made from pure cotton and implies good quality. It may not be applied to fibre blends.

TM

3: International Cotton Emblem

1.2.2 Flax[1] (1)

Flax German: Leinen French: Lin Spanish: Lino

1: Egyptian woman in fine linen fabric

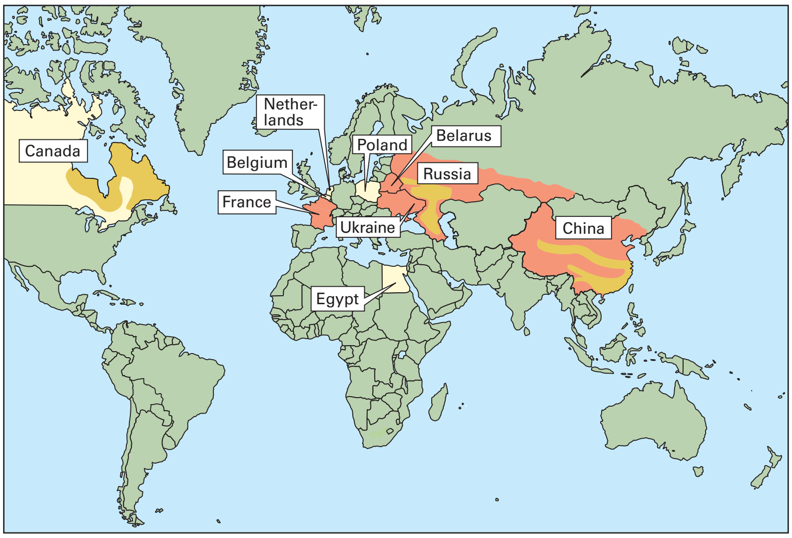
History

Linen[2] has been known in civilised societies for thousands of years. Flax was already being cultivated systematically by ancient Egyptians, Babylonians, Phoenicians, and other civilisations between 5000 and 4000 BC.

Mummies from the pyramids of Egypt are wrapped in linen; cotton was unknown in Ancient Egypt until about 400 BC.

The Romans laid down precise procedures for processing flax fibres which were hardly different, in principle, from those used today.

Linen was especially popular in the Middle Ages. It remains to this day a highly valued natural product.



2: Flax growing countries

Production and Sources

World production of flax has been almost constant for the last 25 years at between 600 000 and 700 000 tonnes. This represents less than 1.5% of world fibre production.

The main producing countries, by area (*Figure 2*), are:

Leading Producers	Others
China	Egypt
Russia	Belgium
Belarus	Netherlands
Ukraine	Poland
France	

In recent years, attempts have been made to expand flax production in Europe and the USA.

3: Flax plant

4: Flowering flax

5: Ripe flax

The Flax Plant

Flax fibres are extracted from the stalks of the flax plant (*Figure 3*), which may be grown either for its fibres or for its seed. For fibre extraction, tall varieties with white to light blue flowers and a height of 80 to 120 cm are grown. The shorter types are grown for linseed oil (*Figure 4*).

Flax is an annual plant; it must be re-seeded every year. It thrives in temperate climates. Regions with a maritime climate grow the best flax qualities.

Planting is in March and April, and growth takes 90 to 120 days. The plant has side branches only at the top of the stem, from which the flowers grow. After flowering, the mature plant develops seed capsules the size of peas. The seeds are about 2 mm long and are very rich in oil (*Figure 5*).

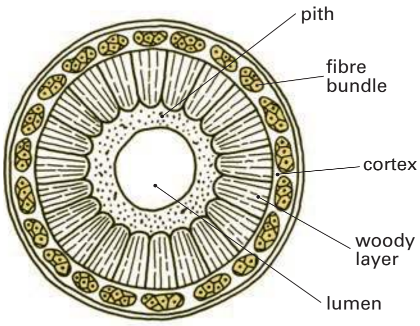
Harvesting is in July and August.

[1] Flax: fibres extracted from the flax plant
[2] Linen: yarns made from flax fibres and fabrics made from linen yarns

1.2.2 Flax (2)

1: Flax Harvesting

2: Hackled Flax



3: Flax stem cross-section, schematic

4: Flax fibres, longitudinal view

5: Flax fibres, cross-section

Harvesting and Fibre Extraction

Pulling: Traditionally, the plant was harvested whole, including the roots, in order to preserve the full length of the fibres. Nowadays harvesting machinery is available either for pulling or, more often, for cutting (*Figure 1*).

Drying: Usually, the stalks will be stacked in bundles in the field (stooking) and left to dry out, but drying ovens can also be used.

Retting: Degrading the woody part of the stems so that the fibres are loosened. Retting can be natural, in the field or pond (dew retting), or can be accelerated by using tanks of warm water, with or without extra chemicals.

Extraction of the Fibre Bundles

Roughing out: Removing the seeds and other extraneous material from the stems.

Breaking and Scutching: After loosening the fibres from the wood by retting, the flax straw is broken and the woody parts are removed by scutching. The products are line fibre, with a length of 45 to 90 cm, and scutcher tow, with a length of 10 to 25 cm.

Hackling, Heckling: This is a process of combing out the bast fibres into spinnable fibre bundles (*Figure 2*). The remaining woody particles and short fibres are removed at the same time. The main product is line flax; the by-product is **hackle**, or **heckle tow.**

Roughing out, Breaking, Scutching and Hackling are all part of a single, continuous process.

Processing into Yarn

Line flax: The longer fibres of the line tow are spun into relatively smooth, strong, uniform linen yarns using the linen (wet spinning) process.

Tow flax: The shorter fibres of the hackle tow are spun into coarser, irregular yarns or may be used for blending with other fibres.

Afine, Cottonised flax: The shortest tow fibres may also be chemically and mechanically reduced further – even to their ultimates – so that they are short and fine enough to be blended with cotton.

Construction of a Flax Fibre *(Figures 3 to 5)*

The cross-section of a flax stalk is composed of several layers which have to be removed in order to release the fibre bundles. The fibre bundles extend all the way to the plant roots. They are made up from individual fibres (ultimates) of about 25 to 40 mm in length which are cemented together by a mixture of lignins, pectins and hemicelluloses. This cement comprises about 30% of the dry weight of flax, with the remainder being mainly cellulose. Flax fibres are relatively stiff, and have a smooth surface, without crimp or convolutions.

Clothing Comfort (*see pages 48, 49*)

Thermal insulation: Yarns and fabrics made from the smooth flax fibres do not enclose much air and have relatively poor insulation properties. Linen fabrics feel fresh and cool, a distinct advantage for Summer clothing.

Moisture absorption: Linen is highly absorbent. It takes up water rapidly and releases it quickly again to the surroundings. In hot weather this helps in regulating the microclimate between body and clothing.

Next-to-skin comfort: Fabrics made from flax fibres are comfortable due to the smooth surface and good moisture absorption.

Other Important Properties (*see pages 41, 42, 43*)

Strength: Flax has very good tenacity and durability. It is stronger wet than dry.

Extensibility: The extensibility of flax, about 2%, is the lowest of all apparel fibres.

Elasticity/creasing: Flax has a low elasticity; it creases very easily.

Electrostatic charge: Practically nil, under normal conditions, since the fibre always contains moisture.

Surface, Lustre: Because of its smooth surface, linen fabric has a subdued lustre, does not soil easily, and does not shed lint.

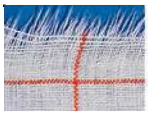
Fineness, Handle: The coarse fibre bundles give linen a firm handle.

Improvement of Properties by Finishing (*see Chapter 7*)

Like cotton, linen fabrics can be given mercerizing and easy-care treatments (*see page 10*).

1.2.2 Flax (3)

Fibre Identification

Microscopy	Burning Test	Tearing Test	Light Test, Oil Test
 fibre ultimate  fibre bundle (cross-section)	**Combustion:** Quick, bright, with afterglow. **Smell:** Like burnt paper. **Residue:** Pale grey, powdery ash.	**Dry tearing:** The torn edges are much longer than with cotton.  Linen  Cotton	When held up to the light, pure linen fabrics show thick places in both warp and weft. An oil spot on a linen fabric is more transparent than on cotton.

Typical Linen Fabrics (with typically irregular yarns)

Crash	Filter cloth	Holland	Interlining
Duck	Half linen (Union)	Huckaback	Mattress ticking

Fibre Blends (*see page 44*)

The most important mixtures are with cotton. "Half linen" or Union is a fabric with cotton warp yarns and linen weft (s*ee Textile Labelling and Linen Seal, below*). Flax is also mixed with other bast fibres, such as hemp and ramie, and with cellulosic or synthetic man-made fibres, such as modal, polyamide, polyester, or polyacrylics. The linen look (yarn structure, colour and lustre) can be imitated to some extent by synthetic fibres, but without the typical linen properties.

Applications

Apparel Fabrics	Accessories	Household Textiles	Technical Textiles
Leisure wear and Summer wear: blouses, shirts, skirts, trousers, jackets, suits, interlinings for stiffening.	Pockets, bags, shoes, hats.	Bed clothing, tablecloths, drapes, furniture and wall coverings, mattress lining.	Lace, trimmings, awnings, tarpaulins, ropes, sewing thread.

Aftercare

The most severe laundering conditions that a fibre could tolerate are seldom those to be recommended for a given item of clothing. Limitations may be imposed, for example, by yarn and fabric construction, type of finish, garment construction and decoration. **Care symbols**, used to indicate the appropriate aftercare regime, are illustrated and explained on *pages 46 and 47.*

Washing	Bleaching	Drying	Ironing	Professional Cleaning
			 steam iron	

Textile Labelling

The laws governing product descriptions allow the name linen to be used only for fibres originating from the **stems of the flax plant.**

Textiles made from **100% linen** may be described as pure linen. Both warp and weft must be made from pure flax yarns.

The term **"half linen"** may be used for fabrics in which the warp is made only from cotton, the weft is only linen, and the overall **linen content is at least 40%.** The label should state "Cotton warp, linen weft".

Registered Trade Marks

The linen industry of Western Europe (spinners, weavers, knitters) has formed an association to promote linen use and offer certain quality guarantees. It has created a trademarked label for its products and has registered the mark world-wide. The **Masters of Linen Seal** has the form of a stylised **"L"** and is administered by the European Confederation of Linen and Hemp **(CELC).** It guarantees European traceability of origin of linen products (grown and manufactured in Europe) through the member companies.

Another trademark is that of the German Linen Association, the **Schwurhand Siegel** which, roughly, means the **Sign of the Pledge**. It is a guarantee of quality and is administered by the **Schwurhand-Zeichenverband e.V.** in Bielfeld.

1.2.3 Seed, Bast, and Hard Fibres

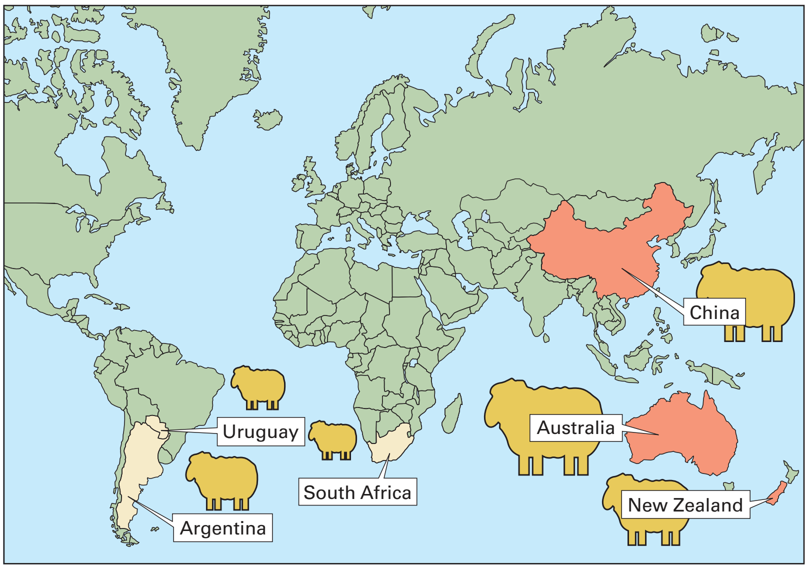
Seed Fibre			Properties and Applications
Kapok	**Seed fibre** from the Kapok tree. **Producers:** Brazil, India, Indonesia, Mexico, East and West Africa.		Kapok fibres cannot be spun into yarns because they are very weak. Their density is only 0.35 g/cm^3, due to the large air-filled lumen. The fibres are water repellent, fine, soft, and lustrous. **Applications:** Kapok fibres are used as stuffings and waddings for e.g. cushions, bolsters, and mattresses. In addition, Kapok is suitable as filling for life jackets.
Bast Fibres			
Hemp	**Bast fibre** from the stems of the hemp plant. **Producers:** Poland, Hungary, Romania, China, Germany, Netherlands, France.	 	Cultivation of hemp was banned for a while but nowadays specific varieties are allowed for fibre production. Production in Central Europe is increasing due to its environmental friendliness i.e. minimum requirement for fertiliser and pesticides. After cutting down the (up to 3m tall) plants, the fibre extraction processes, and the resulting fibre properties, are similar to Flax. Processing of hemp fibre into apparel takes place mainly in China. **Applications:** Hemp fibre is used mainly in industrial outlets such as insulation in automobiles (ca. 40 kg per family car). Apparel uses are e.g. lightweight shirts and blouses. The seed oil is used for cosmetics and for cattle fodder.
Ramie	**Bast fibre** from the stems of the ramie plant. Also known as Oriental linen or New Zealand Flax. **Producers:** China, Brazil, Central America.		Ramie fibres are strong and high grade bast fibres, similar to flax. They are smooth and uniform, easy to dye and resistant to light. The fibres are white, with a durable lustre and good absorbency, but the handle is somewhat harder than cotton. **Applications:** Ramie is used mainly in technical outlets to make fine, light and durable fabrics for kitchen and table cloths, belts and ribbons. Short, waste fibres may be included in banknotes. Ramie is seldom used for clothing.
Jute	**Bast fibre** from the stems of jute plants. **Producers:** India, Bangladesh, Pakistan.		Jute fibres are very woody and irregular. They tend to have a strong aroma, due to the oils used in processing. Strength, extensibility and elasticity are similar to flax. **Applications:** Jute is manufactured into packaging fabrics, wall coverings (hessian), and base cloths for belts and carpets. Jute can also form the backing cloth for floor coverings.
Hard Fibres for Technical Uses			
Sisal	**Leaf fibre** from the leaves of the sisal plant, a type of agave. **Producers:** Brazil, Indonesia, Mexico, East Africa.		Sisal fibres have a high strength and abrasion resistance. They are white in colour, easy to dye, and have good resistance to sea water. **Applications:** Sisal is used for ropes, carpets, nets, and matting.
Manila	**Leaf fibre** from the leaves of a type of banana (Abaca) **Origin:** Philippines (capital: Manila), Ecuador.		Manila fibres are stronger than sisal. They are very resistant to sea water. **Applications:** Manila is used for teabags, banknotes and reinforced plastics, for marine cables and other ropes, also for nets and matting.
Coir	**Seed fibre** from the coconut palm. **Producers:** India, Indonesia, Sri Lanka.		Coir fibres have a very high abrasion resistance, are very durable and have good elasticity. They do not soil easily, are good insulators and are resistant to rotting. They are often used in the raw form. **Applications:** Coir is used primarily for padding materials in the automobile industry, but also for stair-carpets, doormats, floor coverings, stuffed furniture backings, and brushes.
Other Vegetable Fibres			
Fibres extracted from nettle, bamboo, seaweed, hops, kenaf, banana, yucca and other shrubs, trees, or sedges.			

1.3.1 Wool (1)

Wool German: Wolle French: Laine Spanish: Lana

History

Wool felts were known 7000 years ago in China, in Babylon, and in Egypt. Shearing of the wool, rather than pulling, was made possible by the invention of cutting tools in the Iron Age. The Merino sheep, which has the finest wool, was bred in Spain in the 14th century. Sheep breeding began in Australia at the end of the 18th century. Today, Australia rears about 100 million sheep – about 10% of the world's sheep population.



1: Wool producing countries

Production and Sources

During the 20th century, the production of wool roughly doubled. Production of scoured wool is now about 1.3 million tonnes; unscoured wool is about 2.2 million tonnes. This represents about 2% of total world fibre production. Sheep are to be found in almost every country in the world.

The most important wool producers are shown in *Figure 1*.

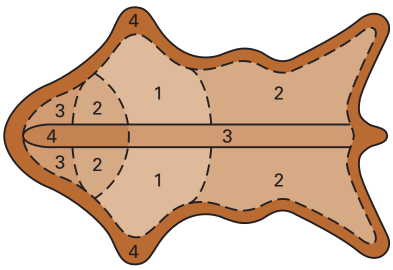
Leading Producers	Others
Australia	Argentina
China	South Africa
New Zealand	Uruguay

Wool Production

Shearing: The sheep are shorn using electric shears. Care must be taken to avoid injuries and to ensure that the coat is separated intact. This coat is called the **fleece.** Wool from the legs is short and coarse. Because of its lower quality, it is separated from the fleece during shearing.

2: Merino ram

3: Examination



4: Fleece

5: Worsted fabric

6: Woollen fabric

Classing: After shearing, the fleece is graded into essentially four qualities (1 = best, 4 = worst) (*Figure 4*). The grader classifies the wool according to fineness, crimp, length, impurities, and colour. Heavy contamination is found in the belly area.

Scouring: An unscoured fleece weighs between 1 and 6 kg. The average Australian fleece weighs 4.5 kg. About 40% of this weight is grease (lanolin), dirt, and burs. The dirt and most of the grease are removed by a gentle scouring.

Carbonising: Vegetable impurities are removed, when necessary, by treatment with sulphuric acid.

Processing into yarn: Wool fibres are spun into fine, smooth yarns by the Worsted process and into coarser, more bulky yarns by the Woollen process (*Figures 5 and 6*).

1.3.1 Wool (2)

Classification of Wool

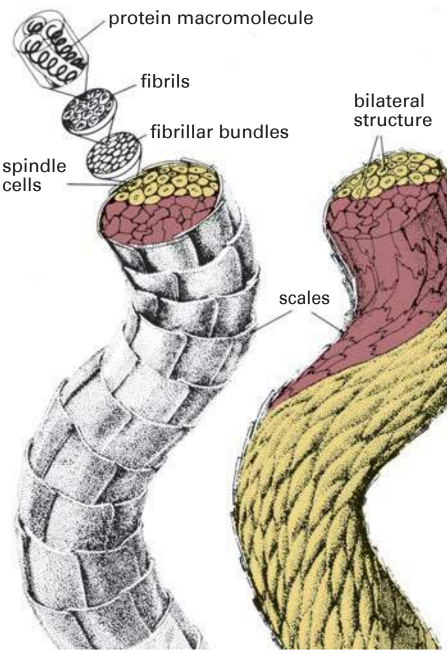
There are hundreds of different types and breeds of sheep. They are classified according to their wool into five basic types: Fine, Medium, Crossbred, Long, and Coarse.

Wool Type	Fine	Medium, Crossbred	Long, Coarse
Breed (examples)	Merino, Rambouillet	Southdown, Corriedale	Lincoln, Romney, Karakul
Fineness, Diameter	finest wools, 15...23 µm[1)] 	medium fine, 24...30 µm 	coarse, over 30 µm 
Length	50...120 mm	120...150 mm	over 150 mm
Crimp, Waviness	 highly crimped	 normal crimp	 low crimp, straight
Sources (examples)	Australia, South Africa	Argentina, Uruguay	New Zealand, Great Britain
Applications	fine outerwear, knitted and woven, shawls, socks	heavier, more robust, sporting clothing	carpets, traditional furniture coverings

1) 1 µm = 1 millionth of a metre = 10^{-6} m

Apart from its fineness, length, crimp, and breed, wool can also be classified according to:

- **Shearing: Lambswool** is from the first shearing, after six months, whilst **Yearling wool** is from the first or second shear after 10-12 months. They are fine, soft, not very strong, with fine tips. **Six-month, Eight-month, Twelve-month wools** are from sheep shorn at intervals of 6, 8 or 12 months.
- **Source: Australian, New Zealand,** etc. **Cape** wool is from South Africa; **Shetland** is typical coarse wool from Scotland.
- **Extraction: Virgin wool** is from living, healthy sheep or lambs. **Dead wool, Fallen wool** is from sheep that have died from natural causes. **Skin wool** has been taken from the skins of slaughtered sheep.
- **Spinning: Worsted wool** is usually fine Merino, spun into fine, smooth, uniform, combed yarns. The very finest and most expensive wools are made into extra-fine combed yarns designated as **super 100s to super 200s. Woollens** are heavier, more voluminous yarns prepared on the woollen spinning system. **Carpet wool** is long, coarse wools for carpet yarns.
- **Recycling: Recovered Wool** is wool that has been recovered mechanically by teasing apart production waste and second-hand clothing. Recovered wool is damaged and is of low quality.



1: Model of the wool fibre

Construction of the Wool Fibre

The wool fibre (*Figure 1*) is made of **protein molecules (keratin).** It is rather similar to human hair. The long-chain protein molecules are formed into **fibrils.** These combine into **fibrillar bundles** which form the mass of the **spindle cells.** This construction gives the wool fibre an extraordinary elasticity. The bulk of the fibre is made from two separate components. These have different chemical constitutions, and they wind in a spiral around each other **(bilateral structure)**. Moisture and temperature have different effects upon the two components, which swell to different extents, causing changes in the overall fibre shape. It is the bilateral structure which causes the fibres to be crimped; finer fibres develop more crimp. Heat and moisture can relax bonds between the protein chains. The bonds are re-formed during cooling and drying, and this is the source of the good smoothing and shaping properties of wool.

Wool absorbs moisture (is hygroscopic). It can absorb about 1/3 of its mass of water vapour without feeling wet. The moisture is released only slowly. In spite of the strong affinity for water of the fibre interior, its surface is water repellent (hydrophobic) because it is covered by an extremely thin skin, the **epicuticle**. This skin causes liquid water to roll up into droplets whilst allowing the passage of water vapour.

The **scales** on the fibre surfaces are capable of hooking onto one another to cause felting, under the influence of water, heat, and mechanical action.

1.3.1 Wool (3)

Clothing Comfort (*see pages 48, 49*)	
Thermal insulation	In smooth, combed yarns, the fine wool fibres are tightly constrained so they can scarcely crimp. Fine combed yarns enclose less air and therefore provide less insulation. Bulky woollen yarns have a looser structure. The fibres can develop their crimp inside the yarn and, due to the large amount of entrapped air, offer excellent protection against cold.
Moisture absorption	Wool is **hygroscopic.** It can absorb up to a third of its weight in moisture vapour without feeling wet, and can chemically bind liquid perspiration. Water vapour is absorbed very rapidly, but water droplets are repelled. Liquid water is absorbed only very slowly. Such behaviour is called **"hydrophobic"**. Wet wool dries very slowly.
Next-to-skin comfort	The softness of wool depends on its fineness. Lambswool and fine Merino wool are especially soft. Fibres that are coarser than about 30 µm can irritate the skin.
Other Important Properties (*see pages 41, 42, 43*)	
Strength	Wool has adequate strength which, nevertheless, is lower than that of most apparel fibres. Textiles made from wool are not particularly durable.
Extensibility	The fibres have very good extensibility, which is greater when wet than dry. Dripping wet wool garments should be laid flat to dry, to avoid stretching.
Elasticity/creasing	Elasticity and "springiness" are excellent. Creases soon drop out of wool clothing (especially under the influence of steam).
Formability	The molecular chains in the wool fibre can be re-oriented under the influence of heat and moisture. In this way, wool fabrics can be more or less durably shaped.
Felting	Felting is the matting together of fibres, under the influence of mechanical action, heat and water. It is facilitated by the scales on the fibre surface, which can hook onto each other. The effect is utilised for the production of felts but it is a disadvantage in the aftercare of wool clothing.
Fineness, Handle	Wool fibres may be fine or coarse, depending on the type. The very finest Merino wools (less than 16 µm) are designated Super 100's. They are sold at special auctions and are made into extremely fine, soft fabrics.
Electrostatic charge	Wool fibres develop only small electrostatic charges because, under normal conditions, they always contain some moisture which conducts the charge away.
Flammability	Wool does not burn easily. It is suitable for protective clothing.
Improvement of Properties by Finishing (*see Chapter 7*)	
Permanent creasing	Ironed creases can be **durably fixed** through heat, pressure and chemicals (Siroset process).
Decatizing	Application of heat, moisture, and pressure **stabilises** and **smoothens** wool textiles. Fabrics have improved handle and lustre, and are then ready for making into clothing.
Anti-felting treatment	Wool can be made **machine-washable** by chemical treatments which greatly reduce the tendency of the fibres to felt.
Soil release	A surface coating is applied, usually a silicone polymer, which **resists soiling** and **facilitates cleaning.**
Flame retardance	**Protection against heat and flames** is good and can be improved by treatment with chemicals that combine with the wool protein molecules.
Carbonising	Removal of **vegetable impurities** using sulphuric acid.
Mothproofing	Treatment of the fabric with e.g. Eulan or Mitin, which make the fibres inedible and to which the moths are averse (household textiles).
Raising	**Fibre ends** are teased out of the textile material to **build a nap.** The weave structure is obscured. Often follows fulling.
Fulling	**Controlled felting** of wool materials. The material shrinks and becomes denser.

1.3.1 Wool (4)

Fibre Identification

Microscopy	Burning Test	Rubbing Test	Solubility Test
 **Cross-section:** round. **Appearance:** overlapping scales, like roof tiles	**Combustion:** small, sputtering flame, self-extinguishing. **Smell:** like burning hair. **Residue:** black, friable cinder.	If a wool fibre is held between thumb and fore-finger (parallel to them), and thumb and finger are rubbed together, then the fibre will travel in one direction. If the fibre is turned around, then it travels in the opposite direction.	**Sulphuric acid:** Cold, concentrated sulphuric acid has scarcely any effect (cf. cotton). **Alkalis:** Boiling 5% caustic soda, and lithium hypochlorite solutions will dissolve wool (cf. cotton).

Typical Wool Fabrics

Afghalaine	Charmelaine	Donegal	Flannel	Fresco	Saxony	Shetland	Tricotine
Baize	Cheviot	Felt	Fleece	Loden	Serge	Tartan	Tweed

Fibre Blends (*see page 44*)

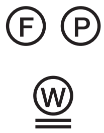
Wool is excellent for blending with synthetic fibres, such as polyester, acrylic, and nylon. Both fibres are complemented in the mixture; the tendency to felting is reduced and the aftercare characteristics are enhanced. In addition, the durability is improved. So long as the proportion of wool is greater than 50%, then its good clothing comfort properties are retained. Common blend ratios are 50:50, 55:45, 60:40, 70:30, and 80:20. Wool is also blended with silk, with cotton, and especially with fine hair fibres.

Applications

Apparel Fabrics	Accessories	Household Textiles	Technical Textiles
Suits, costumes, pullovers, waistcoats, overcoats, dresses, winter blouses.	Gloves, scarves, hats, socks, stockings.	Blankets, carpets, drapes, furnishings.	Fire protection clothing, industrial felts.

Aftercare

The most severe laundering conditions that a fibre could tolerate are seldom those to be recommended for a given item of clothing. Limitations may be imposed, for example, by yarn and fabric construction, type of finish, garment construction and decoration. **Care symbols,** used to indicate the appropriate aftercare regime, are illustrated and explained on *pages 46 and 47.*

Washing	Bleaching	Drying	Ironing	Professional Cleaning
 Washable wool can be **machine-washed** using the wool programme. Sensitive fabrics are **hand-washed** or **dry-cleaned.**		 Wovens can be hung out; knits should be laid flat. **"Total Easy Care"** can be **tumble dried.** TOTAL EASY CARE WOOL WOOLMARK		

Textile Labelling

The regulations governing product labelling allow the terms **New Wool** or **Virgin Wool** to be used only for fibres shorn from a living sheep or lamb. Virgin Wool products must be made from wool fibres which have not previously been spun into yarn or felted, nor previously been incorporated into a finished product. Textiles made from 100% Virgin Wool may be labelled as Pure New Wool, or **Pure Virgin Wool.** An allowance may be made for 0.3% of adventitious foreign fibres, 2% for antistatic dressings, and 7% for visible ornamental effects. New Wool and Virgin Wool descriptors may also be used in **blends** where there is only one other fibre present, and where the proportion of Virgin Wool is at least 25%.

The term **Pure Wool** may also be used for products made from recovered wool.

WOOLMARK® WOOLMARK BLEND® WOOL BLEND®

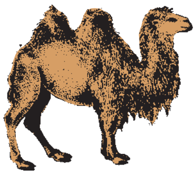
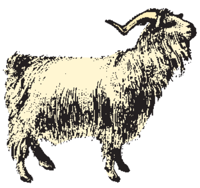
Trademarks for New Wool and Blends

The trademarks Woolmark® Woolmark Blend® and Wool Blend® serve to identify high quality textiles. As well as the fibre content, the mark guarantees a certain product quality level: colour fastness, strength, and dimensional stability. Licensed use of the mark is governed by strict regulations, supervised and controlled by the Woolmark Company.

Woolmark® is applied to high quality textiles of Pure New Wool. **Woolmark Blend®** is applied to fibre blends where there is only one other fibre, and a Virgin Wool content of at least 50%. It guarantees the same quality levels as for the Woolmark. Wool Blend® is applied to blends having from 30 to 49% of Virgin Wool – especially in functional textiles.

1.3.2 Hairs

Fine Animal Hairs

Fibre Name	Appearance	Description
Alpaca **Llama** **Vicuna** **Guanaco** 		Alpaca, llama, vicuna, and guanaco are all types of **llama,** both wild and domesticated, which live in the Andes mountains of South America. They are shorn every two years and the hairs are sorted by colour and fineness. They are fine, soft, lightly crimped, and very warm. They are used in expensive knitted fabrics, jackets, overcoats, and blankets.
Camel 		Camel hair is the downy undercoat of the Bactrian (two-humped) **camel.** It is moulted every year, is very fine, soft, lightly crimped and beige in colour. Camels under one year old are blonde, almost white. Their “baby hair” is especially soft and valuable. Camel hair is used for outerwear. The coarser guard hairs, and those of the one-hump camel, are used for interlinings.
Cashmere **Cashgora** 		The **cashmere goat** lives in Mongolia and the Himalayan mountains at altitudes up to 5000 m. To withstand the cold, it has an unusually fine undercoat. At the yearly coat change, the under-hairs are separated from the coarser guard hairs and are sorted by colour. Textiles made from cashmere are very soft, light, and lustrous; it is the most expensive hair fibre. The **cashgora goat** is a cross between the cashmere and the angora goats.
Mohair **Yak** 		Mohair is the hair of the **angora goat,** which may be shorn twice each year. The best quality comes from Texas, South Africa, and Turkey. The hairs are long, lightly curled, and have a silky lustre. They are white, do not felt easily, and are well suited for dyeing. Mohair is used for outerwear. Yak is the hair of the domesticated **Tibetan ox.**
Angora **Rabbit** 		Angora fibre is the hair of the **angora rabbit,** which is farmed in Europe and East Asia. The name derives from Ankara, in Turkey. The rabbits are shorn up to four times each year. The fine, very light hairs are very good at absorbing moisture vapour. Usually, they are blended with wool and used for thermal underwear and ski underwear. In outerwear, inclusion of the coarse guard hairs gives angora fabrics their typical spiky appearance.

Within the Woolmark, and the textile labelling regulations, fine animal hairs have equivalent status to wool, because they have similar properties. So long as they conform to the quality requirements, fine hairs can be labelled with the Woolmark.

Coarse Animal Hairs

Coarse hairs are used mostly for the manufacture of resilient and stable interlining materials. The most important are **Horse hair, Camel hair** (guard hairs), **Cattle hair,** and **Goat hair.**